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Quantification Of The Effects Of Operative Management For Idiopathic Scoliosis: Implications For Pathogenesis, Pathomechanisms And Future Management

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A thesis submitted to the University of Nottingham
for the degree of Doctor of Medicine

December 2002

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Abstract

Idiopathic scoliosis (IS) is a structural lateral curvature of the spine with rotation for which no cause is established. Surgical treatment for scoliosis focuses on the spine and achieves only partial correction of spine and trunk deformity. This correction deteriorates with time. Some pathomechanisms of deteriorating body shape are suggested from sequential anthropometry. The correction and prevention of future deterioration in body shape are the aims of any scoliosis treatment. Application of knowledge of pathomechanisms to treatment may improve outcome.

Section 1: Infantile and juvenile idiopathic scoliosis: long-term follow-up and effects of Luque trolley instrumentation and anterior release and convex epiphysiodesis.

Patients with infantile (IIS) and juvenile idiopathic scoliosis (JIS) are evaluated by radiological examination before surgery and at intervals after surgery. The patients are also reviewed clinically at longest follow-up by surface and ultrasound methods. Appropriate non-parametric and parametric tests and multivariate analysis are used to evaluate results. Factors important in curve progression are identified and new strategies for treatment suggested.

Section 2: Adolescent Idiopathic Scoliosis: 2-year follow-up and effects of each of posterior and anterior instrumentation with the Universal Spine System.

Patients with adolescent idiopathic scoliosis (AIS) are evaluated before surgery and at intervals after surgery. Data from surface, anthropometry, questionnaire and plain radiography are considered. Statistical analyses were performed using parametric and non-parametric tests where appropriate. Attention is directed at factors that determine rib-hump progression post-operatively.

Aims of studies:

The aims of these studies are to quantitate the change in surface and skeletal morphology after surgery and after follow-up, to infer pathogenesis and pathomechanisms for each of infantile and adolescent idiopathic scoliosis, to consider new strategies for the treatment of IS and to quantify the subjective experience of scoliosis and surgery and compare with established objective measurements of scoliosis deformity.

Place of work: School of Biomedical Sciences and The Centre for Spinal Studies and Surgery, Queen's Medical Centre, Nottingham.

Ethical Considerations: Patients are examined clinically, by back surface measurement and by anthropometric measurements at the time of their routine outpatient appointments. Examinations were performed with the informed consent of the patient and the parent(s)/guardian of the patient. Radiographic investigations are requested according to clinical need in accordance with guidance from the Director of the Centre for Spinal Studies and Surgery, Mr. J.K. Webb FRCS.

Funding: Secured from AO/ASIF foundation.

Contributions of work from other researchers: Back surface and anthropometric measurements were made before September 1995 by A.A. Cole, S.L. Cummings and Professor R.G. Burwell. Subsequent measurements were made by the author. All radiographic measurements and analysis was performed by the author. The work was carried out under the direct supervision of Professor R Geoffrey Burwell.

Review of publications: Work published after June 2001 was not considered in the literature review for this thesis.

Part of this work has been published in peer reviewed journals as follows:

Pratt RK, Burwell RG, Cummings SL, Webb JK. Luque trolley and convex epiphysiodesis in the treatment of infantile and juvenile idiopathic scoliosis. Spine 1999;24(15):1538-47.

Pratt RK, Burwell RG, Cole AA, Webb JK. Changes in surface and radiographic deformity after Universal Spine System (USS) for right thoracic Adolescent Idiopathic Scoliosis (AIS). Is rib hump reassertion a mechanical problem of the thoracic cage rather than an effect of relative anterior spinal overgrowth? Spine 2001;26(16):1778-87.

Pratt RK, Burwell RG, Cole AA, Webb JK. Patient and parental perception of adolescent idiopathic scoliosis before and after surgery in comparison with surface and radiographic measurements. Spine 2002;27(14):1543-50.

Abbreviations

ADP	Adenosine di-phosphate
AIS	Adolescent idiopathic scoliosis
AP	Antero-posterior
AVR	Apical vertebral rotation
AVT	Apical vertebral translation
C(n)	Cervical vertebra, n=number
CDI	Cotrel-Dubousset Instrumentation
CE	Convex epiphysiodesis
CT	Computed tomography
df	Degrees of freedom
EMG	Electromyography
ENG	Electronystagmography
EVA	End-vertebra angle
FPB	Frontal plane balance
GAG	Glycosaminoglycan
HRI	Harrington rod instrumentation
IIS	Infantile idiopathic scoliosis
IS	Idiopathic scoliosis
ISIS	Integrated shape imaging system
JIS	Juvenile idiopathic scoliosis
L(n)	Lumbar vertebra, n=number
MLRA	Multiple linear regression analysis
MRI	Magnetic resonance imaging
NF	Neurofibromatosis
NS	Not significant
OKN	Optokinetic nystagmus
PA	Postero-anterior
PET	Positron Emission Tomography
RMMANOVA	Repeated measures multivariate analysis of variance
RSA	Rib-spine angle
RVA	Rib-vertebra angle
RVAD	Rib-vertebra angle difference

SD	Standard deviation
SAS	Surface asymmetry score
SBP	Sagittal plane balance
SPET	Single Photon Emission Tomography
SRS	Scoliosis Research Society
SSEPs	Somatosensory evoked potentials
SSI	Segmental spinal instrumentation
T(n)	Thoracic vertebra, n=number
USS	Universal Spine System
VR	Vertebral rotation
VT	Vertebral translation

Definitions

Apex vertebra	The vertebra most deviated from the T1-S1 line
Aetiology	The study of cause of disease
Frontal plane balance	Horizontal offset (cm) of T1 on S1, positive to the right
Kyphosis	Angle between upper endplate of T5 and lower endplate of T12
Lordosis	Angle between upper endplate of L1 and lower endplate of L5
Lumbar curve	Apex from L2 to L4
Pathogenesis	The mode of origin of disease
Pathomechanism	Sequence of events from a pathological process resulting in the disease
Rib-spine angle	Angle between T1-S1 line and line through head and neck of the rib
Sagittal plane balance	Horizontal offset (cm) of T1 on S1, anterior being positive
Scoliosis	A spinal curvature measuring 11° or more in the coronal plane by the Cobb method
Segmental measure	Measure performed at more than one vertebral level
Thoracic curve	Apex from T2 to T11
Thoracolumbar curve	Apex from T12 to L1
Vertebral inclination	Angle between posterior surface of vertebral body and the vertical
Vertebral rotation	Measured about an axis parallel to the T1-S1 line
Vertebral tilt	Angle between lower border of vertebra and the T1-S1 line, positive if slopes upward to the right
Vertebral translation	Horizontal translation of vertebral centroid from the T1-S1 line

INTRODUCTION

'He alone is an observer who can observe minutely without being observed'

Johann Kaspar Lavater 1741-1801

'We owe almost all our knowledge not to those who have agreed but to those who have differed'

Charles Caleb Colton 1780-1832

The approach to the study of scoliosis is and has been largely empirical since Francis Bacon founded the empirical or strictly experimental method of scientific inquiry as detailed in his book, Novum Organum in 1620 (the New Machine). This laid out the inductive approach which forms the basis for current scientific method.

The development of new techniques for investigation and study of human biology results in the concurrent development of hypotheses based on the results of observations using new techniques. The application of new scientific paradigms and investigative methods will necessarily modify concepts of scoliosis causation and mechanisms for curve progression. It is widely accepted that idiopathic scoliosis (IS) has a multifactorial causation, in other words scoliosis is the end result from a number of processes. Many of the concepts we are familiar with for aetiology of scoliosis were discussed in records from the 17th century onwards. I will consider concepts for the causation and progression of scoliosis under the following headings:

- Growth and musculoskeletal mechanisms (bone, muscle, ligaments)
- Genetic mechanisms
- Neural mechanisms

Terminology

Scoliosis is a lateral curvature of the spine. If the curve cannot be corrected by changes in posture it is termed structural. Curves may be characterised by various features and lack of consistent definitions hampered efforts to evaluate scoliosis before standardised terminology was presented by the Scoliosis Research Society (SRS)[302]. Primary structural spinal deformity is categorised by presumed cause, namely, congenital; neuromuscular; associated with neurofibromatosis; mesenchymal; traumatic; due to infection or tumour or spondylolisthesis and miscellaneous causes. The largest group is idiopathic, accounting for 80-90% of all subjects with scoliosis.

Idiopathic Scoliosis is classified into infantile, juvenile and adolescent groups by age at diagnosis according to James' classification of 1954[148] which is accepted by the SRS. Scoliosis curves are classified by anatomic level of the apex (cervical, thoracic, thoracolumbar and lumbar)[124] or by the pattern of the curves, including an evaluation of curve flexibility[72,161].

Sevastik has helped to clarify the processes involved in the development of scoliosis[314]. He delineated these processes into aetiology, i.e. the factors causing the deformity; pathogenesis, i.e. the mode of origin of the process triggering the deformity, and pathomechanisms, i.e. the sequence of events in the evolution of the structural changes resulting from the pathological process.

This thesis is based on observational studies of patients with IS before and at intervals after surgery. The effect of surgery on the body and the morphological changes that occur on follow-up may lead to inferences regarding pathomechanisms and pathogenesis of scoliosis. The data gathered in this work is likely to relate to musculoskeletal and growth factors. Previous work on possible mechanisms for scoliosis causation and progression are reviewed below, with emphasis on musculoskeletal and growth mechanisms.

Growth and musculoskeletal mechanisms

Bick[29] has reviewed the historical background of modern orthopaedics, including early studies into scoliosis. He describes how Francis Glisson (1597-1677) and co-workers believed that bony deformities, including scoliosis, seen with rickets were due to unequal growth of bones. Bamfield in 1824[17] observed a relationship between growth and development of scoliosis. Hueter in 1862[145] suggested that scoliosis was the result of unequal growth of the spine and thorax. Adams in 1865[2] found that rapid growth increased the risk of progression. He noted that progression was rarely seen after growth finished.

The discovery of X-rays in 1895 had a major effect on the perception of scoliosis. It resulted in the identification of the various bony abnormalities which cause about 10% of scoliosis and which are now termed congenital scoliosis. The cause of scolioses in those patients without skeletal abnormalities remained unclear.

Normal growth patterns

A clearer understanding of normal growth in children supported the observations made on patients with scoliosis. Ponseti and Friedman[267] reported in 1950 that the diagnosis of scoliosis was most often made during the growth periods of 0-3 years, 5-7 years and over 10 years of age. Tanner[343] published his growth data with the timing of the growth spurt in 1962. More recently the age of onset of the adolescent growth spurt has been given as 9.6 years ±1 for girls and 11.7 years ±0.9 for boys[103].

Growth and progression

Duthie showed a relationship between growth rate and progression in IIS[90]. Duval-Beaupère showed curves increased steadily until puberty then accelerated until growth ceased[91]. She concluded there was no 'cause and effect' relationship between growth and scoliosis, except as a contemporaneous phenomenon[91]. Perdriolle[258] retrospectively studied the natural history of untreated scoliosis and concluded that worsening of scoliosis was a growth phenomenon secondary to asymmetrical loading of the vertebral bodies[257]. This viewpoint does not explain why idiopathic curves cannot be successfully treated by simple realignment of the spine and why progression continues if the spine is fused.

Attempts have been made to prognosticate in IS based on retrospective reviews of untreated patients. Bunnell[41] studied 326 females and found that 'future growth potential and curve severity remain the most reliable considerations in predicting the course of the disorder'. Lonstein and Carlson[180] studied 727 patients with curves from 5° to 29° and found that the three predictors of progression were the magnitude of the curve, the patient's chronological age and the Risser sign, which implies the importance of growth potential.

Radiological investigation of scoliosis allowed estimations to be made of the growth potential remaining and hence the likelihood of curve progression. Risser and Ferguson[284] showed that vertebral growth ceases when the iliac apophysis completely fused. Ponseti and Friedman[267] thought that curves stopped progressing 1 year before complete excursion of iliac apophysis. Calvo[56] found that if the growth rate of the spine segment from T8 to T12 was less than 0.3mm per month then there was no progression of the scoliosis.

Goldberg[118] published a prospective study of the natural history of scoliosis in 339 subjects and found that the child's position on her growth rate curve and her menarchal status were better indicators of curve progression than iliac crest ossification or bone age. Growth is not the only mechanism for curve progression. Risser[283] found in 1964 that scoliosis worsened on average 1° /year after spinal growth had ceased.

The findings for growth in the literature are of significance in that they demonstrate the importance of growth in promoting deformity (pathogenesis and pathomechanisms) but they do not imply causation. Of aetiological interest are the differences in biology between normal subjects and scoliosis patients in respect of growth.

Is growth abnormal in scoliosis?

Problems of data interpretation

Difficulties in the interpretation of data arise when data concerns measurements that are affected directly by the scoliosis deformity, such as sitting and standing height. In such instances growth that occurs may not be reflected in changes in height alone but also in changes in curve magnitude. Bjure and Nachemson[32] derived a formula to adjust height by a factor proportional to Cobb angle. This does not account for deformity in other planes; Carr et al produced a correction factor for height according to deformity in both coronal and sagittal planes using data from the ISIS back surface optical scanning system[59]. Some of the difference in height between groups reported in studies may be due to the correction factors employed[115].

Girls with AIS have been found to be taller than normal subjects[62,66,87,377]. Shohat et al[320] reported on 54,030 male and 38,102 female army recruits. They found that young scoliotic adults were taller, lighter, and thinner than the non-scoliotic controls and that prevalence varied with parental origin (Iraq or Western Europe). They suggested genetic factors and growth pattern are of major importance for the prevalence of scoliosis.

Timing of growth

Burwell and Manning[51] found that 10-14 year olds with AIS or JIS were skeletally older than normals and these findings were confirmed by Nordwall and Willner[237]. These findings suggest that scoliosis subjects are maturing at an earlier chronological age than their peers. Nissinen et al[234] found a slightly earlier mean age for peak sitting height growth velocity in a cohort study of 896 Finnish school children. Goldberg et al[117] compared subjects from the Dublin school screening program for scoliosis against national standards and found an early menarche, increased height at the time of diagnosis but normal growth and height at maturity. However Normelli et al found that menarche was found to occur significantly later in girls with either a thoracolumbar or a double primary curve compared with the control group and compared with girls with a right convex thoracic curves in their study of 84 girls with IS[239]. Girls with a thoracolumbar or a double primary curve were significantly taller than those in the other two groups at menarche. The observed differences were interpreted as indicating that the pathomechanism, and even the aetiology, may vary with the form of IS.

Hormones and growth regulation

Several workers have studied hormone levels in connection with control of growth and the timing of the growth spurt. Conflicting findings have been reported for somatomedin A in AIS[324,329,378] but interpretation of results is difficult because somatomedin A may not be a distinct growth factor but a composite of others and their effects[276]. Misol et al found normal levels of growth hormone in AIS[219] but Skogland and Miller[323] found AIS subjects had a greater response to the growth hormone stimulation test. If the timing of the growth spurt is important, then the maturation of the subjects being studied is an important variable in the interpretation of these studies, and precise details of maturation are not usually given. Ahl et al[4] found higher secretion of growth hormone in early puberty (stage 2) in girls with AIS than normal girls, which implies an earlier growth spurt in scoliotic girls.

Melatonin

Machida et al have promoted the theory that melatonin is implicated in the pathogenesis of IS, based on observations of pinealectomised chickens[188] and pinealectomised bipedal rats[191]. They found lower nocturnal melatonin levels in patients with progressive AIS curves[190]. However these findings have not been substantiated by other groups[12,143].

Roth postulates that IS is due to an imbalance between bone and neural growth, the latter being more sensitive to disruption[293]. He postulates that bone lengthening in the absence of neural growth could lead to scoliosis by upsetting 'osteoneural' balance.

An earlier growth spurt may increase the risk of progression in scoliosis, and combined neural, growth and bone factors may be important, but different hypotheses are needed to explain how the scoliosis develops.

Site-specific growth mechanisms

There are three main schools of thought, namely (i) the asymmetry in growth is anterior-posterior (ii) the asymmetry in growth is left-right and (iii) the disordered growth produces rotation.

Asymmetry in growth is anterior-posterior

In 1922 MacLennan postulated unequal growth of the anterior and posterior elements of the spinal column[45] could cause scoliosis. In 1927 Heuer[142] concluded that there was excessive growth of the anterior elements when he found that the anterior spinal components were longer. These anatomical findings have been confirmed by others[77,78,285]. The Leeds view, put forward by Dickson[84] after Somerville[327], relates lordosis, which could result from anterior overgrowth, to the development of scoliosis.

However, Nissinen et al found that children with scoliosis are more kyphotic than controls[234]. Raso has reviewed the evidence concerning thoracic hypokyphosis as an aetiological factor in IS and concluded that the evidence for this hypothesis is weak[275].

The asymmetry in growth is left-right

Many workers have suggested that excessive growth on the convex side compared with the concave side underlies the development of IS. Experimental studies demonstrated that interference with growth by stapling of vertebrae or epiphysiodesis could result in scoliosis[134,229]. Initially it was felt that such methods implied aetiology and use of a unilateral growth arrest was used in humans to correct scoliosis[7,221,287].

Vertebral torsion as the primary abnormality

Roaf considered that vertebral rotation was the primary abnormality[285]. He postulated an unmatched growth between neural arch and vertebral body[288]. Taylor reported on asymmetry in neurocentral fusion in infants and children in 1983 and concluded that this could explain the vertebral body rotation in scoliosis and that 'different degrees of asymmetry may be under genetic control'[346].

Scoliosis as an exaggeration of a physiological curve

Bouvier first suggested in 1858 that essential scoliosis was an exaggeration of the normal lateral curvatures of the spine[45]. White[372] thought that an exaggeration of the coupling of lateral flexion and vertebral rotation to the convexity which is occasionally seen in some normal subjects could result in a biomechanical cascade towards scoliosis. Stokes in 1989[334] and Veldhuizen in 1987[359] argued against this view. They pointed out that coupling of lateral flexion and vertebral rotation was not seen in scoliotic curves under lateral flexion and simple coupling could not account for the observed deformity.

Asymmetry and scoliosis

If scoliosis is not an exaggeration of a physiological curve then perhaps there are other features of the spine that predispose it to the deformity that appears under whatever aetiological factor is at work. Mellin et al studied spinal mobility and posture in sixty normal 13 to 14 year old boys and girls. Girls had reduced kyphosis ($P<0.01$), forward flexion ($P<0.01$) and lateral flexibility ($P<0.05$) when compared with the boys[209]. Thoracic rotation to the left was smaller than to the right for girls ($P<0.05$). In the girls, thoracic forward flexion and rotation to the left had negative correlations ($r=-0.38$ and -0.39, $P<0.05$) with growth velocity[209]. These findings are in keeping with the side and sex incidence of AIS.

Burwell et al found abnormal trunk growth and asymmetry in the upper limbs[47] and suggested that the finding of upper limb asymmetry may be (i) secondary to scoliosis, (ii) secondary to a developmental abnormality that caused the scoliosis or (iii) a primary influence in determining curve side and possibly site[44].

Asymmetry in AIS subjects has also been observed by other authors in breast size[241], skull and face[116], teeth[254], brain stem[109], femoral neck-shaft angles[298], motor function[116], vibratory response[387], proprioception[19] and language processing[119].

Girls with scoliosis have disproportionately long legs, a cephalo-caudal disproportion in the trunk[62,66,232], even when correcting for loss of height due to the curve. Hsu and Upadhyay found that the loss in spinal length in girls who underwent spinal fusion compared with brace treated girls was compensated by an increase in leg length[144]. The same was found for patients who had tuberculosis of the spine during early childhood which suggests a common 'compensatory stimulatory growth mechanism' may be responsible[165]. Thus these findings may not have aetiological significance.

Other forms of asymmetry

Asymmetry with respect to side as found in the upper limb in AIS is termed 'directional asymmetry'[358]. Van Valen initially described this in 1962 along with two other forms of asymmetry, namely anti-symmetry and fluctuating asymmetry, based on the distribution of left-right differences. The left-right differences in directional asymmetry have a normal distribution with a mean that is significantly different from zero, in anti-symmetry have a bimodal distribution about a mean of zero (for example the size of lobster claws), and in fluctuating asymmetry have a normal distribution, a mean of zero, and are quantified by the variance. It has been proposed by biologists that increased fluctuating asymmetry may represent imperfect expression of the genotype caused by physiologic stress during development[358].

Goldberg et al analysed palmar ridge counts in AIS, in individuals with minor non-scoliosis asymmetry and in healthy control individuals[121]. They found that those with any trunk asymmetry showed increased fluctuating asymmetry, and thus an increased likelihood of losing symmetry under stress, whereas those with AIS showed an increased directional asymmetry and fluctuating asymmetry, thus increasing the likelihood and predicting the pattern of that loss of symmetry[121]. Dangerfield et al have also reported an increase in fluctuating asymmetry with increasing curve severity[75]. Goldberg puts forward a hypothesis of scoliosis as an asymmetrical phenotype expressed from a genotype susceptible to environmental stress (fluctuating asymmetry)[46]. This hypothesis can explain the equal male: female preponderance in IIS, but does not explain why AIS is much more common in girls, or why right sided curves are most common.

The Hueter-Volkmann effect as a pathomechanism for curve progression

Roaf suggested that once a scoliosis has developed then a vicious cycle of asymmetrical loading resulting in asymmetrical growth of vertebrae and discs produces curve progression[286]. Animal work in rabbit long bones[9] and rats' tails[339] have demonstrated reduction in physeal growth in response to load, in keeping with the Hueter-Volkmann law[145]. Although biomechanical models have supported the concept that asymmetrical loading of vertebrae does occur in scoliosis[335] they do not explain why physiological lordosis and kyphosis do not progress in the same way as scoliosis does during the growth spurt. Stokes reviewed the literature in this connection and concluded that quantitative relationships between growth in the physes and forces acting on them have yet to be established[336].

Growth mechanisms in the thoracic cage

Scoliosis affects the thoracic cage as well as the spine, and a number of workers have promoted the idea that disordered growth of ribs may secondarily cause spinal deformity. This view resulted on a background of observations that implicated the thoracic cage in scoliosis pathogenesis and pathomechanisms.

The thoracic cage and idiopathic scoliosis

Stromeyer first stated that ribs may play a part in aetiology of IS in 1836[157], through the unequal activity of muscles. Bisgard[30] and Loynes[183] reported scoliosis in adults after thoracoplasty. While this is suggestive of a possible role of the rib cage in the development of a scoliosis, the important factor of growth is not present.

Langenskiöld and Michelsson's experiments on rabbits in 1962 demonstrated that various surgical interventions including rib head excision could produce a scoliosis[169]. Both Piggott[261] and Manning[195] subsequently used rib head excision in the treatment of human scoliosis from 1968. However Stilwell[333] had reported in 1962 that the rabbit techniques used by Langenskiöld and Michelsson did not work in primates. In his review of aetiology, James thought that Langenskiöld and co-workers had demonstrated much relevant to progression of scoliosis but little relevant to aetiology[149].

Piggott[261] reported encouraging initial results for 25 children with progressive IS treated by rib resection. Barnes[18] found no significant difference between bracing alone and rib resection with bracing in the treatment of progressive IIS at 6 years follow-up. However allocation into control and study groups was not random, because parents were involved in decision making which could easily reflect surgeon preference.

Evidence suggestive of a role for the thoracic cage in IS came from Mehta's longitudinal study of IIS. Mehta found that the rib-vertebra angle difference (RVAD) at the curve apex was predictive in distinguishing between resolving and progressive IIS[207]. She noted the lack of a consistent relationship between rib droop on the convex side and Cobb angle. She stated that 'The radiological evidence of the early rib-vertebral angle difference in scoliosis, thought to be due to a disturbance of the soft tissues in the region of the costo-vertebral joint, supports the experimental and mechanical evidence of the importance of this region in the development of a scoliosis'. Kristmundsdottir et al found that a convex RVA of less than 68^{o} predicted curve progression in IIS and implicated factors causing convex rib droop as causing curve progression[166].

The Swedish Approach

Work on the role of the ribs in IS has been the subject of many years of research at Huddinge University Hospital in Sweden. Their position was outlined by Sevastik in 1984[316] and later in 2000[315]. Based on the results of experimental, anthropometric and clinical studies they hypothesised that 'asymmetric growth of the ribs may be the primary cause of the thoracospinal deformity at least in some cases of right convex, thoracic, idiopathic scoliosis'.

Experimental work

Sevastik et al[318] found that unilateral left rib osteotomy followed by wiring with an overlap in growing rabbits produced a mild left scoliosis. However, when this was combined with rib osteotomy on the right side, a severe left scoliosis developed. This was interpreted as due to overgrowth of the fractured right ribs and the hypothesis was proposed that asymmetrical growth of ribs might be one cause of scoliosis in man. Interestingly, if a contralateral osteotomy was performed at 1 week, then again, only a mild scoliosis developed. An alternative interpretation of these results would be that the thoracic cage acts as a stabiliser to the spine, and stability is lost in these experiments.

Clinical work

5 patients with recently diagnosed progressive thoracic IS were investigated by ^{99m}Tc-MDP bone scans[317]. The increased uptake on the concave side in the costochondral region in four of the five patients was interpreted as suggesting 'the development of idiopathic scoliosis might be caused initially by increased longitudinal growth of the ribs on the concave side'. Normelli published on the asymmetry in size and vascularity of breasts in normal and scoliotic girls[240,241]. The left breast was larger than the right by visual inspection in 50% of scoliotic girls compared with 26% of normals. The vascularity of the breasts was increased on the left in many cases. She concluded that 'unilateral stimulation of rib growth due to a greater vascularity of the left breast and the underlying costosternal junctions might be one initiating factor in the development of right convex thoracic idiopathic scoliosis in adolescent girls'.

Sevastik concludes that the above studies 'support the working hypothesis that asymmetric growth of the ribs might be the unknown primary cause of at least some cases of right convex adolescent idiopathic scoliosis in girls'.

Further studies in Sweden

This hypothesis was supported by further rabbit experiments. Elongation a rib on the right side by 1 cm in rabbits resulted in immediate left-convex scoliosis and a significant decrease in the cervicothoracic lordosis and thoracolumbar kyphosis, said to resemble IS in man[312]. A left-convex thoracic scoliosis developed after partial resection of three right intercostal nerves in growing rabbits[313]. In one group of these animals, increase in length by 1 cm of a convex rib resulted in immediate correction of the scoliosis. In two groups of rabbits, resection of three convex intercostal nerves, 1 and 2 months after the first operation, resulted in regression of scoliosis or halted its progression. These results were felt to support the concept that the precipitating factor in the development of scoliosis is asymmetric longitudinal rib growth. They also suggested that regulation of the rib length could be a promising approach to the effective correction of progressive scoliosis at an early stage in man.

The work continued in a similar vein with papers published by Bo Sevastik[308-310]. In 1997, the rib-vertebra angle (RVA) asymmetry was studied in 3 groups[311]: (i) rabbits with experimentally induced scoliosis, (ii) 19 patients with right thoracic AIS, and (iii) 10 patients with right neuromuscular scoliosis. The pattern of RVAs was similar in all groups and it was concluded that the 'typical pattern of the RVAs on the concave and convex sides seems to be independent of the underlying cause of the spinal curvature. It is likely that the RVADs result from a passive mechanical adaptation of the ribs to the lateral curvature of the spine'. Taken at face value, this most recent paper appears to effectively argue against asymmetric growth of the ribs as a primary cause of IS in some patients. However Sevastik, in his most recent review[315], states the results accord with the early structural vertebral changes seen in AIS and challenge statements made by Grivas et al[128] relating the early development of RVA asymmetry to muscular dysfunction and the pathogenesis of IS. Sevastik describes a case history of a 6 year old Chinese girl with scoliosis treated by shortening of the ribs on the concave side alone with cessation of progression at 3 year follow-up[315]. He postulates that increased vascularity of the left anterior hemithorax in adolescent girls results in overgrowth of the left ribs, which disturbs the equilibrium determining normal alignment of the spine, resulting in scoliosis. He advocates rib operations for the surgical treatment of 'early progressive thoracic curves' in young patients. Thus Sevastik is revisiting the methods tried first by Piggott[261] and Barnes[18] some 30 years ago.

The counter argument

Stokes et al studied the three dimensional shape of the rib cage using stereo-radiography in patients with scoliosis and control subjects[337]. In the control group and a group with minimal scoliosis, there was no statistically significant rib asymmetry. 11 of 19 patients with right single thoracic curves had rib arc lengths greater on the right side at the curve apex and 9 of 15 patients with left lumbar scoliosis had longer ribs on the left side. Overall the mean rib length difference in patients was between 1% and 4%. Stokes went on to model a human thorax to investigate how asymmetric growth of the thorax might initiate scoliosis. Thoracic growth of 20% with asymmetric growth of the ribs resulted in the model having a small thoracic scoliosis curvature *convex* toward the side of the *longer* ribs. He concluded that this supported 'the idea that growth asymmetry could initiate a small scoliosis during adolescence'.

His findings contradict the suggestion of Sevastik[316] and Normelli[240] who expect the concave rib to be longer according to their model. If Stokes' measurements from the 3-

dimensional correction are correct, then we cannot accept the rabbit model as a valid model for human scoliosis.

Alternative explanations of RVAD

Grivas et al[129] studied the rib cage deformity seen in chest radiographs of 21 pre-operative IIS patients and compared them with control chest radiographs of 412 children attending the Accident and Emergency department. They found that the RVAD was greatest at T6 in IIS and that the upper rib cage was narrower in IIS. They suggested that there was impaired rib control of spinal rotation due to a growth defect in the upper rib cage. Neuromuscular factors were postulated to be causing both the scoliosis and the upper rib cage funnelling. In the same paper, the RVADs for normal subjects were considered by age group. Infant boys were found to have asymmetry of RVAD (left droop), while juvenile and adolescent girls were found to have asymmetry of RVAD to the right. None of the chest radiographs had a scoliosis of more than 5° present. The pattern of RVAD matched that seen in IS, and extremes of these normal asymmetries were felt to be of aetiological significance. A muscular hypothesis was put forward to explain these asymmetries.

Other theories regarding the role of the thoracic cage in Idiopathic Scoliosis

Pal and co-workers have published a series of papers studying the mechanics of weight transmission in cadaveric spines[246,249,250] and have supplemented this with morphological study of trabeculae[248]. They inferred that spinal balance is maintained by a symmetrical distribution of forces acting through the ribs and that asymmetry in breast size, rib growth or upper limb could lead to an asymmetrical distribution of forces acting through the ribs and hence cause scoliosis[247].

Pal's hypothesis does not explain why patients with congenital limb malformation develop a scoliosis convex to the side to the normal limb[176,193]. He would have predicted the heavier normal limb would result in a scoliosis concave to the side of the normal limb. It seems more likely that muscular activity on the affected side of the body is counterbalancing the weight and activity of the normal arm, resulting in rib and spine deformity.

The significance of the sternum

Gardner proposed that the sternum and thoracic cage stabilise the thoracic spine like flying buttresses supporting the walls of Gothic churches[107], based on observations of surgery for

IS. He implicates the thoracic cage in the pathogenesis of IS and advocates rib osteotomy is added to spinal fusion.

Various explanations for the behaviour of the ribs in IS have been suggested above. The problem with animal experiments is that healthy quadruped animals cannot be expected to be a good model for bipedal humans with IS. In the case of humans, thoracic surgery resulting in generally non-progressive scoliosis is not a good model for what happens in IS. When we consider patients with IS, it is already impossible, by the nature of the deformity, to distinguish primary from secondary changes.

Muscular

Nicholas André coined the term *orthopaedic* for the title of his 1741 treatise *L'orthopédie ou L'art de prevenir et de corriger dans les enfans, les difformites du corps* (greek: *orthos* meaning straight, and *paidon* meaning child). He saw normal skeletal development as dependant on muscle balance[291]. The most popular hypothesis during the 18th and 19th centuries was that bad posture and habitual asymmetric weight bearing could cause scoliosis. Stromeyer thought that abnormal activity in respiratory muscles could cause unequal forces on the spine via the ribs and thus cause scoliosis (from Keith[157]). Other suggestions were that lateral curvature was due to 'debility' or loss of muscle tone[2], wasting of the paravertebral muscles due to corset use[291] and unequal muscle action in the trunk[289]. Tunstall Taylor proposed in 1904 that muscle (abdominal obliques) forces were transmitted the to the spine by the ribs causing lateral curvature, vertebral rotation and pelvic asymmetry[347].

Contrary to the above, Adams believed that over-activity of the convex muscles observed in scoliosis was secondary to attempted attainment of spinal equilibrium[2]. Virchow noted the back muscles and tendons on children with scoliosis were atrophied but that the degree of atrophy did not relate to the severity of the scoliosis[291]. James reviewed the aetiology of scoliosis in 1967[149]. He concluded that there was no evidence for muscle weakness playing any part in the development of human IS.

Concepts combining musculoskeletal and growth aetiologies

Pravas suggested in 1827 that unequal muscle growth resulted in scoliosis[289]. Carey used a blocks and springs model to test the effect of different muscle groups on the production of lateral curvature[57]. He concluded that any condition which upset the balance of muscle and bone during the period of growth could result in a scoliosis.

New investigative techniques

If muscles are deforming the spine, then the question arises whether the abnormality lies in the muscle itself or in its activity. These aspects have been examined through electromyography (EMG), histology and biochemistry.

EMG findings

The finding of increased electromyographic activity on the convex side of IS curves has been interpreted as either causative of[132,281] or secondary to the curve[393]. Gueth and Abbink performed EMG studies in congenital scoliosis and IS and found no difference in muscle activity between the groups[133]. Robin reviewed the EMG research in 1990 and reported that most workers had found an increase in EMG activity on the convex side[291]. There were two contradictory interpretations, either (1) the convex muscles are stronger and could be a primary deforming force or (2) the convex muscles are weaker and thus being activated more often to balance the spine. Robin thought that the debate was insoluble.

Histology

Differences in muscle fibre types between convex and concave sides of IS curves[125,322,386] have been interpreted either as causing IS[322] or secondary to the deformity[125,386]. Differences in protein metabolism by side exist in AIS, JIS and neurofibromatosis[42] in keeping with differences in fibre types.

The relationship of the rotatory action of muscles on the spine in relation to gait and scoliosis was explored by Wemyss-Holden et al[369]. Waters and Morris demonstrated EMG activity of the internal and external oblique during gait[362]. Benninghoff described the flat muscles of body walls as acting as a single functional unit in both rotation and flexion of the trunk[24]. He described muscle 'slings' extending from the cervical spine to the lower limbs. Applying a similar concept and following on from the work of Burwell and co-workers that produced the 'Nottingham concept for aetiology of IIS'[43], Wemyss-Holden introduced the term 'Composite Muscle Trunk Rotator' and tested the concept with a model[369,370]. He concluded that the concept could explain the trunk rotational deformity of

AIS but he did not imply that imbalance existed in AIS and recommended that further work be done[369].

Regulation of muscle and platelet function

Findings of platelets abnormalities are important in scoliosis because they suggest a generalised cellular defect which probably would not be secondary to spinal deformity[181]. Work from Jerusalem showed some abnormalities in the distribution of platelet contractile proteins in soluble and insoluble fractions in patients with IS[225]. Further work showed abnormal platelet aggregation in response to ADP and epinephrine in patients with IS, but not in congenital scoliosis and normal subjects[102]. The authors suggested that a muscle disorder may be involved in the pathogenesis of IS. Liebergall et al presented an overview of the 'profound functional anomalies in platelets found in scoliosis' and attempted to link them together[178].

Kindsfater et al measured platelet calmodulin in 27 patients with AIS and found that calmodulin levels correlated with previous curve progression (<5° or >10° in the previous 12 months, P<0.01)[160]. They suggested calmodulin levels could be used as a predictor of curve progression.

However, other workers have not found abnormal platelet function[154,306] or electron microscopic morphology[306] in IS subjects when compared with controls. Enslein and Chan reported decreased platelet aggregation in AIS and other chronic orthopaedic conditions[96]. The consensus indicates that the changes in platelets may indicate generalised defects underlying IS[181]. What is not clear is whether these defects apply to a specific subgroup of patients, whether the abnormalities are directly genetically mediated or whether they result from or they cause abnormal processes perhaps in growth or maturation control.

Ligaments

The investigation into the importance of ligaments in the possible aetiology and pathogenesis of IS has involved animal experiments, work on laxity and spinal flexibility, examination for collagen defects and consideration of the intervertebral disc.

Laxity and flexibility

Burwell, Dangerfield and Vernon found that patients with AIS have more ligamentous laxity than controls[48]. Weber studied 72 girls with IS and controls and concluded that patients with IS show symptoms of hypermobility, but the development of these symptoms was different from that of the hypermobility syndrome[365]. The question arises whether ligamentous laxity is a risk factor for curve progression. Patients with IS have less spinal flexibility than controls[104] and flexibility decreases with increasing curve size[269] but the spine is directly affected by the scoliosis so it is not possible to separate cause from effect.

Ligaments, proprioception and neurological feedback mechanisms

The assertion that the ligamentous laxity associated with scoliosis might be secondary to defective proprioception was not supported by SSEP studies, except possibly in the case of thoracolumbar curves[101]. Jiang et al[153] found the ligaments of scoliosis subjects were less well innervated than those of controls and concluded that this had aetiological significance[153].

Collagen defects

There are contradictory findings for the existence of collagen abnormalities in IS. Abnormal glycosaminoglycan (GAG) sequences[14] and dermal elastopathy[93] have been reported in IS, which were suggested to have a role in the genesis of early or severe IS[93]. Uden and co-workers found that collagen from patients with AIS was less able to aggregate platelets[355]. Others reported normal collagen and GAG content in ligaments from IS patients compared with controls[236,360].

The study of collagen disorders has provided an avenue for the investigation of the genetic basis to IS and will be discussed under *Genetic theories of aetiology*, page 26. The metabolism of collagen and other structural proteins will be commented on under the heading of *Protein metabolism*, page 26.

Discs

Published work indicates that discs of patients with IS have decreased mucopolysaccharides[268], increased collagen in the nucleus pulposus[53,268], decreased collagen in the annulus[53], and some changes in proteoglycan distribution[255,290]. Any changes found in scoliosis discs were generally believed to be a secondary phenomenon53,255,[290,333]. Taylor and Melrose have recently reviewed the literature regarding the role of the intervertebral disc in AIS and concluded 'all of the recorded observations are far more likely to be associated with effect rather than cause'[348].

Protein metabolism

Whether there are abnormalities in protein metabolism in IS in humans is disputed. Findings for IS include increased catabolism of protein[331], increased serum alpha1-globulin[111], decreased alpha2- and beta-globulin[34], 'increasing' hydroxyproline excretion[392] and normal hydroxyproline excretion[62]. These contrasting findings may be a reflection of studying IS as a single entity, where one group of patients have different characteristics to another, a problem more likely in small sample groups or if there are wide inclusion criteria. Altered protein metabolism may occur in some patients with IS.

Worthington, in a 1991 review, concludes that 'Sixty-five to ninety percent of all scoliosis is of unknown origin or idiopathic. During the last 30 years, researchers world-wide have found a variety of abnormalities in tissues throughout the body including peripheral muscle, skin, ligaments, platelets, bone, intervertebral discs, serum and urine. The primary defects appear to be related to collagen and proteoglycan synthesis. The systemic abnormalities seen in idiopathic scoliosis cannot be explained by the biomechanical effects of the curvature'[385]. This is only partly true as we still don't know the extent of secondary changes in soft tissues which are possible in IS. Possible genetic theories of aetiology are now discussed.

Genetic theories of aetiology

As the term 'idiopathic scoliosis' was not used until 1950, interpretation of the early studies on genetics is difficult. Wynne-Davis carried out a survey of the 180 case records from Edinburgh in 1968 and concluded that IS had a dominant or multiple gene inheritance with a stronger family history in girls, with variable penetrance and expression[388]. The general population incidence for IS was 0.39% compared with 6.94% for first degree relatives, 3.69% for second degree and 1.55% for third degree relatives[388]. MacEwen and Cowell reported on 75 IS cases and suggested a dominant sex-linked inheritance with variable penetrance and expression[187], findings supported by the work of Cowell et al[73] and Robin and Cohen[292].

In 1982 Wynne-Davies showed IIS was associated with breech presentation, prematurity, and the onset of the curve in the winter months and concluded that there was a multifactorial genetic background with a variable additional environmental element[389].

Findings of asymmetrical postural sway[177] and abnormal sagittal profile[58] in siblings of scoliosis patients has been interpreted as being representative of an inherited tendency to scoliosis.

Underlying genetic disorders

The large number of congenital malformations and diseases associated with scoliosis have been classified by the SRS[124]. The number associated conditions serve to demonstrate firstly the large number of different pathological processes that may cause scoliosis and secondly, how a genotype may interact with growth processes or possibly environmental factors to cause a scoliosis much later in life.

In recent years the genetic abnormalities underlying a number of connective tissue disorders have been identified[105,216]. Interestingly, these abnormalities are usually unique to a particular family or individual[216], which has the implication that many different gene mutations could cause IS. However studies on a total of 15 pedigrees of AIS segregating in an autosomal dominant pattern[60,218] failed to identify the structural genes of FBN1, elastin, and collagen Types I and II as the involved genes within these families.

Bentley and Donell voiced the possibility that one day gene therapy could be used for the treatment of IS[26]. In the case of IS, it seems likely that individuals will require genetic modifications tailored for their specific mutations and administration before deformity occurs, lest there are secondary pathomechanisms for progression present. Gabriel reviewed the progress in the identification of the genes for neurofibromatosis and the findings in IS. He comments that the advances in basic science are yet to produce pragmatic results as far as treatment is concerned[105]. As Nancy Miller points out in her recent review, genetic determinants of IS will only be identified when homogenous study populations within the spectrum that is IS are critically defined[217].

The Central Nervous System and Neuromuscular theories of aetiology

The thesis that IS is caused by some deficit in the CNS and possible linked defective muscle control is an attractive one. Failure of putative reflex homeostatic mechanisms could result in buckling of the spine under stress, for example during growth. Theoretically these reflexes may be unaltered by the deformity itself, avoiding the question of cause and effect. Contradictory results have been reported but more recent work using more reliable measures and the application of newer techniques of imaging promise further understanding of the control of spine equilibrium.

Animal work

Scoliosis can arise following division of unilateral dorsal nerve roots[262] and after posterior horn lesions[263] in monkeys and after various lesions in other animals. Work in humans is reviewed below.

Nerve roots

Lloyd-Roberts et al noted there were degenerate cells in convex dorsal root ganglions of an IIS specimen[179]. They suggested that progression was the result of a developing scoliosis trapping nerve roots causing convex muscle weakness. There is little other evidence to support the presence of a nerve root lesion in IS, and as Edgar points out, IS is not usually associated with sensory abnormalities[94]. There is no evidence for a peripheral nerve conduction problem in AIS[297].

Spinal Cord

Dorsal column - Proprioception and Vibration disorders

Contradictory results of vibration testing in scoliosis subjects have been reported[20,204]. Both studies used the Bio-Thesiometer (Biomedical Instrument Company, Newbury, Ohio) which was found to be unreliable on reproducibility testing[204]. Patients with AIS, when compared with control subjects, have been found to have subtle deficits in equilibrium function[391], side asymmetry in the ability to reproduce knee flexion angles[19] and side asymmetry in the threshold for detection of elbow movement[71]. Asymmetry was also found in controls, but their function was better[71]. Keessen et al used a spatial orientation device and found placement inaccuracy in right-handed scoliosis subjects and spinal asymmetry subjects (school screeners) compared with controls. They postulated that proprioceptive dysfunction is a causative factor of spinal asymmetry[156].

Syringomyelia

MRI has demonstrated an incidence of syringomyelia in up to 28% of AIS[61]. Surgery to decompress the syrinx can result in stabilisation of the curve[139,307], but these patients had not been followed through the adolescent growth spurt so longer follow-up will be needed to assess whether the arrest of progression is permanent.

Somatosensory evoked potentials (SSEPs)

Interpretations of SSEPs are open to subjectivity. Abnormal lower limb evoked potentials have been reported[109,189,192] after comparison with control subjects. Others report no significant findings on SSEP studies[101,319]. It appears that SSEPs are too blunt a tool with which to dissect the intricacies of neural control.

Hindbrain and midbrain

Disorder of equilibrium function

Spinal equilibrium requires the co-ordinated and integrated function of the nervous system, which must compensate for the continual change in muscular and skeletal proportions with growth.

Vestibular dysfunction was postulated to contribute to the multifactorial aetiology of IS[10,295], based on findings for electronystagmography in IS subjects and control subjects. However the incidence of IS in hearing-impaired children, known to have a high incidence of vestibular dysfunction, is 1.2%, compared with a national incidence of 4%-10%[384]. The authors suggested that IS has a neural aetiology because hearing-impaired students appeared to be protected by their presumed neural dysfunction.

Beirne et al proposed that equilibrial dysfunction could be an effect of scoliosis rather than a cause[22], after finding equilibrial dysfunction in patients with progressive idiopathic and progressive congenital scoliosis but not in controls.

Postural sway

Postural sway is greater in IS than in normal children[54], though stabilometry (postural control), electroencephalography (EEG, central nervous system) and electronystomography (ENG, vestibular function) were not predictive of curve progression in a prospective study of 52 patients with AIS[296]. Goldberg has not found any correlation between the magnitude of sway and curve magnitude[114].

Cerebrum

Abnormal EEG recordings have been found in IS[86] and AIS[259] but no relationship was found between EEG with curve progression[296].

There does not appear to be a relationship between handedness and the side of the IS curve[295] unless the curve is classified on the basis of the convexity of the low thoracic component only[112]. Other CNS functions in IS have been evaluated revealing asymmetry of language processing in IS[119] and an association between curve progression and less right right-ear advantage for language[96].

Comment

Many conditions are associated with scoliosis (see *Underlying genetic disorders*, page 27) which suggests that the causes of IS are unlikely to be unique. Use of X-rays and MRI revealed hemivertebrae and syringomyelia respectively as causes of scoliosis. Some causes are likely to reside in the relatively unexplored areas of the neuro-physiology of spine balance which could be investigated using single photon emission tomography (SPET) or positron emission tomography (PET). These techniques are developments of ECT (Emission Computed Tomography) and, unlike CT, give a picture of organ function, not strict anatomy. PET can be used to study glucose metabolism as a marker of neural cell activity, neural oxygen metabolism and blood flow, and neural receptor mapping.

Irrespective of the method of investigation, the question of whether abnormalities found are secondary to scoliosis rather than of aetiological significance will remain. There are two ways to avoid this problem, namely (i) prospectively study a population before any subject develops scoliosis, for example as done by Nissinen et al[234] or (ii) study a characteristic that is established before scoliosis develops, such as epidermal ridges[120] or genetic makeup. An element of serendipity is necessary in either approach. The former requires selection of factors to be studied which will be fruitful. The latter approach requires grouping of curves into types of common aetiology, as studying all curves may obscure important causes of scoliosis in certain subtypes[239]. Of course, these fruitful factors and the appropriate means of grouping curves are not known.

Despite the efforts of many researchers over the years, the aetiology, pathogenesis and pathomechanisms of IS remain obscure. Application of paradigms from the expanding fields of molecular biology and genetics may provide insights into the processes involved.

Introduction to studies presented in this thesis

The patients who are the subjects of this study attended Queen's Medical Centre, Nottingham for treatment of their scoliosis. They fall into two main groups, those with IIS or JIS and those with AIS. The aim of this study is to evaluate the effect of surgery on the scoliosis deformity both at the time of surgery and on follow-up. Surgery is an intervention to the natural progression of scoliosis and careful study of its immediate and long-term effects may shed light on the possible pathomechanisms of scoliosis progression. Little is likely to be gleaned on potential aetiologies of scoliosis, however a better understanding of pathomechanisms for scoliosis progression could direct future surgical management to the patients' benefit. Our understanding of what constitutes 'the patients' benefit' is traditionally founded in what the medical profession deems a good outcome. However, the patient might be unimpressed at having a smaller Cobb angle after surgery. Those aspects of treatment that the patient, and their parents, find important are also studied here.

The general methods used in the studies are detailed under the heading of General Methods, see page 32 below. The remainder of the work is divided into two main sections (i) studies on IIS and JIS and (ii) studies on AIS, the latter with three subsections representing different areas of work. Each section and subsection has its own introduction and a brief description of methods particular to that study. Results and discussion for each subsection then follow.

The thesis is concluded with a summary of inferences drawn from these studies and application of these results for surgical management of scoliosis, their importance in pathomechanisms of scoliosis and their relevance to future studies of IS.

GENERAL METHODS

Radiographic, anthropometric and back surface measurements were used to assess the patients studied in this thesis, before surgery and at intervals after surgery. Some radiographic and back surface measurements were taken at multiple intervals down the back or spine and these are termed *segmental* in this thesis e.g. vertebral tilt measured for each vertebra from T1 to L5 is a *segmental* measurement. Use of the term rotation refers to axial vertebral rotation unless stated otherwise.

The methods used to assess scoliosis patients are described below, and these methods have been in use in Nottingham since 1987[52]. Note that not all of the measurements described were taken on all of the patients. The measurements taken on any group of patients are detailed in the corresponding sections of this thesis.

Back surface appraisal

Rib-prominence

Simple mechanical methods for measuring back surface deformity (humpmeter, formulator and Scoliometer) are time consuming and require trained personnel to achieve good reproducibility. More complex systems such as Moiré topography, rasterstereography and optical scanning (ISIS, Quantec) can rapidly acquire large quantities of data, but reproducibility is poor[76,253,353,354]. Appreciable variation in back shape occurs with changes in patient positioning, postural variation and postural sway[113,127,367] and this adversely affects reproducibility. To overcome this, Scutt et al suggested that patients be assessed in the prone position[304], but there is the possible effect of anterior chest wall asymmetry to consider. Others have fixed the pelvis[244], but with limited success. We evaluated back surface asymmetry was using an OSI Scoliometer (Orthopedic Systems Inc., Haywood, California; PAROX GmbH, Drechslerweg. 40, 4400 Münster, Germany)[40] at each of 10 levels from C7 to S1[357] by one of three observers (R.K. Pratt, A.A. Cole, R.G. Burwell) with the patient in the standing forward bending position. This gives an angle of trunk inclination (ATI) at each level. Intra-observer error (RGB) has been reported to be ±3° (±1.95 standard deviations)[356]. Reported inter-observer error (one standard deviation) is ±2.0° in the thoracic region and ±2.2° in the lumbar region[227]. Use of the Scoliometer for back shape assessment in the standing forward bending position is supported in the literature[6,49,227].

We also had available an Integrated Shape Imaging System (ISIS, Oxford Metrics Ltd, Unit 87, West Way, Oxford, England) for use in quantifying the cosmetic defect of scoliosis[354].

Reproducibility of Scoliometer and ISIS assessments of back-shape with the patient in different positions

Method

16 pre-operative patients had 10 level Scoliometer readings taken *twice* in each of the standing forward bending position, the sitting position and lying prone. The patients then stood down and the surface anatomy was remarked and back-shape measured again in each of the three positions. ISIS scans were then obtained twice in each of the standing and sitting positions. The patient then stood down, was remarked for surface anatomy and scanned twice in each position again.

For the purposes of reproducibility calculation, 10 level data sets were considered in pairs. The first set of data obtained for any given method and patient position was compared with the data set obtained for the same measurement and patient position after remarking and repositioning. The second set of data obtained for any given method and patient position was compared with the second set of data obtained for the same measurement and patient position after remarking and repositioning. This was felt to give the best approximation to clinical practice, without having to subject patients to the inconvenience of revisiting hospital for reproducibility measurements.

The difference between corresponding measurements was calculated and 95% confidence limits calculated according to the method of Bland and Altmann[33].

Results

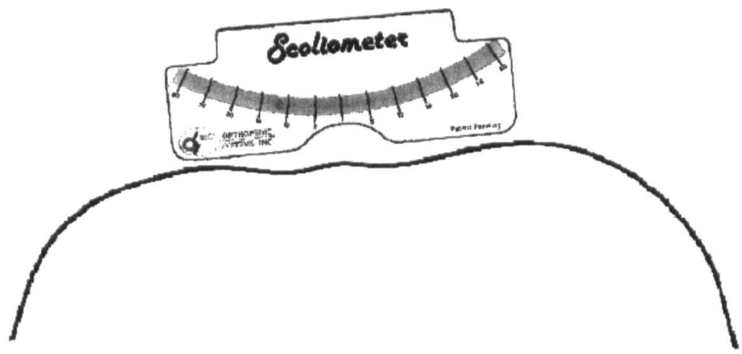
The ISIS scanner developed a fault so two patients did not have ISIS scans. The differences between the first set of data obtained and the first set of data obtained after remarking and repositioning were calculated, giving 95% confidence intervals. In the same way, confidence intervals can also be calculated for the differences between the second set of data obtained and the final set of data obtained. Thus four sets of data produce two sets of 95% confidence intervals (Table 1).

Table 1. Reproducibility for measuring ATI by Scoliometer and ISIS at each of 10 levels four times on 16 patients in different patient positions (FB=forward bending).

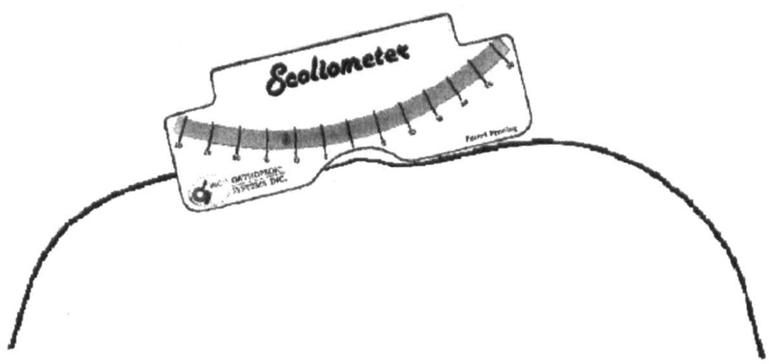
Back surface level	Mean 95% Confidence limits (±1.96 * SD)				
	Scoliometer (n=16)			ISIS (n=14)	
	Standing FB	**Sitting FB**	**Prone**	**Standing**	**Sitting**
1	± 3.9°	± 4.9°	± 7.0°	± 11.8°	± 10.7°
2	± 4.1°	± 4.4°	± 6.3°	± 1.87°	± 9.4°
3	± 4.1°	± 4.1°	± 4.0°	± 12.7°	± 9.8°
4	± 3.8°	± 4.6°	± 4.3°	± 11.2°	± 8.1°
5	± 4.2°	± 5.8°	± 3.0°	± 12.7°	± 9.1°
6	± 4.2°	± 6.5°	± 4.3°	± 12.8°	± 9.0°
7	± 4.3°	± 7.8°	± 4.1°	± 12.2°	± 6.5°
8	± 5.8°	± 7.4°	± 5.1°	± 10.8°	± 6.7°
9	± 4.9°	± 10.4°	± 3.8°	± 11.3°	± 6.2°
10	± 3.9°	± 5.1°	± 3.6°	± 3.0°	± 0.8°
Mean for 10 levels	± 4.3°	± 6.1°	± 4.5°	± 11.0°	± 7.6°

Conclusion

Review of the results in Table 1 reveal differences by position of the patients and between Scoliometer and ISIS. Use of the Scoliometer with the patient in the standing forward bending position gives the most reproducible measurement of ATI. Lying the patient prone gives similar results. There was poor reproducibility for the Scoliometer with the patient sitting and forward bending, especially for the lumbar region. This finding probably reflects the difficulty of measuring lumbar back shape in those patients who are unable to bend forward enough to bring their lumbar spine towards horizontal, as depicted in Figure 1.



Back horizontal - left hand side of Scoliometer being 1 cm closer to observer than right side causes small measurement error



Incomplete forward bending - left hand side of Scoliometer being 1 cm closer to observer than right side causes large measurement error

Figure 1. Use of Scoliometer. Measurement error increased by patients not being able to bend forward fully.

There is good reproducibility for use of ISIS only at the S1 back level, because patient position is adjusted so that the back surface at this level is perpendicular to ISIS. There are large variations in ATI equivalent measures for the standing position, and smaller variations for the sitting position, which probably reflects postural sway[113,127,367]. It is likely there is less postural sway in the sitting position.

Back shape is assessed using the Scoliometer with the patient in the standing forward bending position in this thesis.

General anthropometric methods

Standard techniques were used as described by Tanner et al[344]. Equipment used included the Harpenden Stadiometer and Harpenden Anthropometer (Holtain Ltd, Crosswell, Crymych, Dyfed SA41 3UF) and a nylon tape measure. Measurements were repeated on 14 patients to evaluate intra-observer error (RKP), quoted to two standard deviations. Skeletal measurements included weight in kilograms (±0.37), stature and sitting height (±10 mm), acromial heights (±16 mm), antero-posterior and lateral chest diameter at the level of T4 (±11 mm), bi-acromial width (±8 mm) and bi-iliac width (±7 mm). A plumb-line dropped from C7 (vertebra prominens) past S2 with the patient standing was used to assess frontal plane trunk tilt (±8.0 mm).

Radiographic appraisal

Full length postero-anterior standing radiographs were evaluated to determine the following:

- Curve type by apical level[124] and according to the King classification[161].
- The side of the major curve.
- Cobb angle, by the method of Cobb[64].
- Apical vertebral rotation (AVR), using a Perdriolle template[256].
- Risser grade[256].
- The distance between the centroid of T1 and the centroid of S1.
- The frontal plane balance measured as the angle between the T1-S1 line and the vertical (the lateral margin of the radiograph being vertical), with a negative angle denoting a lean to the left.

- Frontal plane balance, expressed as the horizontal offset (cm) of T1 on S1.
- Segmental vertebral tilt from T1 to S1 inclusive, being the angle that the lower border of each vertebra makes with the T1-S1 line[382]. Vertebral tilt was positive if the left side of the vertebra was lower than the right[380].
- Segmental vertebral rotation (VR), using a Perdriolle template[256], from T1 to L5 inclusive.
- Segmental vertebral translation (VT), the horizontal translation of each vertebral centroid from the T1-S1 line, from T1 to S1 inclusive[382].
- Segmental convex and concave rib-spine angles (RSAs) to the T1-S1 line[349] from T1 to T12 (Figure 2). Rib-vertebra angle difference[206], concave and convex apical rib-vertebra angles (RVAs)[166] and segmental RVAs[382] can be calculated from segmental RSAs and segmental vertebral tilt.
- Upper and lower end-vertebra angles (EVAs), as described by Wojcik et al[380].

Full length standing lateral radiographs of the spine were evaluated to determine the following:

- The distance between the centroid of T1 and the centroid of S1.
- The sagittal plane balance measured as the angle between the T1-S1 line and the vertical (the lateral margin of the radiograph being vertical), with a negative angle denoting a lean backwards.
- Sagittal plane balance, expressed as the horizontal displacement of T1 on S1 (cm), positive if T1 is anterior to S1.
- Segmental vertebral inclination in the sagittal plane of the posterior surface of each vertebral body, from T1 to S1 inclusive, by the method of Kiel et al[159].
- Kyphosis (upper endplate of T5 to lower endplate of T12), using the method of Cobb[64].
- Lordosis (upper endplate of L1 to lower endplate of L5), using the method of Cobb[64].

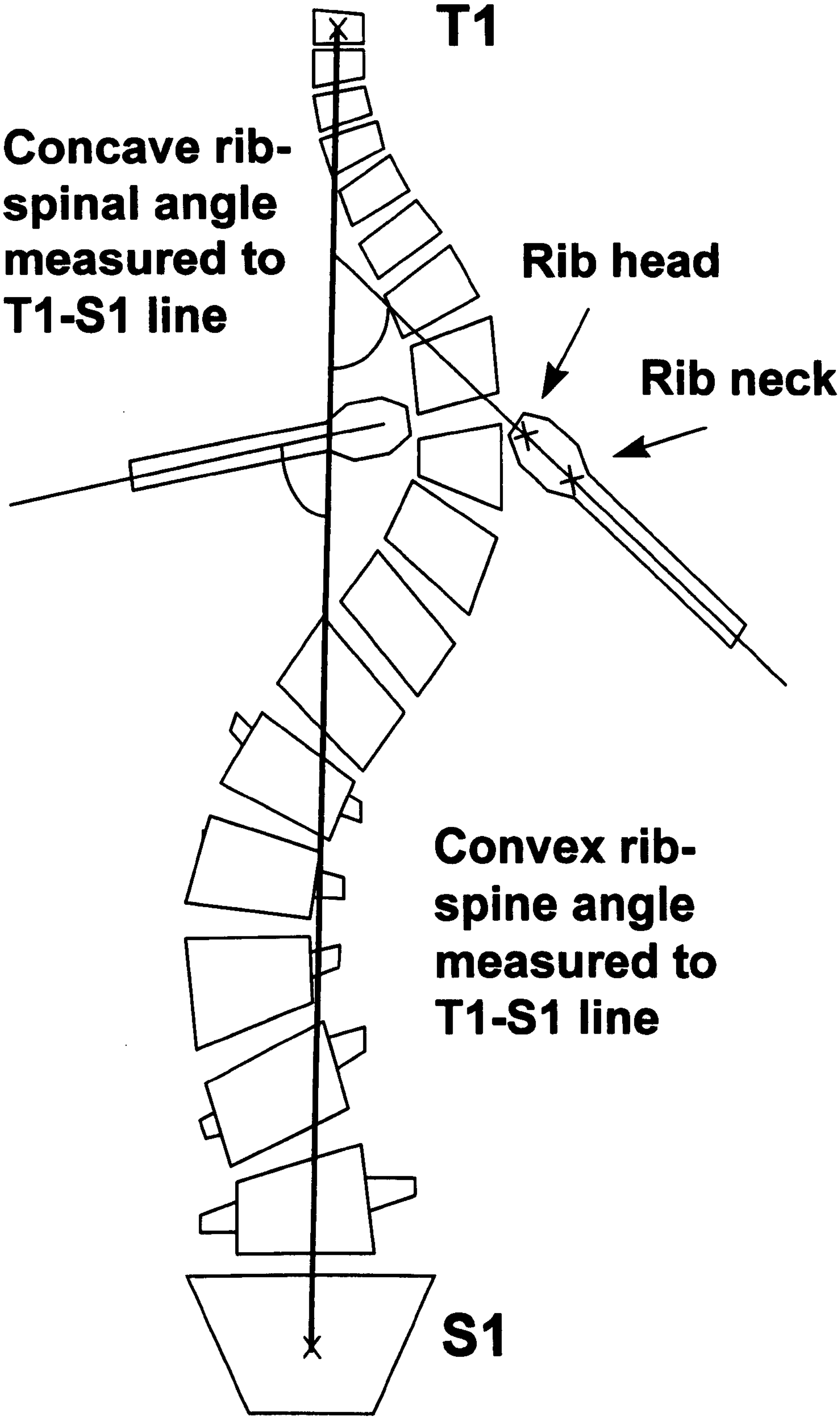


Figure 2. Measurement of rib-spine angles.

- Pre-operative side bending films to the concave and convex sides were measured to determine:

- Cobb angle and apical vertebral rotation on each side bending film.
- Curve flexibility as a percentage of pre-operative Cobb angle, using the Cobb angle measured on the side bending film to the convexity of the curve.

Reproducibility

Radiographic measurements were repeated on 10 postero-anterior films of patients with IIS to evaluate intra-observer error (RKP). The skeleton is smaller in these patients so reproducibility would be expected to be worse than for AIS. The mean and standard deviation of the differences between two readings were calculated[33] (Table 2).

Table 2. Reproducibility for measuring each of Cobb angle, apical vertebral rotation, concave rib-spine angle and convex rib-spine angle, twice on 10 PA spinal radiographs.

Measurement	Mean difference (degrees)	Standard deviation of difference	95% Confidence limits (±1.96 * SD)
Cobb angle	0.1	2.5	±5.5°
AVR	-1.2	5.0	±11.1°
Apical vertebral translation	-0.3	2.5	±5.5 mm
Concave rib-spine angle	0.7	4.5	±10.0°
Convex rib-spine angle	-1.0	2.8	±6.2°
T1-S1 distance	0.8	3.3	±6.9 mm
Horizontal offset T1 on S1	0.3	1.4	±2.8 mm

Where:

SD = standard deviation

Reproducibility of rib-spine angle measurement

There is little published on reproducibility of rib-vertebra angles. McAlindon and Kruse[201] reported inter-observer accuracy of ±6.2° and intra-observer accuracy of ±4.4° (accuracy was defined as ± two standard deviations of the measurement error). Error was calculated by subtracting each reading from every other reading. Intra-observer error was reported from 3.7° to 6.1° with one standard deviation ranging from 3.2° to 4.6°. Mean inter-observer error was reported as 3.6° with one standard deviation being 2.6°. It is implicit that signed differences where not used, (as then expected mean difference should be close to zero if there are no systematic errors) and as a result the spread of measurement error was effectively halved. Signed differences should be used because a repeat measurement can be greater or less than the first. It is impossible to evaluate the true variation of measurement as these are the only figures given in the paper, but a more likely intra-observer error would be of the order of ±16° (mean + 1SD * 2) and ±12° for inter-observer error. These estimates would be in keeping with the errors for RSA in Table 2.

In addition to measurement error, another source of error in assessing RSAs might be found in errors of positioning the patient perpendicular to the radiographic film. It is probable that rotation of the ribs with respect to the radiographic film could alter the RSA projected onto the film. No studies were available on the effect of trunk rotation on RSAs so this was investigated further.

Effect of thoracic cage rotation on measurement of RSAs

An articulated spine (not scoliotic) with the thoracic cage intact was mounted on a rotating base-plate with a protractor attached. Thus the skeleton could be rotated through known angles. Radiographs were taken with the skeleton rotated at 10° intervals from -50° to +50° measured to the X-ray beam. The apparatus was then dismantled, reconstructed and the experiment repeated. This gave two films for each of 10 positions of rotation. The left and right RSAs for all 12 sets of ribs were measured twice on each film and the mean RSA at each level was plotted against the degree of rotation of the thoracic cage to the radiographic film (Figure 3 and Figure 4).

Inspection of Figure 3 and Figure 4 reveal that the RSAs for ribs of T5, T6, T7, T8, and T9 do not vary as much from the RSA at zero degrees rotation as RSAs for the upper ribs (T1-4) and the lower and floating ribs (T10, 11 & 12). In addition, most variation occurs when right sided ribs are rotated clockwise and when left sided ribs are rotated anti-clockwise to the X-ray beam. As the head and neck of ribs incline caudally and posteriorly in normal

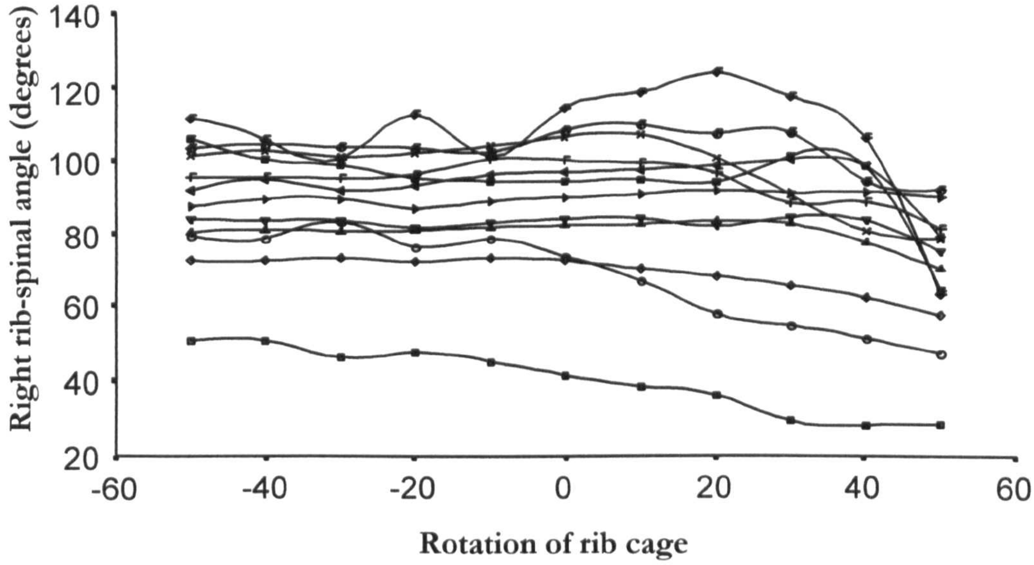


Figure 3. Mean measurements for segmental right side RSAs at different angles of rotation of the thoracic cage to the radiograph.

For figure 13 and 14: ▪ T1 rib × T4 rib ◂ T7 rib ◇ T10 rib
◆ T2 rib + T5 rib ▿ T8 rib ○ T11 rib
⊕ T3 rib ▸ T6 rib ▴ T9 rib ▫ T12 rib

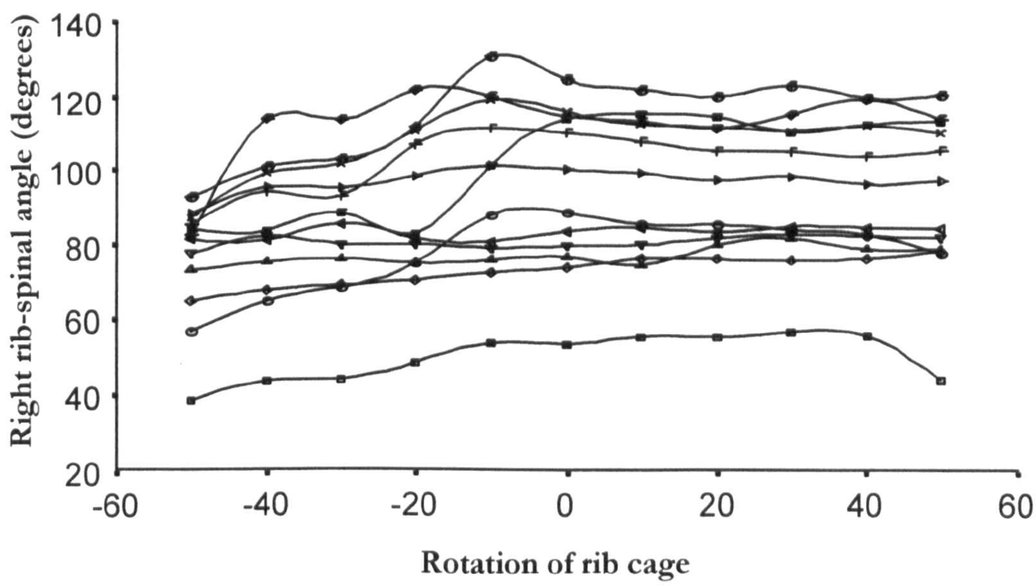


Figure 4. Mean measurements for segmental left side RSAs at different angles of rotation of the thoracic cage to the radiograph.

anatomy, they appear foreshortened in the radiographs when rotated as described above, resulting in less reproducible RSA measurements.

Analysis of changes

Each vertebral level was considered separately. Rotations were considered as being towards or away from the side of the rib measured, and left and right RSAs were analysed together. Left RSAs measured with the thoracic cage rotated anticlockwise and right RSAs measured with the thoracic cage rotated clockwise were analysed together (denoted as 'ribs rotated towards' in Table 3), and right RSAs measured with the thoracic cage rotated anticlockwise and left RSAs measured with the thoracic cage rotated clockwise were analysed together (denoted as 'ribs rotated away' in Table 3).

Significant variation of RSA occurred due to rotation of the thorax at each vertebral level (RMMANOVA). Paired T tests identified significant variations from RSA in zero rotation as detailed in Table 3.

Table 3. Significance of difference in RSA measurements comparing zero degrees rotation to various degrees of rotation of ribs towards or away from observer.

Level	**Ribs rotated away by:**					**Ribs rotated towards by:**				
	50°	**40°**	**30°**	**20°**	**10°**	**10°**	**20°**	**30°**	**40°**	**50°**
T1	NS	NS	NS	NS	NS	NS	NS	NS	NS	***
T2	NS	NS	NS	NS	NS	***	***	NS	NS	***
T3	**	***	*	NS	NS	NS	NS	NS	**	***
T4	**	*	**	**	***	NS	NS	***	***	***
T5	**	***	***	**	NS	NS	NS	***	***	***
T6	**	NS	NS	**	NS	NS	NS	NS	NS	*
T7	NS	NS	NS	NS	NS	NS	NS	NS	NS	*
T8	NS	NS	NS	NS	NS	NS	NS	NS	NS	*
T9	NS	NS	NS	NS	NS	NS	NS	NS	NS	*
T10	NS	NS	*	NS	NS	**	***	***	***	***
T11	NS	NS	NS	NS	NS	NS	**	***	***	***
T12	NS	**	NS	*	**	NS	***	***	***	***

Where:

* denotes a P value<0.05

**		denotes 0.0005<P<0.01

***		denotes P<0.0005

N.B. P value of 0.0004 taken as significant (Bonferroni's correction), i.e. ***.

Implications for RSA measurement

There is an effect of thoracic cage rotation on reproducibility of measurement of RSA. This effect varies with the vertebral level considered. Generally measurement of RSA for ribs rotated towards the observer are less reproducible (for example those ribs on the convexity of the curve) than the same measurements on ribs rotated towards the observer. Effects of thoracic cage rotation on reproducibility of measurement of RSA is least for ribs at T6, T7, T8 and T9. Reproducibility also appears worse when T3, T4 and T5 ribs are rotated away from the observer. It follows that results for upper and lower convex thoracic ribs and T3-5 concave ribs should be interpreted with caution.

Questionnaires

Traditional evaluation of medical treatment includes measures of morbidity, mortality and consideration of clinical, radiological, laboratory and other physician based data. Over the past 25 years there has been a trend towards incorporating patient based measures in the evaluation of treatments[108,152]. There has been a proliferation of instruments for the assessment of general well being or the assessment of specific conditions. The better researched instruments have been formally validated on both normal and diseased sample populations, are reliable and are responsive to change.

Validity

Validity may be considered in four sub-categories: face validity, content validity, criterion validity, and construct validity. *Face validity* refers to whether items on a questionnaire make sense, in that they should not be ambiguous. *Content validity* refers to choice of items in questionnaire (which should be relevant to the condition being investigated) and the relative importance given to these items. *Criterion validity* refers to the extent to which an instrument corresponds with other measures. *Construct validity* refers to the ability of an instrument to confirm expected hypotheses about the construct being tested. For example, I would expect patients in pain to experience less pain after taking analgesia. If the instrument did not demonstrate a reduction in pain after analgesia, then there are a number of explanations: (i) The theory is wrong, and pain is not relieved by analgesia; (ii) the instrument does not measure pain or (iii) both (i) and (ii) are true. Testing for construct validity is an ongoing process as no one experiment can prove a construct is true, while only one non-confirmatory experiment may disprove it.

Reliability

Reliability is a measure of the amount of error in a measurement. It is normally assessed by testing and retesting a sample population. Reliability is most easily understood in terms of confidence limits. However some knowledge of the size of the quantity being measured is required for meaningful interpretation. A formal definition of reliability is R=subject variability / (subject variability + measurement error)[340], known as the Intraclass correlation coefficient (ICC). Pearson's correlation coefficient tells us the extent to which the relationship between two variables can be described by a straight line. This will usually overestimate reliability compared with ICC and the standard deviation of the test group is required to calculate the standard error of the measurement. Difficulties in interpretation of correlation coefficients are compounded by use of different measures of reliability and occasional failure to report which correlation test has been used. Use of a non-parametric test would raise questions regarding data distribution.

The time elapsing between reassessments is important. Too long and there may be a real change in patient status, too short and a memory effect becomes a factor. For example, reliability has been reported for patients with low back pain for the Oswestry Disability Index (ODI)[98] with r quoted as 0.99 (Pearson's correlation coefficient). Tests were readministered the next day which is probably within the memory span of the subjects. The correlation drops to r=0.83 if the patients are retested after a week[131]. To circumvent this problem, some researchers determine internal reliability using the Cronbach's alpha statistic[74]. Internal reliability refers to the extent to which each item in a questionnaire correlates with other items in the questionnaire. If this correlation is too low then items are measuring very different quantities which may not all be relevant to that being assessed, so those spurious items should be discarded. If this correlation is too high then there may be redundant items. Acceptable range for Cronbach's alpha is felt to be between 0.70 and 0.90[340]. It is controversial that such a method can be used for assuming reliability over time[294].

Sensitivity to change

Sensitivity to change or 'responsiveness' refers to the ability of an instrument to detect changes in health status and is important if the instrument is to be used to assess the impact of medical interventions. This largely depends on the content of the instrument, for example if a questionnaire has questions referring to average symptoms over a month then it is unlikely to be sensitive to recent changes in health status. The reliability of the instrument will also determine the minimal change that may be detected. However the minimal change detectable may not be clinically significant.

Questionnaires used in this study

Pre-operative and post-operative questionnaires were given to patients and to fill in at pre-operative and 2-year assessments. These questionnaires comprised of 5 sections, namely a self-perception section, a pain section, the Oswestry Disability Index (ODI), the Psychosocial Adjustment to Illness Scale (PAIS), and an aims/results of surgery section. The self-perception section, pain section and the ODI were identical at pre-operative and 2-year assessments. The PAIS required small modifications to four questions (Section 1 Q5,7 and Section 2 Q5,6) so that the questions at the 2-year assessment made grammatical sense in the context of a post-operative assessment. The aims/results of surgery sections were also filled in separately by parents. The questionnaires are given in Figure 5, Figure 6, Figure 7, Figure 8 and Figure 9 at the end of this section, page 51. The questionnaires were drawn up by Mr A. A. Cole FRCS and Mr J. O'Dowd FRCS.

The self-perception section (Figure 5)

This section is the same as that used in the Ste-Justine AIS Cohort Study to study the perception of self and body for patients with AIS and a control group[123] except that the 2 Ste-Justine Study questions relating to sexual relationships were excluded. The items were taken or adapted from the Duke-UNC health profile[251] and the Sante-Quebec survey[274]. Nine of the 13 items come from the Emotional Function dimension of the Duke-UNC health profile[251]. This section was designed to assess the respondent's level of self esteem, in terms of respect for self and belief in their ability to get along with others. Parkerson et al evaluated the Duke-UNC using 395 primary care patients[251]. Internal consistency for the Emotional Function dimension was 0.85 (Cronbach's alpha[74]). Test-retest reliability was performed when patients reattended the practice and was evaluated using Spearman rank correlations with $\rho=0.72$, $n=55$. The time interval between tests was not specified.

Scoring:

Each statement was scored on a 5 point scale (0 to 4), with the highest score being given to the most positive perception. The sum of the scores for the 13 statements was termed the total score.

The pain section (Figure 5)

Pain is subjective experience so its expression by the patient will be modulated by psychological and physiological factors. The patient must be co-operative, able to communicate and cogent. Methods used to measure pain include rating scales, pain diagrams, questionnaires, physiological methods (blood pressure, sweating, EEG etc.) and analgesic use. The pain section uses a combination of a visual analogue scale, a pain diagram and a descriptive pain questionnaire.

The visual analogue scales were initially developed to measure mood[5] but were then adapted to measure pain[147]. Revill et al found that 10, 15, and 20 cm lines are less variable on reproducibility testing than 5 cm lines[277], with the 95% confidence limits for the difference between initial and 24 hour ratings on a 15cm line being ± 6.6% (derived from data presented). The score is the distance of the line the patient marks from one end of the scale in millimetres. However visual analogue scales only measure one dimension of pain, namely pain intensity.

The location of the pain was recorded with the use of pain diagrams[328], and patients were asked to mark and number the areas they felt pain.

Questionnaires can explore characteristics of pain such as its nature, persistence and location. Melzack and Torgerson thought that concentrating on just one aspect of pain was 'like specifying the visual world in terms of light flux only, without regard to pattern, colour, texture and many other dimensions of the visual experience'[212]. They picked words drawn from the then clinical literature for pain, and asked their subjects to group them according to what aspect of the pain the words related to[212]. They found 3 major subclasses (sensory, evaluative and affective / emotional words) and 16 subclasses. The words were then ranked by patient and doctors according to the severity of pain implied by the words. Each word could then be given a numerical value. The McGill pain questionnaire was developed and its use was tested on 297 patients[210]. The questionnaire administered to the AIS patients is a shortened version of the McGill pain questionnaire using 15 of the 78 words, known as the short-form McGill Pain Questionnaire[211]. The first 11 words are in the sensory subclass and next 4 are in the affective subclass, and are rated on a categorical intensity scale with the following weights; none=0, mild=1, moderate=2, severe=3.

I scored the questionnaire according to the method suggested by Melzack[211]. The pain rating score for each subclass is the sum of the intensity values (scores 0 to 3). The total score is the sum of all the intensity values. Melzack published the scores associated with different types of pain before and after therapeutic intervention[211]. These are reproduced in Table 4 below:

Table 4. Mean pain rating values for 3 kinds of pain obtained with the short-form McGill Pain Questionnaire before and after a therapeutic intervention.

Scale:		**Sensory**	**Affective**	**Total**	**VAS**
Pain	**Treatment**	**Mean / SD**	**Mean / SD**	**Mean / SD**	**Mean / SD**
Post-surgical	Before	11.7 / 7.2	3.7 / 3.5	15.4 / 9.6	5.2 / 2.3
	After	6.9 / 7.3	2.2 / 2.8	9.1 / 9.7	2.4 / 1.8
Labour	Before	13.4 / 7.8	3.9 / 3.9	17.2 / 11.0	5.0 / 2.3
	After	1.0 / 2.0	0.2 / 0.5	1.1 / 2.4	0.5 / 0.9
Musculo-	Before	11.1 / 8.7	4.6 / 3.7	15.7 / 11.9	4.1 / 1.6
skeletal	After	3.3 / 3.3	1.0 / 1.7	4.3 / 4.9	2.0 / 1.3

Where:

SD = standard deviation

Patients with post-surgical pain had analgesic drugs, patients with labour pain had epidural anaesthesia and patients with musculoskeletal pain had transcutaneous electrical nerve stimulation.

Validity: Melzack reported that the McGill Pain Questionnaire correlated with a visual analogue scale for pain, with r ranging from 0.5 to 0.65[210]. Dubuisson and Melzack reported that the scale was able to correctly classify 73 of 95 patients who had eight pain syndromes into diagnostic groups[89]. Melzack reported correlations ranging from 0.6 to 0.89 between the McGill Pain Questionnaire and the short-form version[211].

Reliability: Melzack has reported on results for 10 patients who repeated the McGill Pain Questionnaire three times with between 3 and 7 days between each repeat, and showed a consistency of response of 70%[210]. No data has been published on the reliability of the short-form version.

Oswestry Disability Index (ODI) (Figure 6)

The Oswestry Disability Index was first published in 1980[98] and this is the version used in this study. Reliability was assessed by test-retest correlation (Spearman rank) on 22 patients over a 24 hour period[98]. Validity was established by following 25 patients for 3 weeks after their first episode of low back pain. The pain improved as the scores improved. A second version was produced by a Medical Research Council group[13]. Fairbank and Pynsent have summarised the published work on validation and reproducibility for the ODI[99]. Test-retest reliability was 0.89[271] (Intraclass correlation coefficient), ranging from r=0.83[131] to r=0.99[98] (Pearson's correlation coefficient), depending on the patients studied. Cronbach's alpha has been reported as ranging from 0.71 to 0.89[99], which is acceptable[340].

Scoring:

The ODI consists of 10 sections, each of which has six statements. If the first statement is ticked then the score=0 for that section, if the last statement is marked, then the section scores 5, with intervening statements scored according to rank. Total score is the sum of all the section scores. The ODI score is expressed as a percentage of the maximum score, which is usually 50. If a section is missed out by the patient, often the sex question, then the maximum score will be 45 and the ODI is expressed as a percentage of 45.

Section 8 of the ODI (sexual activity) has been omitted in studies of teenagers with spondylolisthesis and metastatic cancer[99]. This section was included in the Ste Justine study, but this reflects the mean age of participants of 33 years old[122]. Section 8 was omitted in our questionnaire.

Psychosocial Adjustment to Illness Scale (PAIS) (Figure 7 and Figure 8)

The PAIS[80,81,222] consists of 46 questions which are divided into 7 domains namely health care orientation (8 questions), vocational environment (6 questions), domestic environment

(8 questions), sexual relationships (6 questions), extended family relationships (5 questions), social environment (6 questions) and psychological distress (7 questions). The instrument measures adjustments rather than quality of life so has applications in longitudinal studies. Originally the PAIS was interview based but the instrument was revised and a self-report format was introduced[80]. The sections on sexual relationships and those relating to extended family relationships were omitted because they were not thought to be applicable for our patients with AIS. In addition, 6 of the 8 questions for domestic environment and 3 of 6 questions on social environment were omitted for the same reason e.g. 'how would you characterise your relationship with your spouse' was not considered to be a relevant question. The other sections remained complete, leaving a total of 26 questions for analysis. The questions score between 0 and 3, with 0 denoting complete adequacy and 3 denoting complete inadequacy. The scale direction is alternated on even numbered items to reduce positive response bias. The sum is calculated for each domain and a total score is calculated from the summation of subscale scores once they have been standardised. Higher scores indicate a more positive psychosocial adjustment.

Validity: Validity testing revealed moderate to high correlations (r=0.60–0.81) with instruments measuring global adjustment and emotional functioning[81,213,368,374].

Reliability: Morrow et al[222] found inter-rater reliability coefficients ranged from r=0.33 to 0.83, all but one being greater than r=0.6, for 37 patients with Hodgkin's disease. Formal psychometric testing of the self-report version showed that the internal consistency coefficients for the domains range from 0.63 to 0.93 across different patient populations[80].

Current problems section for evaluation of pre-operative aims of surgery (patients and parents) and 2-year realisation of aims (Figure 9)

The patients were presented with 9 problems that may be associated with scoliosis and were asked to rate them on a 4 point categorical scale according to their viewpoint (no problem, mild, moderate and severe problem). Patients were also given the option of adding new problems. They were then asked to select four items from the above scale and rate them according to whether they thought surgery would address them and to what extent (no, mild, moderate improvement and fully correct). Parents filled in a similar form. At 2-year follow-up the patients were asked about their current problems and to what extent surgery had improved them. Information was also obtained from parents regarding their perceptions of current problems.

Scoring

Each statement was scored according to the categorical scale used (i.e. no problem=0, mild=1, moderate=2 and severe problem=3). The scores for each of the 9 statements used in the 'aims of surgery' and 'current problems' sections were summated to give an overall score for that section (minimum score=0, maximum score=27).

Pre-operative self-perception section

Tick one box per statement that best describes you

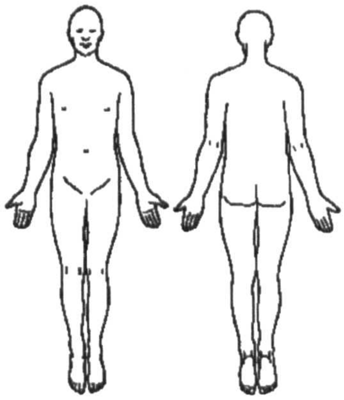
	Not at all	A little	Somewhat	A lot	Exactly
I have a good figure for my age	❑	❑	❑	❑	❑
I am in good shape for my age	❑	❑	❑	❑	❑
I try to look my best	❑	❑	❑	❑	❑
I like the way I look	❑	❑	❑	❑	❑
I like who I am	❑	❑	❑	❑	❑
Other people find me attractive	❑	❑	❑	❑	❑
I hate parties and social occasions	❑	❑	❑	❑	❑
I like meeting new people	❑	❑	❑	❑	❑
I am comfortable being around people	❑	❑	❑	❑	❑
I'm not as well dressed as most	❑	❑	❑	❑	❑
I'm a failure at everything I try to do	❑	❑	❑	❑	❑
I give up too easily	❑	❑	❑	❑	❑
I usually feel quite lonely	❑	❑	❑	❑	❑

Pre-operative pain section

1. *Please rank each of the types of pain below either none, mild, moderate or severe in relation to any pain that you have felt* **recently** *in your back*

	None	Mild	Moderate	Severe
Throbbing	☐	☐	☐	☐
Shooting	☐	☐	☐	☐
Stabbing	☐	☐	☐	☐
Sharp	☐	☐	☐	☐
Cramping	☐	☐	☐	☐
Gnawing	☐	☐	☐	☐
Hot burning	☐	☐	☐	☐
Aching	☐	☐	☐	☐
Heavy	☐	☐	☐	☐
Tender	☐	☐	☐	☐
Splitting	☐	☐	☐	☐
Tiring-exhausting	☐	☐	☐	☐
Sickening	☐	☐	☐	☐
Fearful	☐	☐	☐	☐
Punishing-cruel	☐	☐	☐	☐

2. *Indicate the areas on your body where you feel pain and number them 1,2 etc.*



3. *Pain is worse in*

a	back	☐
b	buttock or hip	☐
c	down the leg	☐
d	all of the above	☐
e	neck	☐

4. *Mark on the following line the average intensity of this pain in your* ***back***

No pain **I**____**I** Worst possible pain

Figure 5. Self-perception and pain sections of the questionnaire.

Oswestry Disability Index (ODI), version 1

LOW BACK DISABILITY QUESTIONNAIRE

This questionnaire has been designed to help the doctor find out how any back pain associated with your scoliosis is affecting your ability to manage the activities of every day life. Please answer every section in order to allow a full assessment. Tick only one answer from each section selecting the one that most closely fits your situation today.

PAIN:
- ☐ I can tolerate the pain I have without using pain killers.
- ☐ The pain is bad but I cope without taking pain killers.
- ☐ Pain killers give complete relief from pain.
- ☐ Pain killers give moderate relief from pain.
- ☐ Pain killers give very little relief from pain.
- ☐ Pain killers have no effect on the pain and I don't use them.

PERSONAL CARE:
- ☐ I can look after myself normally without causing pain.
- ☐ I can look after myself normally bit it is very painful.
- ☐ It is painful to look after myself, I am slow and careful.
- ☐ I need some help but manage most of my personal care.
- ☐ I need help every day in most aspects of self care.
- ☐ I do not get dressed, wash with difficulty and stay in bed.

LIFTING:
- ☐ I can lift heavy weights without extra pain.
- ☐ I can lift heavy weights but it causes extra pain.
- ☐ Pain stops me lifting heavy weights off the floor, but I can manage if they are conveniently positioned eg. on a table.
- ☐ Pain stops me lifting heavy weights but I can manage light to medium weights if they are conveniently positioned.
- ☐ I can lift only very light weights.
- ☐ I cannot lift or carry anything.

WALKING:
- ☐ Pain does not prevent me walking any distance.
- ☐ Pain prevents me walking more than 1 mile.
- ☐ Pain prevents me walking more than 1/2 mile.
- ☐ Pain prevents me walking more than 1/4 mile.
- ☐ I can only walk using sticks or crutches.
- ☐ I am in bed most of the time and have to crawl to the toilet.

SITTING:
- ☐ I can sit in any chair for as long as I like.
- ☐ I can only sit in my favourite chair as long as I like.
- ☐ Pain prevents me sitting for more than 1 hour.
- ☐ Pain prevents me sitting for more than 1/2 hour.
- ☐ Pain prevents me sitting for more than 10 mins.
- ☐ Pain prevents me sitting at all.

STANDING:
- ☐ I can stand as long as I want without extra pain.
- ☐ I can stand as long as I want but it causes extra pain.
- ☐ Pain prevents me standing for more than 1 hour.
- ☐ Pain prevents me standing for more than 1/2 hour.
- ☐ Pain prevents me standing for more than 10 mins.
- ☐ Pain prevents me standing at all.

SLEEPING:
- ☐ Pain does not prevent me from sleeping well.
- ☐ I can only sleep well by using sleeping tablets.
- ☐ Even when I take tablets I sleep for less than 6 hours.
- ☐ Even when I take tablets I sleep for less than 4 hours.
- ☐ Even when I take tablets I sleep for less than 2 hours.
- ☐ Pain prevents me from sleeping at all.

SOCIAL LIFE:
- ☐ My social life is normal and gives no extra pain.
- ☐ My social life is normal but increases the degree of pain.
- ☐ Pain has no significant effect on my social life apart from limiting more energetic activities eg. dancing.
- ☐ Pain has restricted my social life and I do not go out often.
- ☐ Pain has restricted my social life to my home.
- ☐ I have no social life because of pain.

TRAVELLING:
- ☐ I can travel anywhere without extra pain.
- ☐ I can travel anywhere but it gives me extra pain.
- ☐ Pain is bad but I manage journeys over 2 hours.
- ☐ Pain restricts me to journeys of less than 1 hour.
- ☐ Pain restricts me to short trips of less than 30 mins.
- ☐ Pain prevents me from travelling except to the doctors / hospitals.

Figure 6. The Oswestry Disability Index.

Psychosocial Adjustment to Illness Scale (PAIS)

Please tick one statement per question that you feel most closely describes you at the moment

SECTION 1

(1) Which of the following statements best describes your usual attitude about taking care of your health?

- ☐ I am very concerned and pay close attention to my personal health
- ☐ Most of the time I pay attention to my health care needs.
- ☐ Usually, I try to take care of health matters but sometimes I just don't get around to it.
- ☐ Health care is something that I just don't worry too much about

(2) If your present condition required some special attention and care on your part, would you please select the statement below that would best describe your reaction.

- ☐ I would do things pretty much the way I always have done them and I wouldn't worry or take any special considerations for my condition.
- ☐ I would try to do all the things I was supposed to do to take care of myself, but lots of times I would probably forget or I be too tired or busy.
- ☐ I would do a pretty good job taking care of my present condition
- ☐ I would pay close attention to all the needs of my present condition and would do everything I could to take care of myself.

3) In general, how do you feel about the quality of medical care available today and the doctors who provide it?

- ☐ Medical care has never been better, and the doctors who give it are doing an excellent job.
- ☐ The quality of medical care available is very good, but there are some areas that could stand improvement.
- ☐ Medical care and doctors are just not of the same quality they once were.
- ☐ I don't have much faith in doctors and medical care.

4) With your condition you have received treatment from both doctors and other medical staff. How do you feel about them and the treatment you have received from them, so far?

- ☐ I am very unhappy with the treatment I have received and don't think the staff has done all they could have for me
- ☐ I have not been impressed with the treatment I have received, but I think it is probably the best they can do.
- ☐ The treatment has been pretty good on the whole, although there have been a few problems.
- ☐ The treatment and the treatment staff have been excellent

5) When they have surgery, different people expect different things following their surgery, and have different attitudes about having surgery. Could you please check the statement below which comes closest to describing your feelings.

- ☐ I am sure that I am going to overcome the operation and its problems quickly and get back to being my old self.
- ☐ The thought of my operation has caused me some problems, but I feel I will overcome it fairly soon, and get back to the way I was before.
- ☐ The thought of my operation has really put a great strain on me, both physically and mentally, but I am trying very hard to overcome it, and feel sure that I will be back to my old self soon after the operation.
- ☐ I am very worried at the thought of my operation and there are times when I don't feel that I will ever get back to my old self.

6) Having surgery can be a confusing experience, and some patients feel that they do not receive enough information and detail from their doctors and medical staff about their operation. Please select a statement below which best describes your feelings about this matter.

- ☐ My Doctor and the medical staff have told me very little about my treatment even though I have asked more than once.
- ☐ I do have some information about my treatment but I feel I would like to know more.
- ☐ I have a pretty fair understanding about my treatment and feel that if I want to know more I can always get the information.
- ☐ I have been given a very complete picture of my treatment and my doctor and the medical staff have given me all the details I wish to have.

7) In a condition such as yours, people have different ideas about their treatment and what to expect from it. Please select one of the statements below which best describes what you expect about your treatment.

- ☐ I believe my doctors and medical staff are quite able to direct my treatment and feel it is the best treatment I could receive.
- ☐ I have trust in my doctor's direction of my treatment; however, sometimes I have doubts about it.
- ☐ I don't like certain parts of my treatment which are very unpleasant, but my doctors tell me I should go through it anyway.
- ☐ In many ways I think my treatment is worse than the condition, and I am not sure it was worth going through it.

Figure 7. Psychosocial Adjustment to Illness Scale, Section 1.

SECTION 2

1) Has your condition interfered with your ability to do your schoolwork (job)
- ☐ No problems with my schoolwork (job)
- ☐ Some problems, but only minor ones
- ☐ Some serious problems
- ☐ I am totally prevented from doing my schoolwork (job)

2) How well do you physically perform your schoolwork (job) now?
- ☐ Poorly
- ☐ Not too well
- ☐ Adequately
- ☐ Very well

3) During the past 30 days, have you lost any time at school (work) due to your back?
- ☐ 3 days or less
- ☐ 1 week
- ☐ 2 weeks
- ☐ More than 2 weeks

4) Is school (work) as important to you now as it was before you were told you needed an operation?
- ☐ Little or no importance to me now
- ☐ A lot less important
- ☐ Slightly less important
- ☐ Equal or greater importance than before

5) Have you had to change your goals concerning your education (job) as a result of your condition?
- ☐ My goals are unchanged
- ☐ There has been a slight change in my goals
- ☐ My goals have changed quite a bit
- ☐ I have changed my goals completely

6) Have you noticed any increase in problems with your classmates (co-workers) since your condition began?
- ☐ A great increase in problems
- ☐ A moderate increase in problems
- ☐ A slight increase in problems
- ☐ None

SECTION 3

1) How would you describe your general relationships with the other people you live with (eg. parents, brothers, sisters, aunts etc.)?
- ☐ Very Poor
- ☐ Poor
- ☐ Fair
- ☐ Good

2) Has your condition resulted in a decrease in communication between you and members of your family?
- ☐ No decrease in communication
- ☐ A slight decrease in communication
- ☐ Communication has decreased, and I feel somewhat withdrawn from them
- ☐ Communication has decreased a lot, and I feel very alone

SECTION 4

1) How interested are you in sport?
- ☐ Very interested - I spend a lot of time playing sport
- ☐ Moderately interested - I spend an average amount of time playing sport
- ☐ Slightly interested - I play sport sometimes
- ☐ No interest- I play as little sport as possible

2) How interested are you in other non-sporting leisure activities?
- ☐ Very interested - I spend a lot of time doing other leisure activities
- ☐ Moderately interested - I spend an average amount of time doing other leisure activities
- ☐ Slightly interested - I doing other leisure activities sometimes
- ☐ No interest- I have no other leisure activities

3) Do you still participate in these activities to the same degree you once did?
- ☐ Little or no participation at present
- ☐ Participation reduced significantly
- ☐ Participation reduced slightly
- ☐ Participation remains unchanged

SECTION 5

1) Recently, have you felt afraid, tense, nervous, or anxious?
- ☐ Not at all
- ☐ A little bit
- ☐ Quite a bit
- ☐ Extremely

2) Recently, have you felt sad, depressed, lost interest in things, or felt hopeless?
- ☐ Extremely
- ☐ Quite a bit
- ☐ A little bit
- ☐ Not at all

3) Recently, have you felt angry, irritable, or had difficulty controlling your temper?
- ☐ Not at all
- ☐ A little bit
- ☐ Quite a bit
- ☐ Not at all

4) Recently, have you blamed yourself for things, felt guilty, or felt like you have let people down?
- ☐ Extremely
- ☐ Quite a bit
- ☐ A little bit
- ☐ Not at all

5) Recently, have you worried much about your spine or other matters?
- ☐ Not at all
- ☐ A little bit
- ☐ Quite a bit
- ☐ Extremely

6) Recently, have you been feeling down on yourself or less valuable as a person?
- ☐ Extremely
- ☐ Quite a bit
- ☐ A little bit
- ☐ Not at all

7) Recently, have you been concerned that your spinal condition has caused changes in the way you look that make you less attractive?
- ☐ Not at all
- ☐ A little bit
- ☐ Quite a bit
- ☐ Extremely

Figure 8. Psychosocial Adjustment to Illness Scale, Sections 2-5.

Pre-operative aims of surgery (patients)

The following are descriptions of the problems commonly associated with scoliosis. **In your own opinion**, please rank each description as either perfect (not a problem), mild problem, moderate problem or severe problem

	No problem	Mild problem	Moderate problem	Severe problem
Rib-hump/prominence	□	□	□	□
Shoulders not level	□	□	□	□
Hips not symmetrical	□	□	□	□
Waist not symmetrical	□	□	□	□
Front of chest not symmetrical	□	□	□	□
Leaning over to one side	□	□	□	□
Being teased at school	□	□	□	□
Large curve of the spine	□	□	□	□
Getting worse in the future	□	□	□	□
Others - please list below:				
	□	□	□	□
	□	□	□	□
	□	□	□	□
	□	□	□	□

From the list in the table above, select up to 4 items that you would like the surgery to improve or prevent getting worse. Place them in order in the table below with the most important item at the top of the list. Rank your expectations of the results of surgery for each item.

	I expect surgery to:			
	No improvement but prevent getting worse	Mild improvement	Moderate improvement	Fully correct
1.	□	□	□	□
2.	□	□	□	□
3.	□	□	□	□
4.	□	□	□	□

Pre-operative aims of surgery (parents)

Name of parent/guardian: ______________________

The following are descriptions of the problems commonly associated with scoliosis. **In your own opinion**, please rank each description as either perfect (not a problem), mild problem, moderate problem or severe problem.

	No problem	Mild problem	Moderate problem	Severe problem
Rib-hump/prominence	□	□	□	□
Shoulders not level	□	□	□	□
Hips not symmetrical	□	□	□	□
Waist not symmetrical	□	□	□	□
Front of chest not symmetrical	□	□	□	□
Leaning over to one side	□	□	□	□
Being teased at school	□	□	□	□
Large curve of the spine	□	□	□	□
Getting worse in the future	□	□	□	□
Others - please list below:				
	□	□	□	□
	□	□	□	□
	□	□	□	□
	□	□	□	□

From the list in the table, select up to 4 items that you would like the surgery to improve or prevent getting worse. Place them in order in the table below with the most important item at the top of the list. Rank your expectations of the results of surgery for each item.

	I expect surgery to:			
	No improvement but prevent getting worse	Mild improvement	Moderate improvement	Fully correct
1.	□	□	□	□
2.	□	□	□	□
3.	□	□	□	□
4.	□	□	□	□

Current problems questionnaire- patient (2-year follow-up)

The following are descriptions of the problems commonly associated with scoliosis, *both before and after surgery*. **In your own opinion**, please rank each description as either perfect (not a problem), a mild problem, a moderate problem or a severe problem.

	No problem	Mild problem	Moderate problem	Severe problem
Rib-hump/prominence	□	□	□	□
Shoulders not level	□	□	□	□
Hips not symmetrical	□	□	□	□
Waist not symmetrical	□	□	□	□
Front of chest not symmetrical	□	□	□	□
Leaning over to one side	□	□	□	□
Being teased at school	□	□	□	□
Large curve of the spine	□	□	□	□
Getting worse in the future	□	□	□	□
Other items you identified pre-operatively:				
	□	□	□	□
	□	□	□	□
	□	□	□	□
	□	□	□	□

Results of surgery - to be completed by the PATIENT

The following are descriptions of the problems commonly associated with scoliosis. **In your own opinion**, please indicate whether you feel the operation has either fully corrected, moderately improved, mildly improved or made no difference to each item listed. Please compare your recollection of how you were before surgery with how you are now. The 4 items you identified before surgery as causing you the most concern are highlighted.

	Fully corrected	moderately improved	mildly improved	made no difference
Rib-hump/prominence	□	□	□	□
Shoulders not level	□	□	□	□
Hips not symmetrical	□	□	□	□
Waist not symmetrical	□	□	□	□
Front of chest not symmetrical	□	□	□	□
Leaning over to one side	□	□	□	□
Being teased at school	□	□	□	□
Large curve of the spine	□	□	□	□
Getting worse in the future	□	□	□	□

Current problems questionnaire – parent (2-year follow-up)

Current problems - to be completed by: , (parent/guardian)

The following are descriptions of the problems commonly associated with scoliosis, *both before and after surgery*. **In your own opinion**, please rank each description as either perfect (not a problem), a mild problem, a moderate problem or a severe problem, as you see it at the moment.

	No problem	Mild problem	Moderate problem	Severe problem
Rib-hump/prominence	□	□	□	□
Shoulders not level	□	□	□	□
Hips not symmetrical	□	□	□	□
Waist not symmetrical	□	□	□	□
Front of chest not symmetrical	□	□	□	□
Leaning over to one side	□	□	□	□
Being teased at school	□	□	□	□
Large curve of the spine	□	□	□	□
Getting worse in the future	□	□	□	□
Other items you identified pre-operatively:				
	□	□	□	□
	□	□	□	□
	□	□	□	□
	□	□	□	□

Please add any comments you may have about:

1) *counselling before the operation*
2) *the operation*
3) *care in the hospital*
4) *any unexpected events*
5) *the standard of any advice and answers to questions*
6) *the quality of follow-up after the operation*

continue overleaf...

Figure 9. Current problems section: Pre-operative aims of surgery and current problems at 2 years after surgery.

Clinical details

Supplementary information was obtained from the patients and from review of clinical notes regarding date of birth, date of operation, type of surgery, type of implant including use of laminar hooks or pedicle hooks with posterior USS, anterior release or growth arrest, date of radiographic examinations, and complications of surgery.

Statistical methods

Data were analysed on computer using SPSS® version 6.1.3 (SPSS UK Ltd, St Andrew's House, West Street, Woking, Surrey GU21 1EB, http://www.spss.com) licensed to the University of Nottingham.

Data were checked for errors by searching for outliers and inconsistent values. Relationships between variables were first assessed using scatterplots. Correlation coefficients were used to quantify the strength of the linear relationship between two variables, where the correlation coefficient ranges in value from -1 to +1. A value of 0 indicates that there is no linear relationship between the two variables. A value of +1 means that the two variables are perfectly related, while a value of -1 means that the variables are perfectly related but as the values of one variable increase, the values of the other decrease. The Pearson correlation coefficient (r) was calculated for variables which satisfied assumptions for normality. The Spearman correlation coefficient rho (ρ) was calculated for variables which did not satisfy assumptions for normality. This non-parametric equivalent to the Pearson correlation coefficient is based on ranks of data rather than the actual values.

Much of the data consisted of repeated measurements on the same patients at different times. A normal distribution of data values was not generally assumed. The Wilcoxon matched-pairs signed-ranks test was used to compare two measurements taken at different assessments, and tests the hypothesis that the two variables have the same distribution. Differences between pairs are calculated with more weight given to larger differences. This test makes no assumptions regarding the shape of the distribution of data. If multiple comparisons were made then the P value required for significance was 0.05 divided by the number of tests performed (Bonferroni's correction).

Many dependent variables were measured on several occasions for each subject. These variables are related to each other by virtue of being from the same subject or radiograph.

Segmental variables cannot be treated as independent variables for the purposes of analysis. I used repeated measures multivariate analysis of variance (RMMANOVA) procedures for the analysis of such data. Repeated Measures is used to test hypotheses about the means of a dependent variable when the same dependent variable is measured on more than one occasion for each subject. With this analysis it is possible to compare the effect of one or several dependent variables on one or several other dependent variables and to test hypotheses about the interaction between them. Subjects can also be classified into mutually exclusive groups, such as males or females, or type of curve. Hypotheses can be tested about the effects of the between-subject variables and the within-subject variables, as well as their interactions. This is a parametric test, and no non-parametric equivalent was available. The Kolmogorov-Smirnov goodness of fit test against normality, the Bartlett-Box F test for homogeneity of variances, homogeneity plots and plots of residuals were used to detect violations of the assumptions made about data for RMMANOVA.

Multiple linear regression analysis (MLRA) is used to determine the relationship between a dependent variable and a set of independent variables. The dependent variables selected in the context of this thesis where generally outcome variables (e.g. Cobb angle at 2-year follow-up) and the independent variables were pre-operative variables. Variables were entered into the equation in a stepwise manner if the probability of the F value ≤ 0.05 (F=mean square regression/mean square residual). The variable with the lowest probability of the F value was entered first. Further independent variables were entered into the equation until either the probability of the F value>0.05 for all remaining independent variables or if the coefficient of multiple determination (R^2) increased by less than 0.1 for the new variable. R^2 gives a guide to the proportion of outcome determined by pre-operative variables.

SECTION I - STUDY OF PATIENTS WITH INFANTILE AND JUVENILE IDIOPATHIC SCOLIOSIS

Overview

I performed a retrospective analysis of 5-year follow-up data from patients instrumented with Luque trolley with or without convex epiphysiodesis for the treatment of progressive infantile (IIS) and juvenile idiopathic scoliosis (JIS). Two-year results from this centre have been reported[252]. There are no other long-term follow-up studies of pre-adolescent patients who have been treated with instrumentation that allows spinal growth in conjunction with epiphysiodesis. The aim of the study is to assess the effects of these surgical interventions on the growing spine, to establish predictors of outcome and suggest more effective surgical interventions.

Luque trolley instrumentation was used in 8 patients with IS between 1983 and 1984. Luque trolley with convex epiphysiodesis was used in 18 patients between 1984 and 1990.

The changes in Cobb angle from 8-week to 5-year follow-up are as follows - *Luque trolley alone:* Cobb angle worsened for all patients. *IIS treated with Luque trolley and convex epiphysiodesis:* Cobb angle worsened in seven, remained the same in four and improved in two patients. Mean age at operation was 3.1 years (1.5-7.4 years) and instrumented spinal growth was 32% of expected. Pre-operative Cobb angle was 65° (40°-95°). Cobb angle at 5-year follow-up was 32° (0°-86°) which is predicted by each of pre-operative (1) apical concave rib-spine angle (P=0.002) and (2) upper end-vertebra tilt (P=0.04). *JIS treated with Luque trolley and convex epiphysiodesis:* Cobb angle worsened in three and improved in one patient.

Luque trolley instrumentation alone does not prevent curve progression. The addition of a convex epiphysiodesis results in curve resolution in some patients which suggests a vertebral growth effect. Both spine and rib factors predict Cobb angle at 5-year follow-up, implying a role for extra-spinal factors in curve development.

Introduction

The causes of IS in the skeletally immature are unclear and this predicates empirically based treatment. The need for spinal growth in infants and juveniles means that spinal fusion is not desirable.

The traditional treatment of progressive IIS is bracing with subsequent fusion once sufficient spinal growth has occurred[150]. A long term follow-up of such treatment for IIS was published by McMaster and MacNicol[205]. In their study, 22 patients with single thoracic curves spent a mean of 5.5 years in a brace before spinal fusion was performed at the age of 10 years. The mean Cobb angle was 63° before treatment and 68° without the brace before spinal fusion. The Cobb angle corrected by 40-50% after spinal fusion, the seven patients having Harrington instrumentation doing better. Orthodontic moulding occurred in eight of the 22 patients.

Ideally the aim of surgical treatment of IIS and JIS is to correct the deformity without the need for bracing and to maintain that correction with growth. To this end a number of approaches have been tried, including stapling across vertebrae on the convex side[325], posterior fusion[221]; unilateral growth arrest[287], concave costoplasty[261], segmental spinal instrumentation without fusion[186], and costodesis[345]. The initial results were often encouraging but over longer follow-up, the curves progressed. The current treatment of early onset IS at Queen's Medical Centre, Nottingham, incorporates two of the above methods, namely segmental spinal instrumentation (SSI) without fusion and unilateral growth arrest[252].

Luque[186] developed SSI to avoid the need for prolonged brace wearing whilst allowing for further spinal growth. His initial report on 50 patients with a mean follow-up of 23 months included eight patients with IIS. The Cobb angle corrected from 73° to 22° and the mean instrumented segment growth was 2.6 cm over 2 years. His later report on paralytic scoliosis showed maintained correction and continued growth. Experiments on animals provided validation for these concepts[200]. Subsequent reports on the Luque trolley in paralytic scoliosis secondary to poliomyelitis[92] and other types of scoliosis[196,282] describe the problems of spontaneous fusion, modest spinal growth, loss of correction and rod fracture.

Convex epiphysiodesis with convex laminar and vertebral body fusion was reported by Roaf[286] as treatment for all types of progressive scoliosis. He aimed to control progressive deformity by inhibiting growth on the convex side. This technique has been used to treat congenital scoliosis[7,158,350,379] and the most impressive results were seen in patients with hemivertebrae in whom progressive correction of scoliosis occurred on follow-up. Thompson[350] found that the rate of correction after surgery correlated with age at operation, presumably because younger patients have the greatest remaining growth potential. The findings of Winter[379] support Thompson's findings. Winter stated that patients who were 5 years old or less, with a curve of less than 70°, would benefit most from anterior and posterior convex epiphysiodesis. The use of unilateral growth arrest in the treatment of IS has also been reported. Marks[197] described 13 patients with IIS initially treated with anterior and posterior convex epiphysiodesis alone and a further nine patients treated with convex epiphysiodesis and concurrent Harrington instrumentation. The latter nine patients each required a mean of four operations for rod lengthening to accommodate spinal growth. He concluded that convex epiphysiodesis alone did not prevent progression of deformity and that the addition of instrumentation could slow progression but not reverse it.

The initial results of treatment of progressive early IS with Luque trolley alone at this centre were disappointing, so an apical convex epiphysiodesis was added. Patterson[252] reported the operative method for the combined procedure with initial results.

I evaluated the 5-year results of the management of IS in (1) the skeletally immature using the Luque trolley alone and (2) the Luque trolley with an apical convex epiphysiodesis.

Material and Methods

Patients

I reviewed all the patients who were treated with the Luque trolley for progressive IIS and JIS and who have a minimum of 5 years follow-up.

Luque trolley alone

A Luque trolley was implanted in eight patients between July 1983 and August 1984. Data are complete for four boys and three girls. The X-ray films for the other patient were lost after she moved to another area. All the boys had thoracic IIS and three had left curves. One girl had right thoracic JIS, one had right thoracolumbar JIS and the other had a right thoracic IIS. Altogether six patients had failed brace treatment prior to surgery. Mean age at surgery was 7 years 4 months (range 3 years 3 months to 9 years 5 months) and the mean time from X-ray diagnosis of scoliosis to surgery is 3 years 3 months (range 1 year 4 months to 5 years). All were Risser 0 at the time of surgery and all curves were progressing. Between 10 and 12 vertebrae were instrumented.

Luque trolley and convex epiphysiodesis - IIS

A combined Luque trolley with convex epiphysiodesis was performed on 13 boys and one girl, all with thoracic IIS, between September 1984 and June 1990.

Ten of the boys had left curves. Four had failed brace treatment before surgery. All patients had documented Cobb angle progression and apical rib head transition from phase 1 to phase 2[207]. 13 patients had single thoracic curves and apical rib-vertebra angle differences of greater than 20°. One patient had a compensatory lumbar curve and a negative rib-vertebra angle difference at T12. Mean age at surgery was 3 years 6 months (range 1 year 6 months to 8 years 11 months) and the mean time from X-ray diagnosis of scoliosis to surgery was 2 years 7 months (range 4 months to 5 years 10 months). All were Risser 0 at the time of surgery. Between eight and fifteen vertebrae were instrumented and between four and seven vertebrae were fused on the convex side.

Luque trolley and convex epiphysiodesis - JIS

A combined Luque trolley with convex epiphysiodesis was performed on four girls with thoracic JIS, between September 1984 and June 1990. Three girls had right curves. None was treated with a brace pre-operatively. Mean age at surgery was 6 years 8 months (range 4 years 7 months to 9 years 10 months) and the mean time from X-ray diagnosis of scoliosis to surgery was 1 year 3 months (range 1 month to 2 years 7 months). All were Risser 0 at the time of surgery. Between nine and twelve vertebrae were instrumented.

Surgical Technique

Segmental spinal instrumentation without fusion

A posterior extraperiosteal approach is made, using diathermy to prevent new bone formation. The facet joint capsules are preserved. An epidural electrode is placed for cord monitoring. Sub-laminar wires are passed at each level and the end-vertebrae are double wired. Two precontoured Luque rods are then wired in place. Initially 'L' rods were used with the straight ends being left long to allow for spinal growth. The 'L' portion is secured to the laminae of the end-vertebrae. Subsequently 'U' rods were used.

Convex epiphysiodesis

A convex thoracotomy is performed through the rib two levels above the apex. The apex is exposed and the apical discs and adjacent growth plates which did not correct on side bending films are excised on the convex side back to the posterior longitudinal ligament. The excised rib furnishes graft for that side. Combined Luque trolley and epiphysiodesis was staged, epiphysiodesis first, with a mean interval of 5 weeks for the IIS patients. No post-operative bracing was used.

Patient assessment

The children were examined clinically and by radiographs after surgery by myself.

Radiographic data

Data were acquired from radiographs on curve parameters including Cobb angle, apical vertebral rotation (AVR), end-vertebra tilts, apical vertebral translation (AVT), T1-S1 distance, frontal plane balance, apical rib-spine angles (RSAs) to the T1-S1 line[349] (Figure 2, page 38), apical rib-vertebra angle difference (RVAD)[207], side-bending Cobb angles and side-bending apical vertebral rotations. Pre-operative, post-operative, 1-year, 2-year, 5-year and most recent radiographs were measured. Those children who had further spinal surgery had the appropriate peri-operative radiographs measured. Radiographs which corresponded to clinical assessments (below) were measured.

Clinical assessment

All of these patients had surface measurements performed in 1990 or in 1992 by Professor R.G. Burwell and Miss S.L. Cummings. All patients were called for clinical review by myself at the time of the current study (1997).

General anthropometric methods

Skeletal measurements included weight, stature and sitting height, total lower limb lengths, tibial lengths, foot lengths, total upper limb lengths, upper arm lengths, forearm and hand lengths and acromial heights (see *General anthropometric methods*, page 36). A device constructed according to Watson was used to measure and calculate the plagiocephaly index[363].

Back surface measurements

Scoliometer readings were obtained from 10 levels marked on the back between the vertebra prominens and the mid-sacral point. Where possible measurements were obtained in three positions namely: standing forward bending; sitting forward bending and lying prone.

A brief medical and family history was taken and patients were assessed for congenital anomalies and deformities.

Data analysis

Reproducibility

See *Radiographic appraisal*, page 36.

Outcome

Outcome was classified into curve progressing, maintained or resolving according to how the Cobb angle changed from initial post-operative measurement to 5-year follow-up. Based on the reproducibility of Cobb angle measurement (Table 2, page 39), a 5° change in Cobb angle was taken as being significant.

Determination of spinal growth

The distance between the midpoint of the upper instrumented upper endplate and the midpoint of the lower instrumented lower endplate was measured. This measurement was corrected for magnification using the length of the implanted Luque rod. The growth between successive films was then calculated. It was not possible to evaluate growth according to side. The expected spinal growth was calculated after the method of Patterson[252].

Predictive factors

Data from the IIS patients having the combined procedure were analysed with the aim of finding which pre-operative factors independently predict outcome after surgery. The pre-operative variables which correlated (Spearman's rank) with each of 5-year follow-up Cobb angle and percentage correction of Cobb angle, were used to construct a multiple linear regression analysis model. Variables were entered stepwise, with a probability of F to enter at 0.05 ($F=T^2$=mean square regression/mean square residual).

The pre-operative variables considered included: age at diagnosis, age at operation, interval between diagnosis and surgery, Cobb angle, upper and lower end-vertebra tilts, apical vertebral rotation, flexibility and side bending Cobb angles and apical vertebral rotations, interval between release and instrumentation, the number of levels instrumented, curve length and apex, convex and concave rib-spine angles, rib-vertebra angle difference and growth both of the whole spine and of the instrumented segment.

A similar analysis was used with percentage of predicted growth seen in the instrumented segment from post-operative to 5-year follow-up as the dependent variable.

Consideration of predictive factors - further analysis

Pathomechanical hypotheses are suggested for significant predictive factors of outcome. The data were further explored to test these hypotheses. Statistical analysis included the Wilcoxon matched-pairs signed-ranks test, Spearman's rank-order correlation coefficient, repeated measures multivariate analysis of variance (RMMANOVA) and multiple linear regression analysis (MLRA). This Wilcoxon test gives significance of changes in measurements between assessments. Spearman's rank-order correlation coefficient, rho (ρ), is used to assess relationships between continuous variables. A minus sign denotes an inverse correlation. The P value considered significant is adjusted for multiple comparisons using Bonferroni's correction. The repeated measures MANOVA gives the significance of changes between repeated assessments. Using this method, groups of related measurements can be considered as a whole and compared with the same measurements obtained at different times after surgery, avoiding problems of multiple comparisons and adjustment of significance levels.

Results

The results are given according to operation.

Luque trolley alone for JIS and IIS - summary of results

All the patients having the Luque trolley alone progressed in terms of Cobb angle from their initial post-operative correction (Figure 10).

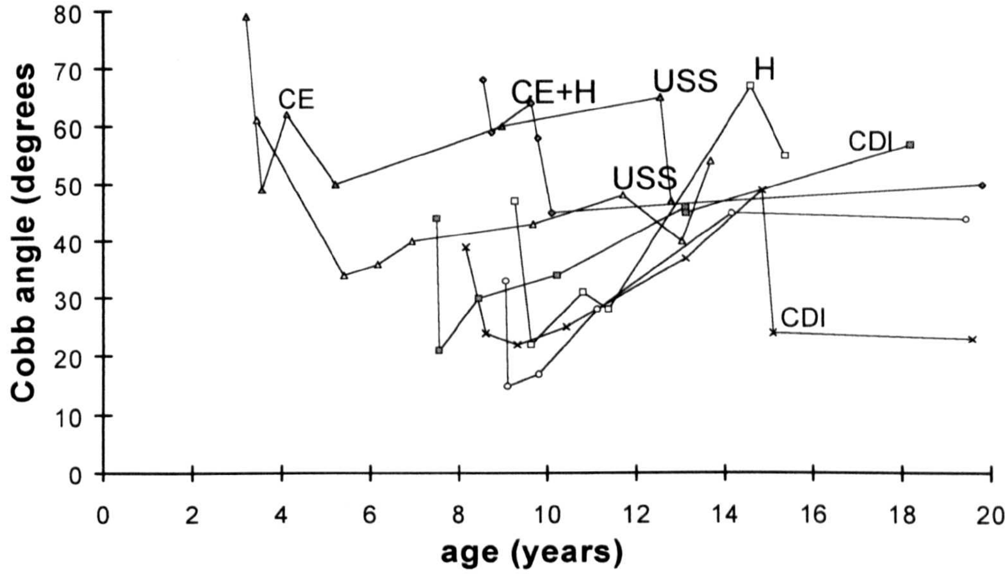


Figure 10. Changes in Cobb angle for patients initially instrumented with Luque trolley alone.

Figures 10 and 11: Timing and type of further surgery is indicated by the labels where CE = late convex epiphysiodesis performed, H = spinal fusion using Harrington rods, USS = spinal fusion using Universal Spine System, CDI = spinal fusion using Cotrel-Dubousset Instrumentation and Ky = removal of Luque trolley followed by 2-level fusion for kyphosis.

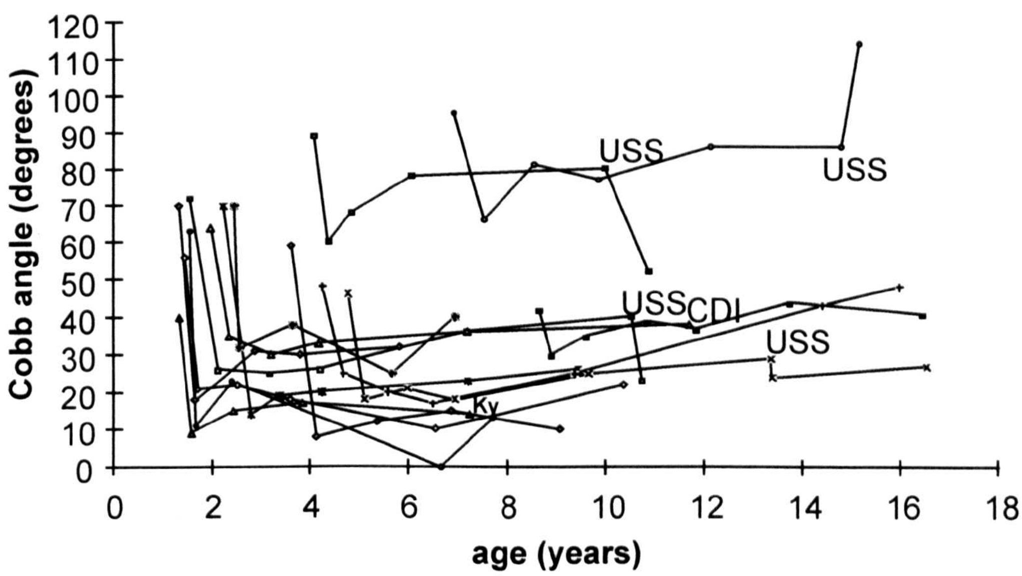


Figure 11. Changes in Cobb angle for IIS patients treated initially with Luque trolley and convex epiphysiodesis.

The rate of progression increased during the adolescent growth spurt in four of the seven patients. The rate of progression also increased in one of the four patients whose spinal growth was greater than that allowed for in the Luque trolley. Growth of the instrumented spinal segment at 5-year follow-up was 2.9cm, 49% of that expected for age and sex matched normals (range 31%-71%).

Spinal fusion with instrumentation was performed on six patients (2 USS, 2 CDI, 2 Harrington rods). Cobb angle corrected from 56° (range 46° to 67°) to 43° (range 20° to 47°). This is indicative of the decreased spinal flexibility secondary to the Luque trolley, with fusion already present in one patient.

IIS treated with combined Luque trolley and CE - summary of results

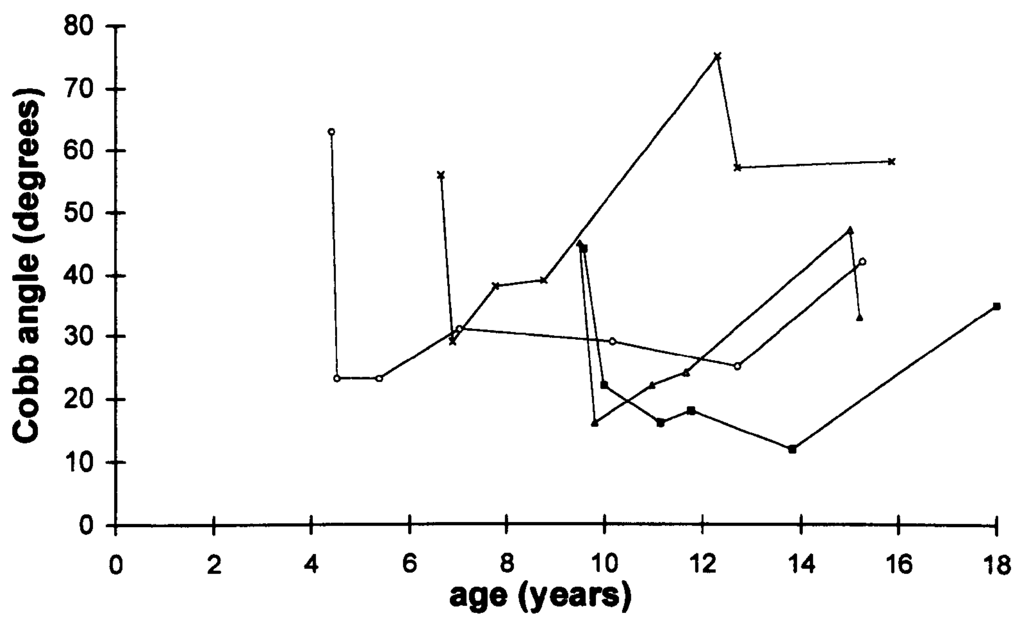
The Luque trolley remained in place for 5 years in 13 patients. The Cobb angle increased in seven patients during 5-year follow-up after surgery, remained the same in four patients and decreased in two patients (Figure 11). One patient had an instrumented spinal fusion before 5-year follow-up was reached.

If the 13 patients are considered, the mean age at operation was 3 years 1 month (1 year 6 months to 7 years 5 months) and mean pre-operative Cobb angle was 65° (40°-95°). Spinal flexibility was 52% (5%-80%). The mean Cobb angle after the combined surgery was 26° (8°-66°) and at 5-year follow-up was 32° (0°-86°). Growth of the instrumented spinal segment at 5-year follow-up was 2 cm or 32% of that expected for age and sex matched normals (range -11% to 53%).

JIS treated with combined Luque trolley and CE - summary of results

The Cobb angle increased in three patients during 5-year follow-up after surgery and decreased in one patient (Figure 12).

A case description of the above results has been published[270].



Timing and type of further surgery is indicated by the labels where USS = spinal fusion using Universal Spine System.

Figure 12. Changes in Cobb angle for JIS patients treated with Luque trolley and convex epiphysiodesis.

Complications

Out of the 25 patients, there were three patients with broken rods and wires and two patients with broken wires alone. Three patients had rod prominence which was associated with rod slippage in two cases. A sinus developed over one of the prominent rods and the rod was removed. A kyphosis developed at the caudal end of two Luque trolleys and at surgical revision the instrumented vertebrae were found to be fused. One patient developed a post-operative chest infection. There were no neurological complications.

Predictive factors

The data for analysis came from the 13 IIS patients who had the combined procedure and who reached 5-year follow-up with the Luque trolley in place.

The pre-operative variables which correlated with outcome measures were: age at diagnosis, age at insertion of Luque trolley, interval between diagnosis and surgery, pre-operative upper end-vertebra tilt, Cobb angle correction on side bending films, flexibility, apical concave rib-spine angle and growth of the instrumented segment. These were used in the multiple linear regression analysis model along with initial Cobb angle and initial AVR and apical convex rib-spine angle, variables which helped define the pre-operative curve.

The factors predicting Cobb angle at 5-year follow-up are firstly the upper end-vertebra tilt (Spearman correlation P=0.002), and secondly apical concave rib-spine angle (Spearman correlation P=0.038, Table 5, Figure 13 and Figure 14).

Table 5. Cobb angle at 5-year follow-up. Stepwise multiple linear regression model with probability of F<0.05 to enter variable into analysis.

Step	Variable	Coefficient	SE	95% CI	R square	T	P
1	Upper EVA	1.68	0.24	1.15 to 2.22	0.83	7.0	0.000
2	Concave RSA	-0.96	0.33	-1.70 to -0.22	0.91	-2.9	0.016
_	Intercept	53	33	_	_	_	_

where:

Intercept = a mathematical constant

Upper EVA = upper end-vertebra tilt

Concave RSA = apical concave rib-spine angle

Coefficient = mathematical weightings of the explanatory variables in the equation

SE = standard error of the coefficients

95% CI = 95% confidence intervals for the coefficients

R square = coefficient of multiple determination

T = square root of mean square regression divided by the mean square residual

P = P value, the variables are significant predictors of Cobb angle at 5-year follow-up

The factors predicting percentage correction of Cobb angle at 5-year follow-up are the upper end-vertebra tilt (Spearman correlation P=0.027), the apical concave rib-spine angle (Spearman correlation P=0.003) and pre-operative AVR (Spearman correlation P=0.964, Table 6).

Table 6. Percentage correction of Cobb angle at 5-year follow-up. Stepwise multiple linear regression model with probability of F<0.05 to enter variable into analysis.

Step	Variable	Coefficient	SE	95% CI	R square	T	P
1	Upper EVA	-0.01	0.002	-0.019 to -0.007	0.60	-4.6	0.001
2	Concave RSA	0.02	0.004	0.009 to 0.026	0.80	4.5	0.002
3	AVR	-0.01	0.003	-0.017 to -0.002	0.90	-2.9	0.018
_	Intercept	-0.13	0.39	_	_	_	_

Where:

AVR = apical vertebral rotation

P = P value, the variables are significant predictors of percentage correction of Cobb angle at 5-year follow-up

See Table 5 for other abbreviations.

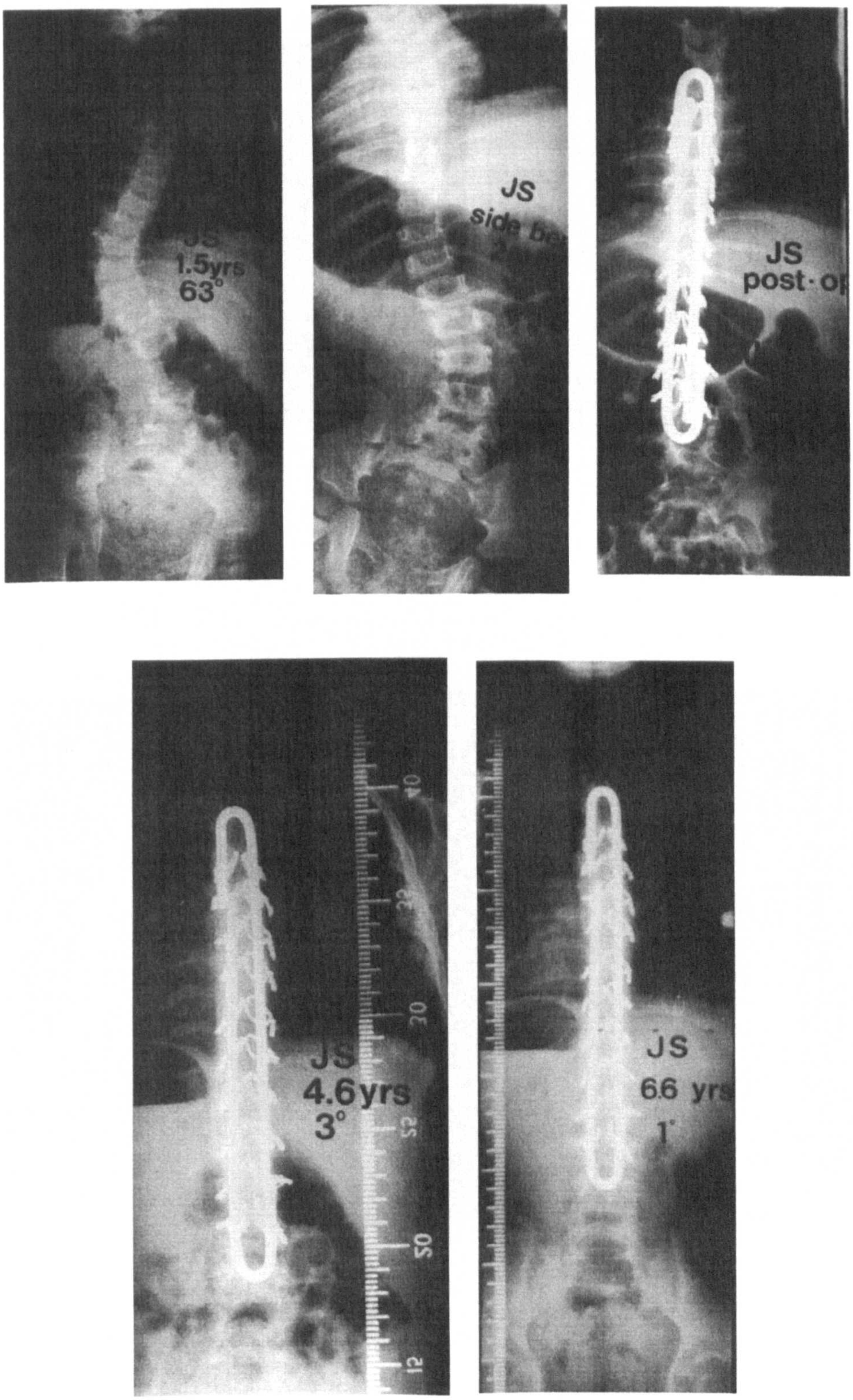


Figure 13. Example of infantile idiopathic scoliosis curve that resolved after Luque trolley and convex epiphysiodesis.

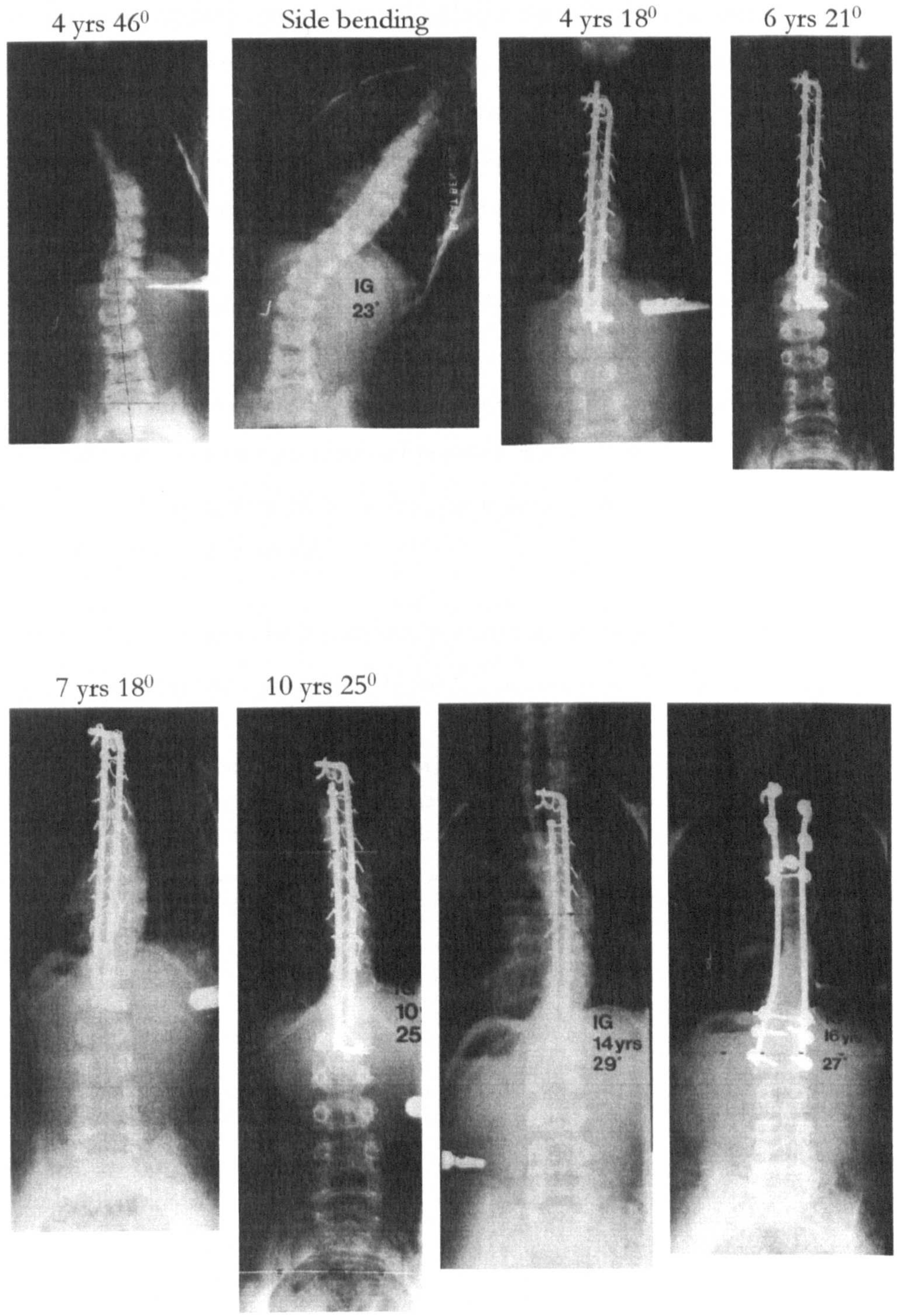


Figure 14. Example of IIS in which correction was initially maintained after Luque trolley and convex epiphysiodesis. Spine was fused after progression occurred when capacity of Luque trolley to elongate was exceeded.

Predictive factors - Factors determining instrumented segment growth

A linear regression analysis was performed with the percentage of predicted growth seen in the instrumented segment from post-operative to 5-year follow-up as the dependent variable. The *percentage* of predicted growth was selected so that the number of instrumented levels would not be a confounding factor. The variables considered were: age at diagnosis, age at operation, interval between diagnosis and surgery, interval between release and instrumentation, the number of levels instrumented sex, pre-operative and post-operative Cobb angle, pre-operative and post-operative upper and lower end-vertebra tilts, pre-operative and post-operative apical vertebral rotation, flexibility and decreasing side bending Cobb angles and apical vertebral rotations, T1-S1 length and curve apex, pre-operative and post-operative convex and concave rib-spine angles and rib-vertebra angle differences. In addition, change in Cobb angle and AVR from pre-operative to post-operative follow-up were included.

Pre-operative Cobb angle predicted the percentage of predicted growth seen in the instrumented segment from post-operative to 5-year follow-up (Table 7):

Table 7. Percentage of predicted growth seen in the instrumented segment from post-operative to 5-year follow-up. Stepwise multiple linear regression model with probability of $F<0.05$ to enter variable into analysis.

Step	Variable	Coefficient	SE	95% CI	R square	T	P
1	Pre-op Cobb	-.007	.002	-0.008 to -0.004	0.44	-2.9	0.014
_	Intercept	0.74	0.15	_	_	_	_

See Table 5 for abbreviations.

The number of instrumented vertebrae was inversely correlated with percentage of expected growth (P=0.02, Spearman rank correlation coefficient) and the instrumented segment growth from post-operative to 5-year follow-up correlates with the change in Cobb angle from post-operative to 5-year follow-up (P=0.006, Spearman rank correlation coefficient).

The predictive factor was the same when the analysis was repeated for all patients with IIS and 5-year data (n=18).

Consideration of predictive factors - further analysis

The factors predicting both Cobb angle at 5-year follow-up and percentage correction of Cobb angle at 5-year follow-up are firstly the upper end-vertebra tilt, and secondly apical concave rib-spine angle. Greater pre-operative upper end-vertebra tilt and smaller apical concave rib-spine angle (more droop) is correlated with larger Cobb angle and lower percentage correction of Cobb angle at 5 years. This suggests that factors in both the upper spine and the ribs are involved in pathomechanisms which result in coronal curve morphology at 5 years after surgery.

I will consider the outcome (Cobb angle or percentage correction of Cobb angle) to be the result of changes seen during two periods of follow-up:

1. Changes seen from pre-operative to post-operative follow-up, which are mainly as a result of the process of surgical correction of the curve through instrumentation.

2. Changes seen from post-operative follow-up to 5 years, which may be the results of pathomechanisms for curve progression.

Several hypotheses (not mutually exclusive) may be suggested to explain the predictive factors of upper end-vertebra tilt and apical concave rib-spine angle using the periods defined above as a framework. Four possible hypotheses are listed below:

1. Upper end-vertebra tilt indicates factors for the resistance of the curve to surgical correction. These factors may be bony, muscular, ligamentous, neurological, hormonal or genetic in origin.

2. Apical concave rib-spine angle indicates factors for the resistance of the curve to surgical correction.

3. Upper end-vertebra tilt indicates pathomechanisms acting to produce curve progression.

4. Apical concave rib-spine angle indicates pathomechanisms acting to produce curve progression.

Questions can be asked of data on these patients to evaluate any evidence for or against these above hypotheses. The variables considered in the analysis are: age at diagnosis, age at operation, interval between diagnosis and surgery, Cobb angle, upper and lower end-vertebra tilts, apical vertebral rotation, flexibility and side bending Cobb angles and apical vertebral rotations, interval between release and instrumentation, the number of levels instrumented, T1-S1 length and curve apex, convex and concave rib-spine angles, rib-vertebra angle difference and growth both of the whole spine and of the instrumented segment for each of preoperative, post-operative, 1-year, 2-year and 5-year follow-up.

The effect of surgery on the spine and ribs

Changes seen from pre-operative assessment to post-operative assessment

Changes are seen in Cobb angle (P=0.0015), apical vertebral translation (P=0.0022, n=12), upper end-vertebra angle (P=0.0015), lower end-vertebra angle (P=0.0015), T1-S1 length (P=0.0019), but not in convex and concave RSAs or apical vertebral rotation (Wilcoxon matched-pairs signed-ranks test).

Do pre-operative measurements of spine or ribs predict changes in Cobb angle with surgery?

There is a significant correlation between the change in Cobb angle from pre-operative to 8-week assessment and the pre-operative concave RSA (P=0.003, Spearman rank correlation, n=13) but not for each of pre-operative convex RSA, RVAD, AVR, upper end-vertebra tilt and lower end-vertebra tilt.

These results suggest that pre-operative upper and lower vertebral tilt do not influence the degree of Cobb angle correction seen after surgery. Further analysis using MLRA reveals that predictors of the change in Cobb angle from pre-operative to 8-week follow-up are (i) pre-operative concave RSA and (ii) pre-operative lower end-vertebra tilt (Table 8).

Table 8. Correction of Cobb angle at from pre-operative to 8-week follow-up. Stepwise multiple linear regression model with probability of F<0.05 to enter variable into analysis.

Step	Variable	Coefficient	SE	95% CI	R square	T	P
1	Concave RSA	-1.02	0.23	-1.48 to -0.56	0.55	-4.3	0.001
2	Lower EVA	0.81	0.29	0.23 to 1.39	0.75	-2.8	0.018
_	Intercept	70	20	_	_	_	_

Where:

Lower EVA	= pre-operative lower end-vertebra tilt
P	= P value, the variables are significant predictors of change of Cobb angle from pre-operative to 8-week follow-up

See Table 5, page 68 for other abbreviations.

Curve flexibility and decreasing Cobb angle on side bending films do not correlate with change in Cobb angle due to surgery. Flexibility will depend on both spinal and rib factors. Surgery involves release of anterior spinal ligaments during performance of the convex epiphysiodesis which may explain why there is no significant correlation between flexibility and curve correction secondary to surgery.

Do changes in vertebral tilt with surgery produce consistent changes in RSAs? – No.

The relationship between concave and convex RSA changes and vertebral tilt changes can be tested by RMMANOVA, entering concave and convex RSAs as 'varying covariates' in the analysis. Values for pre-operative and post-operative concave or convex RSA or RVAD do not regress to changes in upper or lower end-vertebra tilt or Cobb angle (RMMANOVA). Changing spine morphology by surgery does not produce a predictable change in concave or convex RSA or RVAD.

Both spinal and rib factors may potentially resist surgical attempts to correct the scoliosis. The results of the analyses above are consistent with the view that these spinal factors are disrupted to some extent during surgery and rib factors are not, meaning that rib factors are most important in determining curve correction attained with surgery. The rib cage may be acting as a brace for the spine, resisting correcting forces applied during surgery.

Changes seen from post-operative assessment through 1-year, 2-year and 5-year assessments

The analysis of multiple variables from multiple assessments requires use of repeated measures MANOVA.

There are changes in upper and lower end-vertebra tilt by follow-up (P=0.017, RMMANOVA). Further analysis reveals that changes in upper end-vertebra tilt are significant (P=0.026) but those in lower end-vertebra tilt are not (P=0.367, RMMANOVA). Cobb angle did not change during follow-up (P=0.07, RMMANOVA), which is in keeping with finding that 2 patients had improved Cobb angle after surgery, 3 worsened and 8 stayed the same. T1-S1 length increased from post-operative to 5-year follow-up (P<0.001, RMMANOVA). Changes for rib measurements (concave and convex RSA and RVAD) were not significant (RMMANOVA).

Is there a relationship between changes in vertebral tilt during follow-up after surgery and changes in RSAs? – No.

If data from post-operative, 1-year, 2-year and 5-year follow-up assessments are used, a weak (linear) relationship is found between changes in the convex rib-spine angles and upper end-vertebra tilt (P=0.022, RMMANOVA). If Cobb angle increases then convex RSA decreases. No relationship was found for RVAD or concave RSA or convex RSA with Cobb angle, or lower end-vertebra tilt.

Are changes seen in Cobb angle after surgery predictable from other variables?

A linear regression analysis was performed with change in Cobb angle from post-operative to 5-year follow-up as the dependent variable. The variables considered in the analysis follow: age at diagnosis, age at operation, interval between diagnosis and surgery, interval between release and instrumentation, the number of levels instrumented sex, pre-operative and post-operative Cobb angle, pre-operative and post-operative upper and lower end-vertebra tilts, pre-operative and post-operative apical vertebral rotation, flexibility and decreasing side bending Cobb angles and apical vertebral rotations, T1-S1 length and curve apex, pre-operative and post-operative convex and concave rib-spine angles and rib-vertebra angle differences.

Factors predicting the change in Cobb angle from post-operative to 5-year follow-up are (i) pre-operative upper end-vertebra tilt and (ii) pre-operative apical vertebral rotation (Table 9).

Table 9. Change in Cobb angle from post-operative to 5-year follow-up. Stepwise multiple linear regression model with probability of F<0.05 to enter variable into analysis.

Step	Variable	Coefficient	SE	95% CI	R square	T	P
1	Pre-op upper EVA	0.74	0.12	0.62 to 0.85	0.64	6.4	0.0001
2	Pre-op AVR	0.47	0.15	0.32 to 0.62	0.82	3.2	0.010
_	Intercept	-36	7.0	_	_	_	_

See Table 5, page 68 for abbreviations.

Consideration of effect of outliers

Results for these patients fall into the three groups according to changes seen in Cobb angle after surgery has been performed, namely Cobb angle improving (n=2), Cobb angle worsening (n=3) and Cobb angle staying the same (n=8). Inspection of radiographic pattern of the curves reveals that 2 patients in the Cobb angle worsening group (cases 20 & 21) have a marked tilt of the upper end-vertebrae (54° and 57°), which does not correct with surgery. The mean upper end-vertebra tilt is 35°, with a standard deviation of 11.5° so these 2 cases may be considered outliers. One boy had hypophosphatasia and the other boy was mentally retarded with various congenital anomalies (including pectus excavatum, monobrow, short neck, elbow contractures, megaglossus and right foot equinus).

The other patients all have reasonably smooth thoracic curves, without an accentuated tilt of the upper end-vertebra.

The patients with resolving curves after surgery (cases 9 & 14) have T11 as the curve apex. All the other curves have apices between T8 and T10. As the ribs at this level are floating ribs and size of rib-spine angle varies with level of the rib on the thoracic spine, then findings for rib factors in outcome may represent the effect of different apical levels rather than rib effects. In view of these potential confounding effects, data were re-analysed excluding the 4 cases above.

Multiple linear regression analysis

The same variables were used as above. Cases 20 & 21 were excluded. Factors predicting the change in Cobb angle from post-operative to 5-year follow-up were then (i) post-operative concave RSA tilt (P=0.005, R^2=0.47) and (ii) post-operative convex RSA (P=0.046, R^2=0.69, MLRA, n=11).

Given that the level of the apical vertebra may have a confounding effect, the analysis was repeated excluding cases 9 & 14. On the remaining 9 cases, factors predicting the change in Cobb angle from post-operative to 5-year follow-up were (i) pre-operative RVAD (P=0.005, R^2=0.47) (ii) pre-operative convex RSA (P=0.009, R^2=0.76) (iii) pre-operative upper EVA (P=0.005, R^2=0.92) and (iv) pre-operative AVR (P=0.046, R^2=0.97, MLRA, n=9).

These analyses further implicate a role for the rib cage in the progression of scoliosis over a 5-year follow-up period after surgery. Part of this effect could be due to deformity reassertion after surgery and part may be due to ribs causing curve progression. This will be considered further in the Discussion, page 79.

Further analysis was performed in respect of the changes in Cobb angle from 2-year to 5-year follow-up so that any effect of rib-hump reassertion (see Section II on AIS) would be minimised. The most pre-operative factors predicting the change in Cobb angle from 2-year to 5-year follow-up were the vertebral level of the apex of the major curve (P=0.006, R^2=0.33) and the upper EVA (P=0.008, R^2=0.68, MLRA, n=13).

It has already been noted that the patients with a curve apex at T11 had the best outcome in terms of Cobb angle. The above analysis reflects this finding. Further analysis excluding these 2 patients did not produce any significant factors.

Clinical follow-up

17 of 26 patients agreed to attend for clinical review at the time of the current study. Unfortunately numbers were too small (n=7) to demonstrate any meaningful relationship between radiological, surface and anthropometric measurements for this time period.

Discussion

My results show a wide variation in outcome after surgery for early IS. A number of surgical and patient factors need to be considered to account for this finding. The patients having Luque trolley alone and those having a Luque trolley and convex epiphysiodesis are different in terms of age at operation and will be considered separately.

Luque trolley alone

The results for these patients were disappointing because the curves continued to progress after the initial correction. Curve progression was associated with wire and rod breakage in two patients. The other five entered the adolescent growth spurt during the initial 5-year follow-up period.

Luque trolley and convex epiphysiodesis

The results for patients with progressive early IS treated with Luque trolley instrumentation and convex epiphysiodesis were more encouraging, bearing in mind that most of the patients did not reach the adolescent growth spurt during the initial 5-year follow-up period (Figure 11, page 65 and Figure 12, page 67). The Cobb angle remained the same for 5 years after surgery in four patients and improved in three patients. The rate of progression for the other 11 patients varied from 1.4° to 4° per year over 5 years (mean 2.5°/year). The rates of curve progression are generally acceptable but the most interesting finding is that of resolving curves, and this merits further consideration.

Resolving curves after surgery

Resolving IIS and JIS have been described[303] and Mehta's criteria[207] are good enough to predict progressive curves in 80% of IIS cases. Are we simply reporting on some of the 20% of curves which fulfil Mehta's criteria for progression but are in fact resolving curves? This would not appear to be the case. These resolving curves were all greater than 50° before the age of four years which indicates a progressive nature[352]. The resolving curves began to progress after 5-year follow-up because spinal growth exceeded the capacity of the Luque trolley to elongate. Evidently the bracing effect of the Luque trolley was lost and the curves progressed. I would not have expected to see this progression if curve resolution was the natural history of these curves.

The evidence is consistent with the view that curve resolution seen at 5-year follow-up was the result of the surgery. All of our patients had progressing curves before operation and curve resolution was only seen after surgery. I conclude that this curve resolution is a result of the growth mediated effect of the convex epiphysiodesis being expressed in the presence of bracing of the curve by the Luque trolley.

Advantages of the Luque trolley and convex epiphysiodesis

Conventional practice is to brace all progressive curves for several years and to stabilise the spine by fusion at adolescence, or earlier if the deformity cannot be controlled[205]. Mehta discovered that the rib-vertebra angle difference in patients with IIS could be used to predict progression with 80% accuracy[207]. She advocated early corrective treatment with plaster jackets, aiming to channel the high growth rates of the first 3 years of life into correction of the deformity[208]. The implication of the use of braces or plaster jackets for early scoliosis is that the child is always aware of their deformity, as are their peers and elders. The advantage of surgery is that an operation scar can be more easily hidden and the patients need not be continually reminded of their abnormality.

Disadvantages of the Luque trolley

The disadvantages of the Luque trolley are demonstrated in some patients. The potential for further spinal growth after instrumentation means that the capacity of the Luque trolley to elongate can be exceeded. This occurred in 14 patients and in six the rate of Cobb angle progression increased (Figure 15). Altogether four patients had either rod or wire breakage and three had instrument prominence. Two patients did not have a good result after Luque trolley with convex epiphysiodesis. Both patients had severe stiff curves and the initial correction achieved was poor. As a result of the residual curves it appeared that further spinal growth could not be directed linearly along the Luque rods but instead tended to contribute to the subsequent curve progression. If re-operation was required, the curves were often stiff with abundant fibrous tissue, as found in the patients reviewed by Mardjetko et al[196]. This resulted in a smaller than expected Cobb angle correction at definitive fusion, averaging 13° in our series. The effect of reduced Cobb angle correction at definitive fusion on the results of Luque trolley and convex epiphysiodesis will only be apparent after further 10 years follow-up of these patients, by which time they will all have

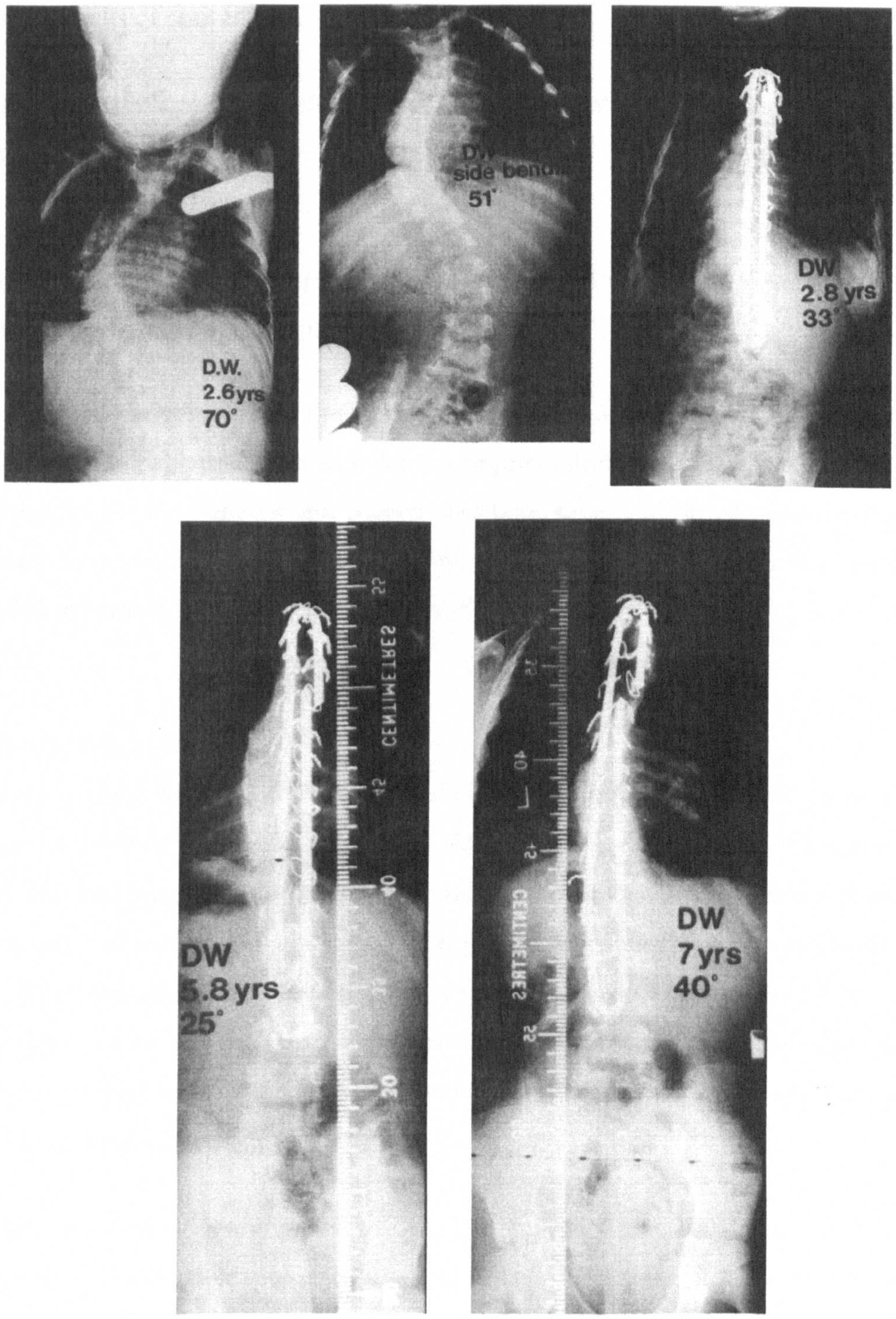


Figure 15. 2 year old with IIS treated by Luque trolley and convex epiphysiodesis. After surgery the curve was resolving with time until spinal growth exceeded the capacity of the Luque trolley to elongate and some loss of correction occurred.

completed their adolescent growth spurt. Only then will a comparison with long-term published results of conventional treatments be possible.

An instrumentation system is needed that will limit curve progression throughout the growth of the child.

Predictive factors

A number of factors correlate with outcome measures and the relative importance of these was determined using multiple linear regression analysis.

The upper end-vertebra tilt and the concave rib-spine angle each predict Cobb angle at 5-year follow-up in patients treated with convex epiphysiodesis and Luque trolley (Figure 16). These factors are independent and suggest that both spine and rib pathomechanisms are important in curve progression after surgery. The nature of these pathomechanisms is suggested by further analysis of the data (see *Consideration of predictive factors - further analysis*, page 73).

Importance of curve appearance

Of the 13 patients who had convex epiphysiodesis and Luque trolley, 2 did very well and their curves resolved and 2 did very badly, obtaining poor correction of the curves after surgery and then going on to progress. Inspection of the radiographs reveals that those who did very well had smooth curves with a low thoracic apex, while those who did badly had a severe tilt of the upper end-vertebra which was where most of the deformity was. These simple observations were reflected in the further analysis for predictive factors, in that pre-operative vertebral level of the apex was predictive of change in Cobb angle from 2-year follow-up to 5-year follow-up.

Prediction of instrumented segment growth

Pre-operative Cobb angle predicted the percentage of predicted growth seen in the instrumented segment from post-operative to 5-year follow-up (Table 7, page 72). Patients with a higher pre-operative Cobb angle achieve less instrumented segment growth.

Spinal growth in scoliosis can be separated into two components relative to the spine, parallel to the spine (cranio-caudal) and perpendicular to the spine (transverse plane). We would expect that the post-operative Cobb angle be more strongly correlated to spinal

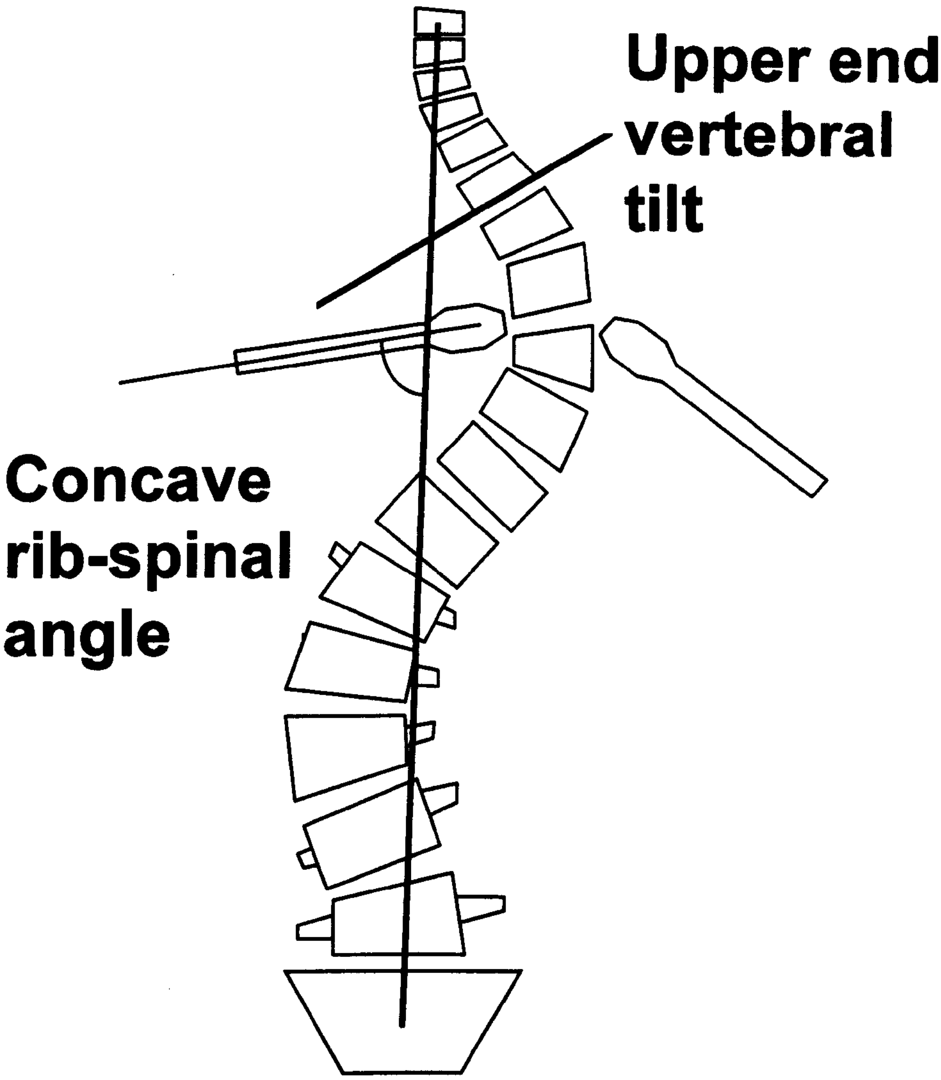


Figure 16. Factors predicting Cobb angle 5 years after Luque trolley and convex epiphysiodesis.

growth than the pre-operative Cobb angle, as mechanically speaking, the smaller the Cobb angle *after* surgery, the less the component of spinal growth perpendicular to the spine, and the more the component of spinal growth in the direction of the instrumentation. This was not found to be the case so there would appear to be other factors involved. One explanation is that patients with a large pre-operative Cobb angle have less growth potential. This explanation is supported by the finding of (i) a lower percentage of expected growth in patients with more instrumented vertebrae (P=0.02, Spearman rank correlation coefficient) and (ii) less growth is found in animal experiments as more levels are instrumented[200]. Loss of growth potential may be secondary to damage of growth plates, which could occur during the natural history of the condition or because surgery is more extensive or traumatic for those with larger curves.

The instrumented segment growth from post-operative to 5-year follow-up correlates with the change in Cobb angle from post-operative to 5-year follow-up (P=0.006, Spearman rank correlation coefficient). Patients who grow more over the instrumented segment demonstrate less progression of Cobb angle or an improvement in Cobb angle. Either the Cobb angle determines the growth along the Luque rods or the spinal growth along the Luque rods relative to the component of spinal growth perpendicular to the Luque rods determines the change in Cobb angle. If the former were entirely true then we would not expect to see improvement in Cobb angle as there is always a component of growth perpendicular to the spine. Without surgery, it would be the Cobb angle which would determine the relative size of the components of spinal growth perpendicular and parallel to the spine. Any degree of spinal curve should result in that curve being perpetuated or worsening owing to the component of spinal growth perpendicular to the spine.

All of these patients had a convex epiphysiodesis which would alter the relative components of spinal growth. If there is no component of spinal growth perpendicular to the Luque rods, which is the aim of a convex epiphysiodesis, then the Cobb angle will improve, as found in two patients. This supports the existence of a convex epiphysiodesis effect.

The role of rib and spine factors in determining outcome of surgery by Cobb angle at 5-year follow-up

The data presented (see *Consideration of predictive factors - further analysis*, page 73 and Table 8) suggest that the pre-operative concave RSA is the most important factor in predicting the change in Cobb angle seen from pre-operative to 8 weeks after surgery and this suggests the rib cage may be acting as a brace for the spine, resisting correcting forces applied during surgery. There is no clear relationship between changes in upper or lower end-vertebra tilt and changes in concave or convex RSAs, so forces other than those produced by surgery tilting the vertebrae are accounting for post-operative RSAs. The implication is that the rib cage is acting as a single unit. There is some evidence of this in that the convex and concave RSAs move in the same direction from 8-week to 5-year follow-up (P=0.027, Spearman rank). This movement in the ribs is compatible with a stress relaxation phenomenon (of surgery inducing forces in the rib cage) because the direction of movement in the convex ribs in the post-surgical period is in the opposite direction to the movement of the concave and convex RSAs from pre-operative to 8-week assessment (P=0.031 and P=0.019 respectively, Spearman rank).

Spine factors

The pre-operative upper end-vertebra tilt is the factor most strongly predicting the change in Cobb angle from post-operative to 5-year follow-up (Table 9, page 77). This suggests that the degree of the upper spine deformity indicates and possibly determines the magnitude of the secondary pathomechanisms which continue to act to cause curve progression. These pathomechanisms may be growth mediated - the more the tilt of the upper end-vertebra, the more the component of growth perpendicular to the rods causing progression even in the presence of a convex epiphysiodesis. However the process that initiates the spinal deformity may be unrelated to these secondary pathomechanisms. The observation that even those whose curves improved after Luque trolley and CE worsened once the growth capacity of the rods was exceeded means these mechanisms for progression are still present.

Consideration of effect of outliers

When curves with obvious characteristics of marked upper end-vertebra tilt or lower thoracic apex were excluded to give a more homogenous group of 9 patients treated by Luque trolley and CE, then the greater the pre-operative RVAD, the more the Cobb angle progression after surgical correction. This implies factors in the rib cage influencing the spine, but it is difficult to know the significance of these findings as the changes in Cobb angle are not great and the curve is being partially controlled by the instrumentation.

The rib cage in IIS

Observations have been made on the rib cage in IS[1,128-130,381] and a number of suggestions have been made regarding the contribution of the rib cage to scoliosis aetiology and pathomechanisms[1,44,128-130,238,247,285,308,316,381]. Some of these theories can be tested against the data from this study.

A muscular tether acting from without the rib cage could result in apical convex and concave rib droop. If this were so, then we might expect that lengthening of the spine due to either surgery or growth would increase the force due to muscular tether acting on the ribs causing the rib droop that is found i.e. there should be some association between spinal lengthening and rib droop. However there was no correlation between (i) the change in convex rib-vertebra angle with surgery and each of change in Cobb angle or T1-S1 length with surgery or between (ii) the change in concave rib-vertebra angle with surgery and each of change in Cobb angle or T1-S1 length with surgery.

In addition, if the changes after surgery are studied, there was no correlation between (i) the change in convex rib-vertebra angle from post-operative to 5-year follow-up and each of change in Cobb angle, T1-S1 length and instrumented segment growth from post-operative to 5-year follow-up and between (ii) the change in concave rib-vertebra angle from post-operative to 5-year follow-up and each of change in Cobb angle, T1-S1 length and instrumented segment growth from post-operative to 5-year follow-up.

The theory that a muscular tether exists which is increased as a result of relative lengthening of the spine with surgery or growth so producing rib droop does not appear to be supported.

The same analysis was performed for all (IIS and JIS) patients, and again the theory that a muscular tether exists was not supported.

Implications for future management

Empirically, there are two main areas where different approaches in the surgical management of IIS are possible, namely in respect of the instrumentation and in respect of rib interventions.

Instrumentation

The surgical treatment of congenital hemivertebrae using convex growth arrest leads to steady curve resolution[350], as the deforming forces are removed. Surgical treatment of IIS using convex growth arrest alone does not halt the progression of deformity[197], and neither does use of Luque trolley instrumentation alone. However, the results of Luque trolley instrumentation combined with an anterior release and convex epiphysiodesis for IIS have been more promising, as described. The drawbacks of the Luque trolley instrumentation in this study have been described above (see *Disadvantages of the Luque trolley*, page 80) and are mainly the inability of the instrumentation to extend enough to allow growth and wire breakage. A sturdier construct would be desirable.

There are some 'growth rods' available commercially. Most require periodic re-operation for lengthening which is not ideal. A telescopic trombone type system (Ulm telescopic rod, Endotec, Industriestraße 48, 51399 Burscheid, Germany) is available for neuromuscular scoliosis and this uses rods of unequal diameter, wiring and polyethylene sliders. However, wires may break and polyethylene can produce wear particles which produce a damaging inflammatory response. The hollow tubes may also become a reservoir for infection. I suggest an alternative design, shown in Figure 17 and Figure 18. The interlocking sliding rod shown in Figure 17 would need a sliding section about 80 mm in length to allow for growth in patients similar to those studied having Luque trolley and convex epiphysiodesis in whom the maximum growth instrumented segment was 33 mm. The rods might be applied to the spine as depicted in Figure 18. Vertebral fixation may be by pedicle screws (if patient aged over 8 years) or by laminar hook or USS pedicle hook (which incorporates an endplate screw for stronger fixation) in younger patients. In the upper and lower zones, the vertebral implants should be fixed to the rods. In the middle zone, the vertebral implants should be attached to the rods but left free to slide. This could be achieved by using sliding rings or using a side-loading construct as found in the USS which is modified not to grip the sliding rod on tightening. For the age group envisaged, a scaled down version would be needed, probably with rods of about 4.5 mm diameter. At this diameter, the rods may not be strong enough. Other problems would be that any contouring of the rods to fit the spine in the sliding region of the rods would stop any sliding occurring. This might be overcome by using outriggers to attach the vertebral implants to the sliding rods.

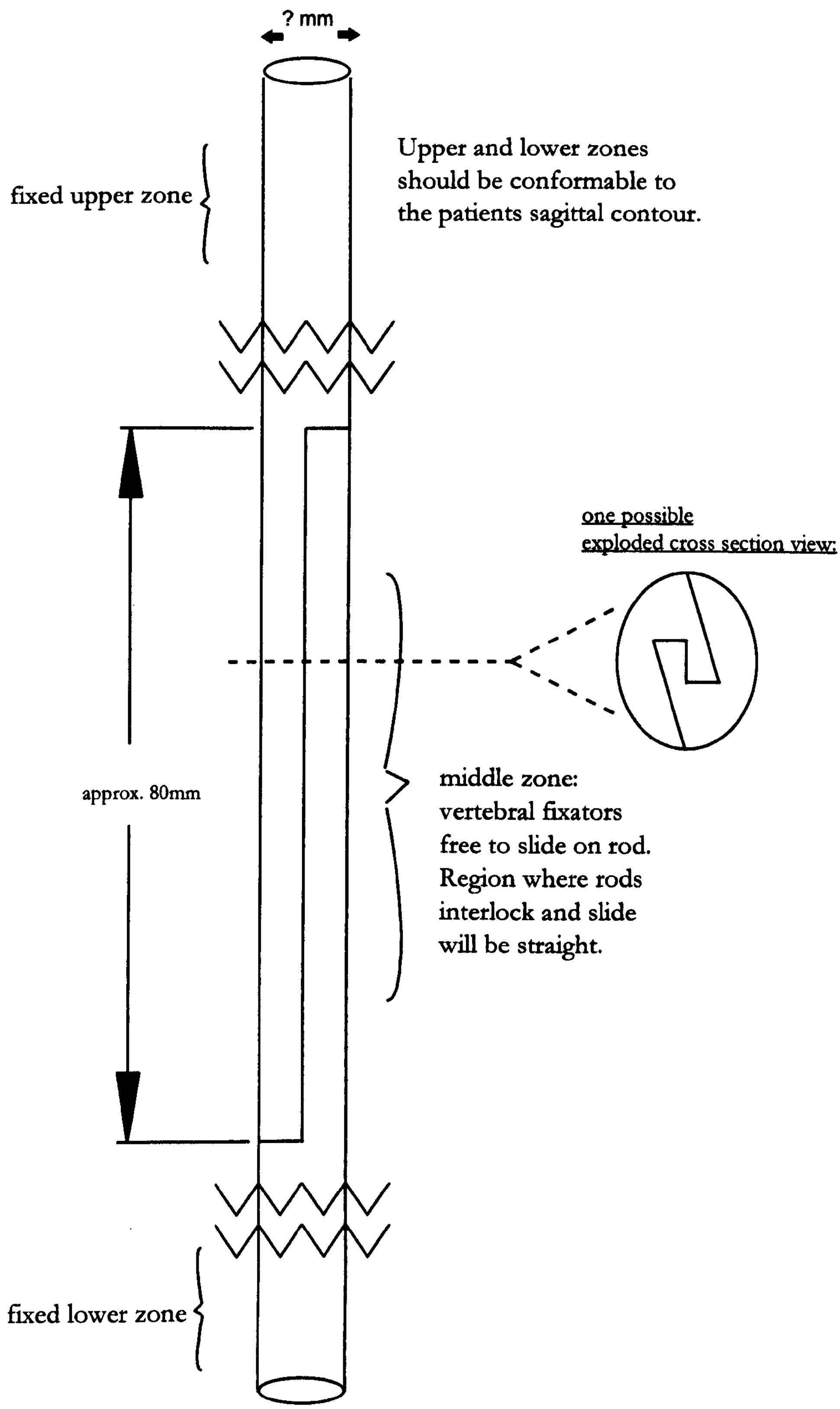
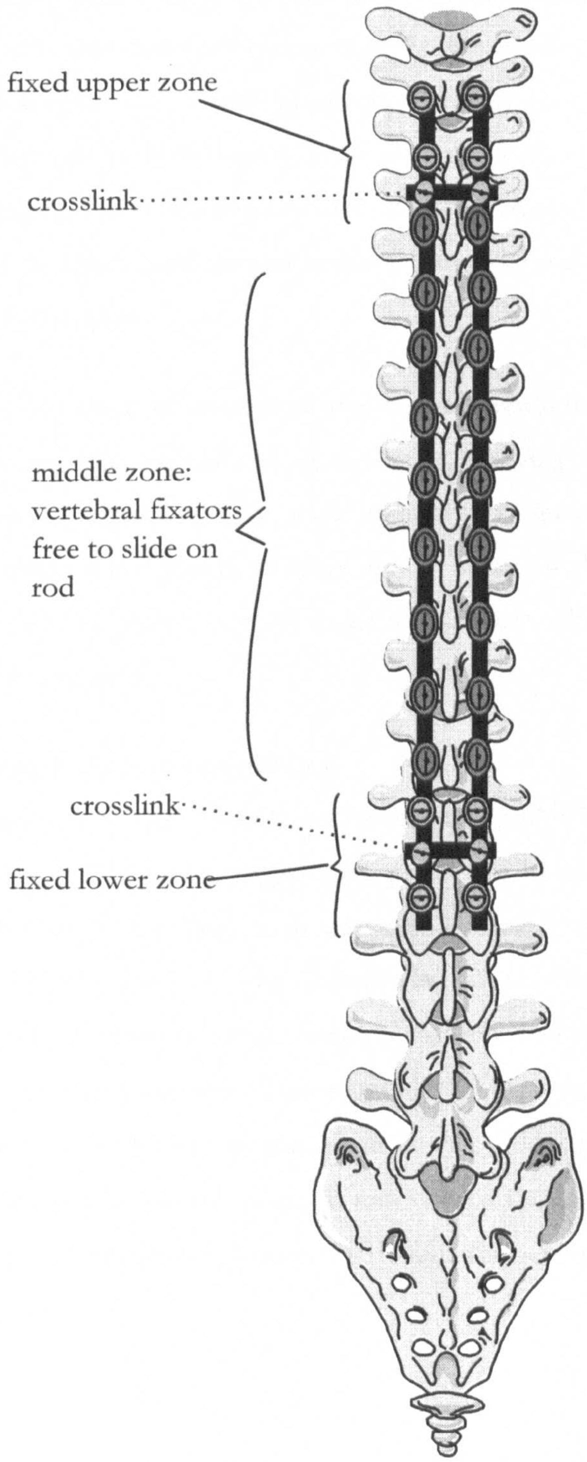


Figure 17. Suggested design for telescopic rod.



Vertebral fixation may be by pedicle screws, pedicle / laminar hooks,wires, slings or pedicle hooks + endplate screws (depending on the age of child).

In the upper and lower zones, vertebral fixators should be fixed to the rods in the normal way, i.e. not able to slide.

In the middle zone, the vertebral fixators should be attached to the rods but left free to slide. This could be achieved by using sliding rings or using a side-loading construct as found in the USS which is modified so as not to grip the rod on tightening. Alternatively sublaminar wires/slings could be used.

For the age group envisaged, a scaled down (i.e. paediatric) USS could be used.

Figure 18. Suggested application of telescopic rods to spine.

Rib interventions

Work by Sevastik and others is suggestive that the thoracic cage and ribs have a role in the etiopathogenesis of IS (see *The thoracic cage and idiopathic scoliosis*, page 17). Concave costoplasty with bracing has been used in the treatment of IIS[18,261] but the long term results were no better than for bracing alone[18]. This implies that the ribs may not be the driving mechanism behind scoliosis progression, though they may still be the trigger[315]. This thesis demonstrates the importance of the concave RSA and by implication the concave ribs in determining the correction of Cobb angle achieved by surgery in patients with IIS treated by convex epiphysiodesis and Luque trolley. These data suggest the thoracic cage acts as a brace to the spine.

The combination of costodesis and convex epiphysiodesis and Luque trolley may reduce the bracing effect of the ribs on the spine, allowing more correction of Cobb angle when compared to performing a single operation. A greater correction of Cobb angle would direct more of the growth effect of the CE along the sliding instrumentation and reduce the component of growth perpendicular to the spine. This would reduce the forces acting for curve progression.

Predictors of curve progression

The work of Mehta[207] and Kristmundsdottir et al[166] have established the value of RVAD and convex rib-vertebra angle in the prediction of progression in IIS. I found the convex rib-spine angle correlates with upper end-vertebra tilt ($P=0.001$ Spearman rank) in this group of IIS patients. Upper end-vertebra tilt and not convex rib-spine angle (or RVAD) was selected by the multiple linear regression analysis for the prediction of Cobb angle progression after surgery. This suggests that convex rib-spine angle is an expression of vertebral tilt in the frontal plane and not an independent factor for outcome in terms of Cobb angle at 5-year follow-up. It may be that the upper end-vertebra tilt can be used as a predictor of progressive curves in IIS but further work will be required to evaluate this possibility.

Conclusion to Section I

The treatment of early IS with Luque trolley and convex epiphysiodesis combines the differential growth effect of convex epiphysiodesis with sliding instrumentation which facilitates spinal growth in a caudal-cephalad direction. The Cobb angle correction at 5-year follow-up for IIS patients treated with this technique was 51% and the instrumented spine segment growth was 32% of that expected. Complications included rod and wire fracture and the capacity of the Luque trolley to elongate being exceeded by spinal growth. Curves were also more difficult to correct at definitive spinal fusion. The changes to instrumentation outlined above may avoid these problems.
The Cobb angle at 5-year follow-up after treatment of progressive IIS by Luque trolley and convex epiphysiodesis is predicted by each of two pre-operative factors (1) upper end-vertebra tilt and (2) apical concave rib-spine angle. The patients with the best results are those with less pre-operative upper end-vertebra tilt and less apical concave rib droop. The implication is that both spine and rib factors are associated with curve progression. The convex epiphysiodesis may be addressing some of the spinal factors in some patients. The Luque trolley acts as a brace for the spine against curve progression.

The use of surgical techniques to harness growth which is guided by instrumentation to correct spinal deformity has advantages compared with long-term childhood treatment by plaster jackets and braces. The present surgical technique of Luque trolley and convex epiphysiodesis does not address possible rib factors involved in pathomechanisms of curve progression. There is scope for improved instrumentation and for new surgical measures to better the outcome.

My findings indicate the importance of (1) the upper part of the curve and (2) the concave ribs in determining outcome after surgery. Children with IIS who meet the established criteria for surgery could be evaluated before surgery for each of upper end-vertebra tilt and apical concave rib-spine angle. If upper end-vertebra tilt and apical concave rib-spine angle predict a good result, then (1) concave rib costoplasty either as an initial surgical treatment, or (2) combined with simultaneous convex epiphysiodesis, or (3) with subsequent convex epiphysiodesis might control scoliosis progression without instrumentation. Children with severe upper end-vertebra tilt and drooping apical concave ribs would be expected to require early instrumentation, costodesis and convex epiphysiodesis. Further follow-up of children so treated will be essential.

SECTION II - ADOLESCENT IDIOPATHIC SCOLIOSIS: EFFECTS OF EACH OF POSTERIOR AND ANTERIOR UNIVERSAL SPINE SYSTEM INSTRUMENTATION

Overview

A prospective study of patients undergoing surgery for correction AIS has been ongoing at The Centre for Spinal Studies and Surgery, Nottingham since 1987. The anthropometric and back shape measurements used in this section were gathered by Professor R.G. Burwell, myself and Mr. A.A. Cole FRCS. All radiograph measurements were performed by myself. The aim was to quantify the effect of surgery on scoliosis, study changes that occurred during follow-up and draw conclusions on possible mechanisms for progression based on these findings.

The posterior USS (Universal Spine System, manufactured by Stratec (Synthes®), Stratec Medical, Eimatstasse 3, Ch-4436, Oberdorf, Switzerland) was introduced for the treatment of AIS at Nottingham in 1991 and anterior USS was used from 1994. Radiographic, anthropometric and surface data were gathered at pre-operative and post-operative assessment at 8 weeks and 1 year and 2 years. Questionnaires were also given to patients and their parents to complete from the summer of 1995 onwards at pre-operative and 2-year assessments.

When data were reviewed, patients were divided by curve type[124] and type of implant used - anterior or posterior instrumentation. Some of these subgroups were too small to allow meaningful analysis. The results for 3 groups of patients were considered, namely (i) patients with right thoracic curves who had 2-year follow-up and posterior instrumentation (ii) patients who had 1 year follow-up for treatment with anterior USS and (iii) patients with concurrent surface and limited radiographic follow-up with assessment by questionnaire.

SECTION IIi: CHANGES IN SURFACE AND RADIOGRAPHIC DEFORMITY AFTER UNIVERSAL SPINE SYSTEM FOR RIGHT THORACIC ADOLESCENT IDIOPATHIC SCOLIOSIS

Overview

34 patients with right thoracic AIS were treated with posterior USS instrumentation between 1991 and 1996. Of these, 27 had complete prospective back surface and radiographic appraisal.

Pre-operative Cobb angle corrected from 58° to 34° by 2 years follow-up. Apical axial vertebral rotation corrected from 26° to 20°, apical vertebral translation from 4.5 cm to 2.4 cm and maximum ATI from 17° to 13° for the same follow-up period. Rib-hump reassertion occurred regardless of age, mainly between 8 weeks and 1 year and correlated with changes in vertebral translation (at 10 vertebral levels) over 2-year follow-up ($P=0.001$ repeated measures MANOVA). Patients with more pre-operative frontal plane tilt of L1 combined with less concave 5th rib droop had greater percentage correction of maximum ATI by 2 years, and concave 9th rib droop predicted reassertion of maximum ATI.

Almost half of initial back-surface correction is lost during follow-up. Segmental vertebral translation measurements correlated most strongly with segmental ATI measurements during follow-up.

Rib-hump reassertion is best explained by unwinding of the thoracic cage tensioned by surgery rather than an effect of relative anterior spinal overgrowth. Spine and thoracic cage factors determine rib-hump correction, so surgical disruption of the latter by costoplasty may prevent rib-hump reassertion.

Introduction

Patients considering surgery for AIS are often interested in the expected cosmetic improvement of their back shape[63] and this can be quantified using a number of different techniques[52]. A search of the literature concerning IS produced only 18 papers that gave data on back surface correction. Only rarely do studies report segmental surface changes occurring during a follow-up period[21,49,371,375]. Radiographic measurements such as Cobb angle are well described, easily obtained, reproducible, widely used and provide a simple description of deformity amenable to statistical analysis. However, radiographic deformity is not the same as back surface deformity of which patients, and their parents, complain. Correlations between surface measurements and radiographic measurements are poor[50,244,338,354] and in this connection it is possible that the radiographic components which correlate best with surface measurements have not yet been identified. The relationship between *changes* in back surface measurements and *changes* in radiographic measurements with surgery and on follow-up have not been evaluated.

In this section I document the results of the posterior USS for thoracic AIS at 8-week, 1-year and 2-year follow-up. The comprehensive multilevel surface and radiographic assessment of patients is used to evaluate the segmental changes in back shape in relation to each of vertebral tilt, translation and rotation at intervals after the surgery. The findings have relevance to rib-hump correction and re-assertion and they suggest pathomechanisms of curve and rib-hump progression which may influence the development of new surgical techniques for the treatment of AIS.

Material and Methods

Patients

34 patients with right thoracic AIS[124] treated using posterior USS instrumentation were recruited between 1991 and 1996. Of these, six patients had incomplete surface measurements. Three declined to attend for 2-year follow-up appointments, two were missed at 1 year follow-up and one was not assessed pre-operatively. One patient did not have an 8-week lateral radiographic film. This left 27 patients with complete surface and radiographic records for analysis.

Operative procedure

Posterior USS was implanted according to the manufacturer's instructions[3]. In summary, instrumented vertebrae are reduced to the appropriately contoured concave rod which is locked only at the caudal end. Passive elongation of the spine occurs. The convex rod is then implanted, cranial end first. With the end-vertebrae held in a normal position the intermediate vertebrae can be derotated and held. Distraction is not used. The Cotrel-Dubousset instrumentation (CDI) type derotation manoeuvre is not used. Patients at Risser stage 0 or 1 had an anterior growth arrest. Patients with stiff curves (Cobb angle greater than 65° on standing PA radiograph and greater than 40° on side bending films to the convexity) had an anterior release. Consultants, visiting fellows or senior training grades performed the surgery. At surgery, the spinous processes were left intact to act as landmarks during surface back shape examination at follow-up.

Patient assessment

See General Methods section, page 32.

Data analysis

Data were used to record changes in radiographic and surface measurements after surgery and during 2-year follow-up and to evaluate the relationship between radiographic and surface changes. We determined which pre-operative factors predicted back surface and Cobb angle correction at 2-year follow-up.

Statistical analysis included the Wilcoxon matched-pairs signed-ranks test, repeated measures multivariate analysis of variance (MANOVA) and multiple linear regression analysis (MLRA), see Statistical Methods, page 56. This Wilcoxon test gives significance of changes in measurements between assessments. The repeated measures MANOVA gives the significance of changes between repeated assessments. In the latter connection 10 ATI measurements down the back pre-operatively were considered as a whole and compared with the same measurements taken at different times after surgery. This analysis was also performed using segmental vertebral tilt, rotation and translation data. Only if change had occurred when all assessments were considered simultaneously in the analysis was further analysis performed to determine when these changes had occurred. The relationship between segmental ATI and each of segmental vertebral tilt, rotation and translation as they changed between pre-operative, 8-week, 1-year and 2-year assessments was evaluated. For this purpose it was assumed that a lumbar vertebra is about 1.3 times the height of a thoracic vertebra[252], so back surface levels 1 to 10 most closely correspond to the vertebral levels T1, T3, T5, T7, T9, T11, L1, L3, L4 and S1 respectively. The vertebral tilts, rotations and translations at these levels were used as covariates for repeated measures MANOVA of segmental ATI. The relationship between segmental ATI and segmental concave and convex rib-spine angles as they changed between the four assessments was also evaluated. For this purpose it was assumed that back surface levels 1 to 7 most closely correspond to ribs at vertebral levels T1, T3, T5, T7, T8, T10 and T12 respectively, allowing for the downward slope of the ribs.

MLRA was used to determine the predictive capacity of pre-operative variables on the outcome variables. The outcomes chosen were: percentage correction of maximum ATI, percentage correction of Cobb angle and percentage correction AVT, all at 2 years. The percentage correction of apical vertebral rotation is not presented as an outcome variable because RMMANOVA did not reveal significant changes in segmental vertebral rotation over the study period (see *Segmental ATIs and segmental vertebral rotation*, page 113). Percentage corrections are defined as $\frac{\text{pre-operative value - value at 2 years}}{\text{pre-operative value}} \times 100$. Percentage figures were chosen to allow comparison of smaller curve with larger curves on an equal basis. Analyses of corrections not converted to percentage were also performed.

MLRA was also performed for changes in outcome variables occurring mainly as a result of surgery (pre-operative to 8-week follow-up) and on follow-up after surgery (from 8-week to 2-year assessment) in a similar fashion to that above. Other analyses were performed as deemed appropriate.

MLRA was repeated according to King-Moe type for type II and III curves. Variables were entered as described in Statistical Methods, page 56.

Results

23 females and 4 males with right thoracic AIS had posterior USS implanted. By King-Moe type 14 patients had type II curves, 11 patients had type III curves, one patient had a type I (she had a 62° thoracic curve and a 52° lumbar curve but the smaller lumbar curve was the stiffer curve with a flexibility of 29% compared with the flexibility of the thoracic curve which was 62%) and one patient had a type V curve. Six patients had an anterior release (at Risser stages 0 (1); 1 (1); 3 (2) & 4 (2)) and 5 patients had a growth arrest performed (4 at Risser stage 0, 1 at Risser stage 1). The mean age at operation was 15 years (12.4-18.9 years) and the mean Risser stage was 2.2 (0-5). The pre-operative Cobb angle was 58° (37°-88°), the pre-operative apical vertebral rotation (AVR) was 26° (9°-38°) and apical vertebral translation (AVT) from the T1-S1 line was 4.5 cm (2.7-8.3). Kyphosis measured 31° (13°-58°) and lordosis measured 43° (22°-70°). Between 8 and 13 vertebrae were instrumented (mean=10). Mean Cobb angle correction on side-bending films was 40% (3%-74%). The mean maximum rib-hump measured with a Scoliometer was 17° (10°-30°).

Results from pre-operative to 2-year follow-up are summarised in Table 10 and Table 11 (Wilcoxon signed-ranks test). Overall, the USS does not have lasting adverse effects on frontal plane balance (Table 10), and the same is true for King-Moe type II curves (Table 11).

Table 10. Surface and radiographic results of surgery: mean findings for all King-Moe types (27 patients).

Measure	Pre-op	Post-op	1 year	2 years
Cobb angle	57.8	31.3**	33.4**†	34.2**††
AVR (degrees)	26.0	20.7**	21.2**	20.0**
AVT (cm)	4.5	1.8**	2.1**††	2.4**††‡‡
FPB (cm)	-0.8	-1.5*	-0.9†	-0.7††
FPB (cm)(abs)	1.3	1.7	1.5	1.4
SPB (cm)	-1.4	0.7*	-0.1	-0.5
Kyphosis	31.0	23.7**	25.9*	26.3
Lordosis	42.6	36.3*	40.8††	47.5††‡‡
Max ATI	16.8	9.7**	12.9**††	13.1**††

Where:

AVR = apical vertebral rotation

AVT = apical vertebral translation

FPB = frontal plane balance (T1 to the left of S1 is negative)

FPB (abs) = the absolute magnitude of frontal plane balance

SPB = sagittal plane balance

Max ATI = maximum ATI measured by Scoliometer out of 10 levels down the back

*, ** = P value (Wilcoxon) for comparison with pre-operative assessment

*=0.01<P<0.05, **=P<0.01

†, †† = P value (Wilcoxon) for comparison with 8-week assessment

†=0.01<P<0.05, ††=P<0.01

‡, ‡‡ = P value (Wilcoxon) for comparison with 1-year assessment

‡=0.01<P<0.05, ‡‡=P<0.01

Results by King-Moe type

King II curves

Mean age at operation was 14.5 years (12.4-18.9 years) and mean Risser stage was 1.7 (0 to 4). 8 to 13 vertebrae were instrumented (mean=10). Mean Cobb angle correction on side-bending films was 37% (10%-66%). Results from pre-operative to 2-year follow-up are summarised in Table 11.

Table 11. Surface and radiographic results of surgery: mean findings for patients with King II curves (n=14).

Measure	Pre-op	8 weeks	1 year	2 years
Cobb angle	58.3	32.5**	34.3**	34.9**
AVR (degrees)	23.0	18.1	18.4*	15.5**
AVT (cm)	3.9	1.3**	1.7**††	1.9**††‡‡
FPB (cm)	1.1	2.3*	1.6†	1.2††
FPB (cm)(abs)	1.6	2.3	1.6	1.3
SPB (cm)	-3.0	0.3**	-0.9	-0.6
Kyphosis	30.7	25.5	43.6	48.4
Lordosis	39.7	36.9	43.6††	48.4*††
Max ATI	15.4	8.4**	11.6**††	12.1††

See Table 10 for abbreviations.

King III curves

Mean age at operation was 15.5 years (12.4-18.7 years) and mean Risser stage was 2.6 (0 to 4). 8 to 12 vertebrae were instrumented (mean=10). Mean Cobb angle correction on side-bending films was 42% (3%-74%). Results from pre-operative to 2-year follow-up are summarised in Table 12.

Table 12. Surface and radiographic results of surgery: mean findings for patients with King III curves (n=11).

Measure	Pre-op	8 weeks	1 year	2 years
Cobb angle	56.9	30.2**	32.7**	34.3**†
AVR (degrees)	29.6	24.4*	25.6*	27.5
AVT (cm)	5.2	2.4**	2.9**†	3.1**††
FPB (cm)	0.3	0.8	0.6	0.4
FPB (cm)(abs)	0.8	1.0	1.3	1.2
SPB (cm)	-0.6	-0.1	0.6	-0.4
Kyphosis	29.7	19.0*	23.4	25.1†
Lordosis	46.7	36.4*	38.4	45.3†‡
Max ATI	18.7	11.1**	14.6*†	14.7

See Table 10 for abbreviations.

Analysis of segmental back surface measurements

The changes in maximum ATI are given in Table 10. Figure 19 shows ATI plotted against surface level down the spine for each of the pre-operative, 8-week, 1-year and 2-year assessments. The significance of differences between assessments in Figure 19 above was determined using repeated measures MANOVA. Surface deformity (ATI at 10 back surface levels) changes significantly during the study period ($P<0.001$, for all assessments, Table 13). From pre-operative to 8-week assessment significant correction of surface deformity occurs , which is partially lost from 8-week to 1-year follow-up with no change from 1-year to 2-year follow-up (repeated measures MANOVA, Table 13).

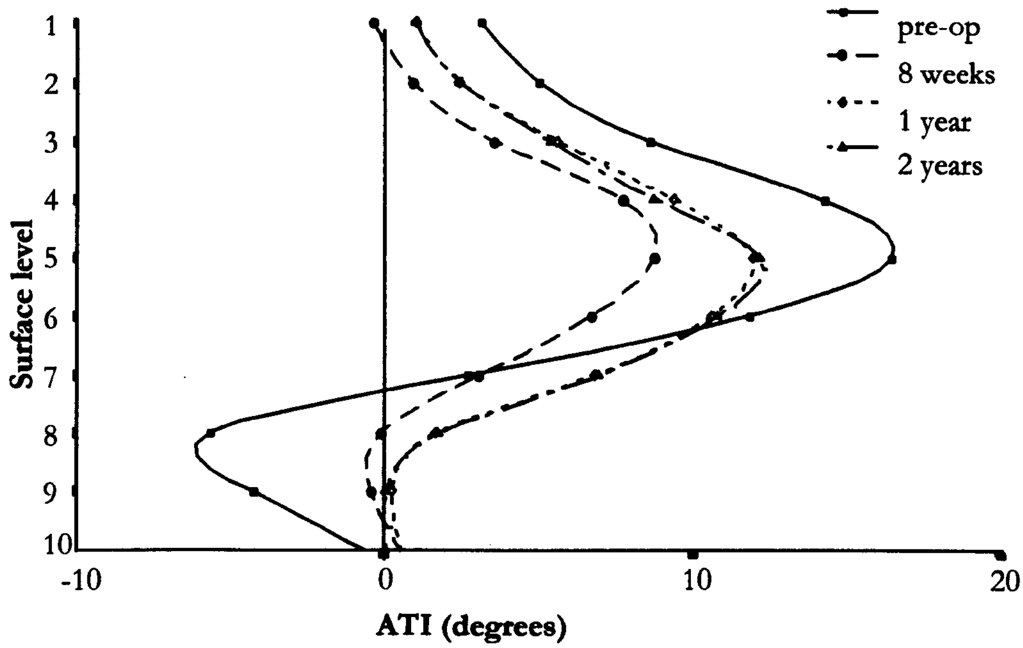


Figure 19. Mean angle of trunk inclination (ATI) plotted against 10 surface levels for AIS treated by USS (n=27).

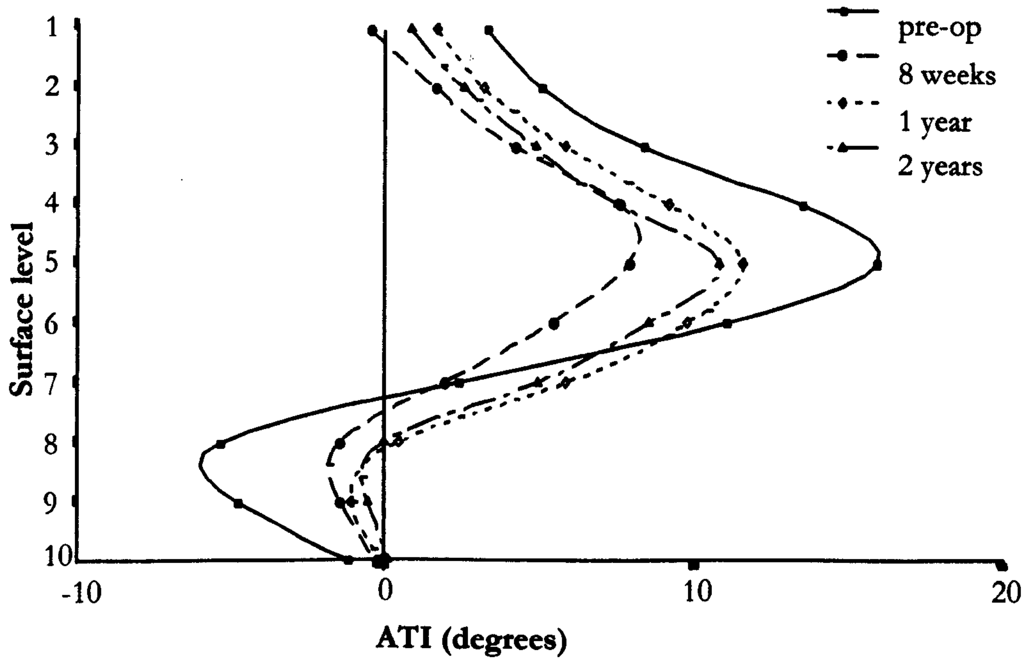


Figure 20. Mean ATI plotted against 10 surface levels, Risser stages 0 to 3, no growth arrest (n=13).

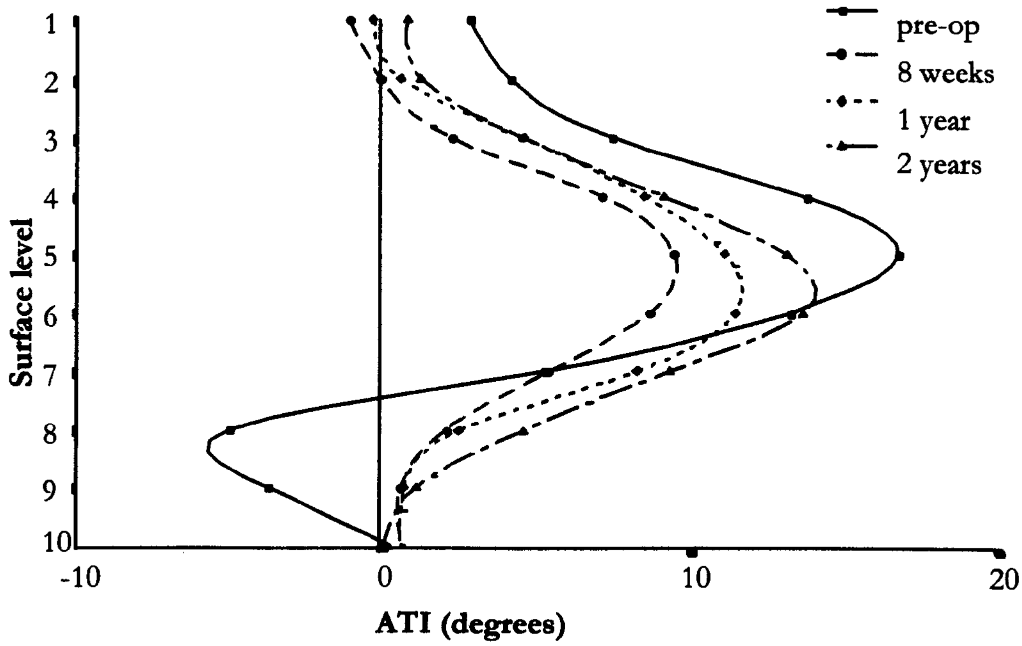


Figure 21. Mean ATI plotted against 10 surface levels, Risser stages 4 & 5 (n=9).

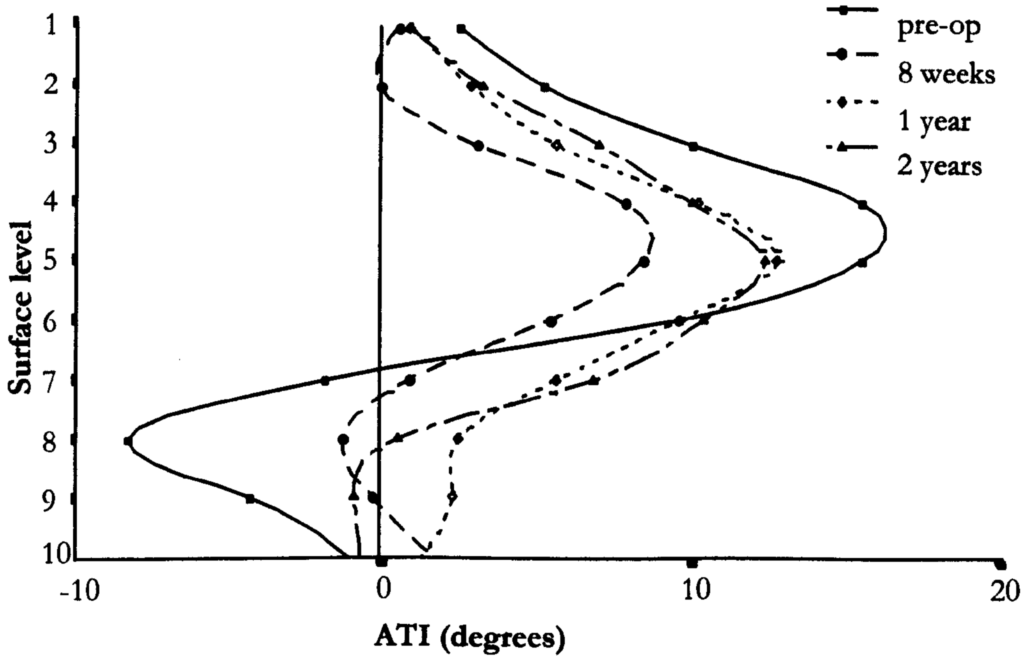


Figure 22. Mean ATI plotted against 10 surface levels, growth arrest performed (n=5).

Table 13. Segmental ATI at pre-operative, 8-week, 1-year and 2-year assessments. Repeated measures multivariate analysis of variance for all assessments and then for each assessment interval separately.

Source of variation	df	Sums of Squares	Mean Square	F	P
ATI pre / 8 weeks / 1 year / 2 years	3	828	276	8.3	<0.001
Within+Residual	78	2587	33	_	_
ATI pre - 8 weeks	1	612	612	26	<0.001
Within+Residual	26	610	23	_	_
ATI 8 weeks - 1 year	1	540	540	24	<0.001
Within+Residual	26	573	22	_	_
ATI 1 year - 2 years	1	0.98	0.98	0.03	0.865
Within+Residual	26	863	33	_	_

Where:

Source of variation = Source of variations in the response variable

df = degrees of freedom

Sums of Squares = magnitudes of differences between repeated measures

Mean Square = sums of squares divided by the degrees of freedom; estimates the variation in the data

F = test statistic for the F distribution - equals the mean square for each factor divided by the mean square of the error term

P = P value, the significance of changes in the response variable with repeated measurement

This loss of correction of surface deformity is termed rib-hump reassertion. From 8 weeks to 1 year rib-hump reassertion is not related to either age or maturity (by Risser stage) (P=NS, repeated measures MANOVA). Figure 20 and Figure 21 illustrate the rib-hump reassertion seen in patients of Risser stage 0-3 and Risser 4-5 respectively. A similar pattern of rib-hump reassertion is seen in patients who had an anterior growth arrest (n=5), see Figure 22.

Analysis of segmental vertebral tilt, rotation and translation

Figure 23, Figure 24 and Figure 25 show the graphs of vertebral level for each of vertebral tilt, vertebral rotation and vertebral translation. In Figure 23 and Figure 25 a similar pattern is observed, namely an initial correction of radiographic deformity which is partially lost on follow-up, the greatest loss occurring between the 8-week and 1-year assessments. Figure 23 shows that vertebral tilt (for all levels analysed simultaneously) changes from pre-operative to 8-week assessment, from 8 weeks to 1 year, but not from 1-year to 2-year follow-up (repeated measures MANOVA, Table 14).

Table 14. Segmental vertebral tilt at pre-operative, 8-week, 1-year and 2-year assessment. Repeated measures multivariate analysis of variance for all assessments and for each assessment interval separately.

Source of variation	df	Sums of Squares	Mean Square	F	P
Tilt pre/8 wk/1 yr/2 yr	3	572	191	10	<0.001
Within+Residual	78	1477	19	_	_
Tilt pre - 8 weeks	1	563	563	21	<0.001
Within+Residual	26	700	27	_	_
Tilt 8 weeks - 1 year	1	99	99	7.2	0.012
Within+Residual	26	356	14	_	_
Tilt 1 year - 2 years	1	0.05	0.05	0.00	0.948
Within+Residual	26	299	11	_	_

For abbreviations see Table 13.

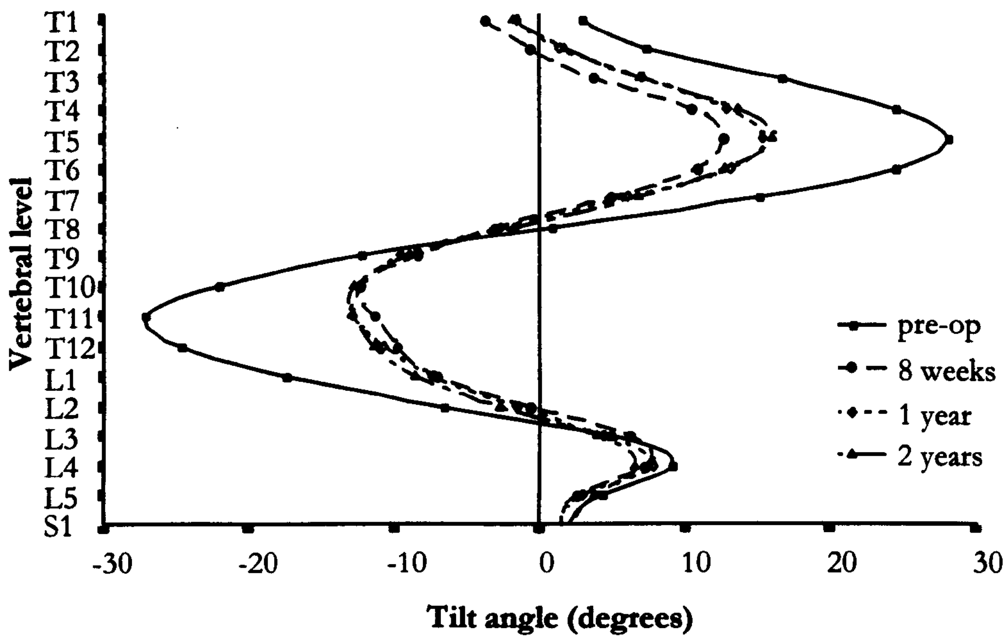


Figure 23. Mean vertebral tilt plotted against vertebral level (n=27).

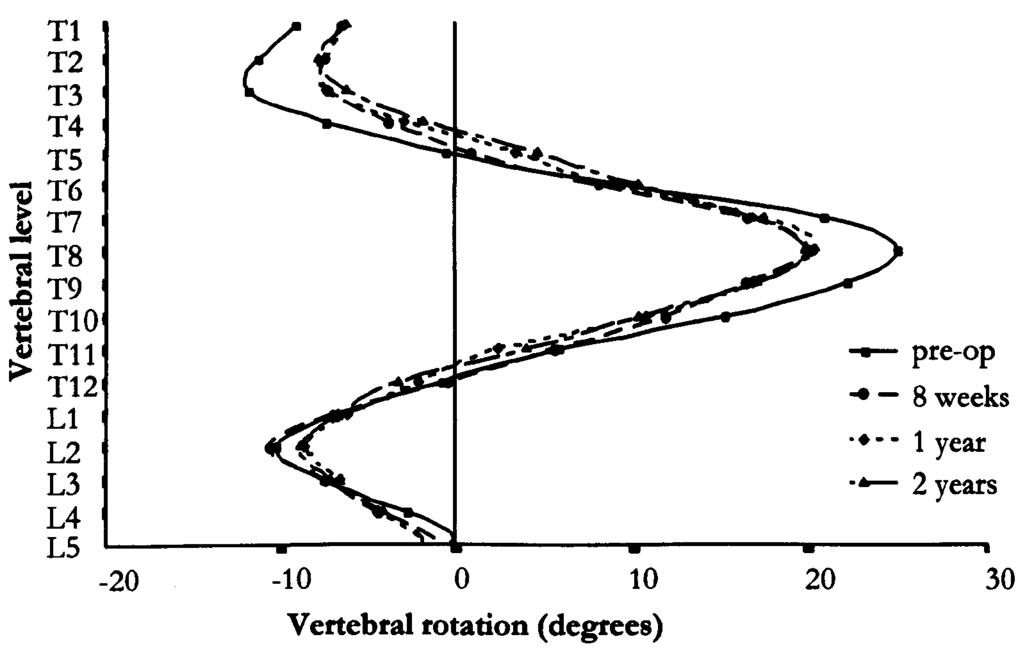


Figure 24. Mean vertebral rotation plotted against vertebral level (n=27).

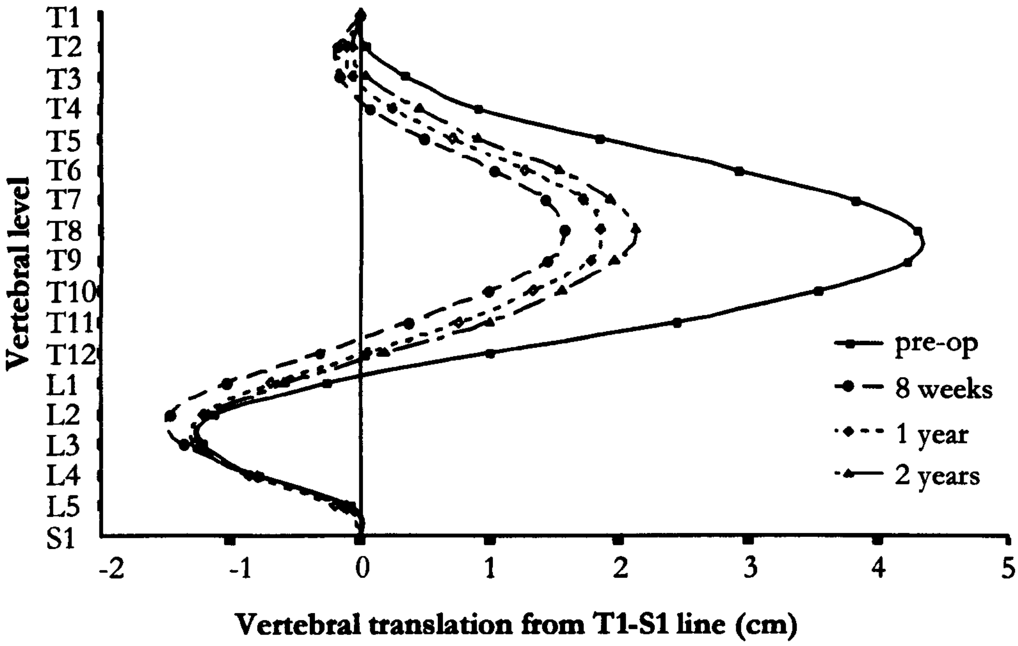


Figure 25. Mean vertebral translation plotted against vertebral level (n=27).

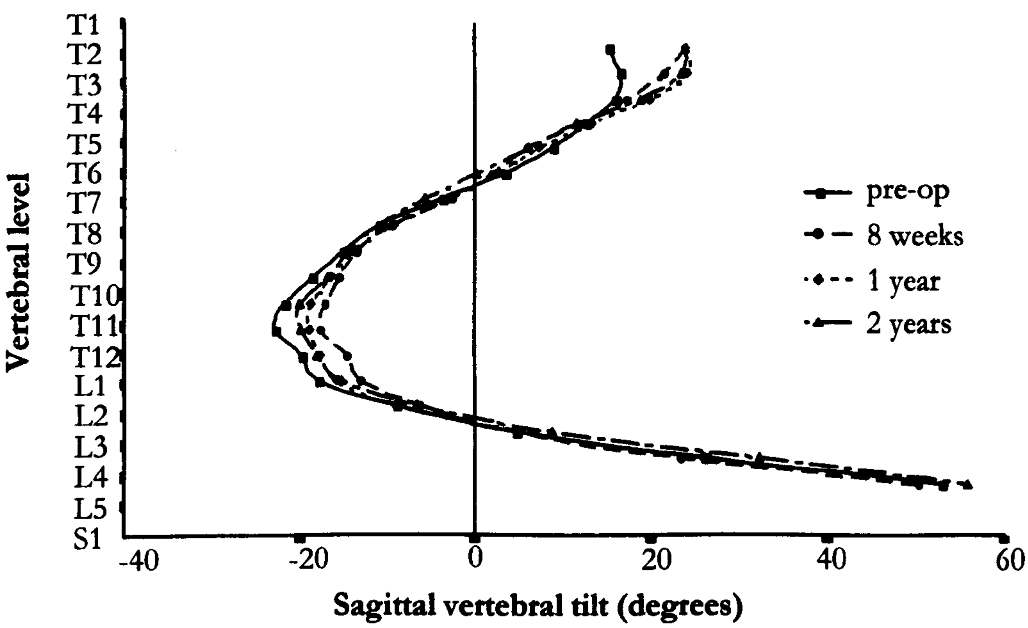


Figure 26. Mean sagittal vertebral tilt plotted against vertebral level (n=27).

Figure 25 shows that vertebral translation (for all levels analysed simultaneously) changes from pre-operative to 8-week assessment, from 8-week to 1-year and from 1-year to 2-year follow-up (repeated measures MANOVA, Table 15).

Table 15. Segmental vertebral translation at pre-operative, 8-week, 1-year and 2-year assessments. Repeated measures multivariate analysis of variance for all assessments and for each assessment interval separately.

Source of variation	df	Sums of Squares	Mean Square	F	P
Translation pre-op/8 weeks/1 year/2 years	3	392	131	47	<0.001
Within+Residual	78	217	2.8	_	_
Translation pre - 8 wks	1	339	339	87	<0.001
Within+Residual	26	102	3.9	_	_
Translation 8/52 - 1 yr	1	10	10	10	0.004
Within+Residual	26	26	0.99	_	_
Translation 1 - 2 years	1	4.9	4.9	17	<0.001
Within+Residual	26	7.73	0.30	_	_

For abbreviations see Table 13.

Changes in segmental vertebral rotation over the study period (Figure 24) were not significant (P=0.883, repeated measures MANOVA).

Analysis of sagittal plane segmental vertebral tilt

Two patients had sacralisation of L5 and these cases, L5 and S1 tilt in the sagittal plane were taken as the same. Changes in segmental sagittal vertebral tilt over the study period (Figure 26) were not significant (P=0.205, repeated measures MANOVA).

Analysis of concave and convex rib spinal angles measured from T1 to T12

Graphs of concave and convex rib spinal angles (RSAs) by vertebral level for each assessment are shown in Figure 27. Inspection of Figure 27 for convex RSAs does not reveal a pattern of change as seen for the variables considered above (i.e. segmental vertebral tilt, translation and ATI). Repeated measures MANOVA on pre-operative, 8-week, 1-year and 2-year assessments show convex RSAs (at 12 levels) change significantly during the study period (P=0.002). Significant changes in convex RSAs occur from 8-week to 1-year follow-up but not from pre-operative to 8-week assessment or from 1-year to 2-year follow-up (repeated measures MANOVA, Table 16).

Table 16. Segmental convex rib-spine angles at pre-operative, 8-week, 1-year and 2-year assessments. Repeated measures multivariate analysis of variance for all assessments and for each assessment interval separately.

Source of variation	**df**	**Sums of Squares**	**Mean Square**	**F**	**P**
Convex RSA pre-op/8 weeks/1 year/2 years	3	1802	601	5.4	0.002
Within+Residual	78	8719	112	_	_
Convex RSA pre- 8 wks	1	4.5	4.5	0.03	0.871
Within+Residual	26	4317	166	_	_
Convex RSA 8/52- 1 yr	1	756	756	15	0.001
Within+Residual	26	1288	50	_	_
Convex RSA 1 - 2 years	1	7.4	7.4	0.13	0.719
Within+Residual	26	1444	56	_	_

For abbreviations see Table 13, page 103.

Concave RSAs change significantly during the study period (P<0.001, repeated measures MANOVA on pre-operative, 8-week, 1-year and 2-year assessments). Significant change in concave RSAs occur from pre-operative to 8-week assessment but not from 8-week to 1-year follow-up or from 1-year to 2-year follow-up (repeated measures MANOVA, Table 17).

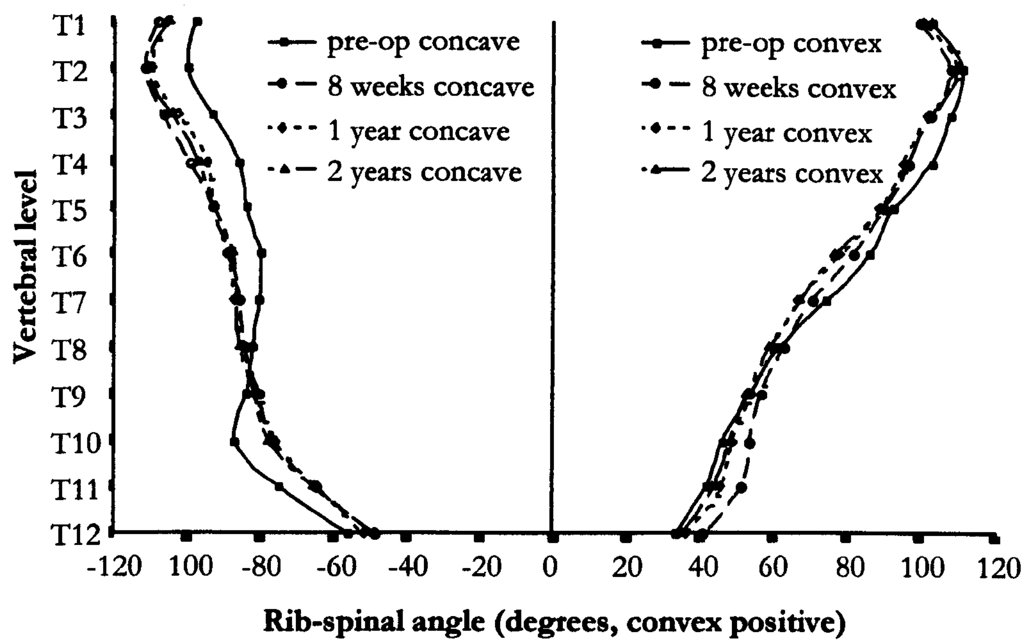


Figure 27. Concave & convex RSA by vertebral level (n=27).

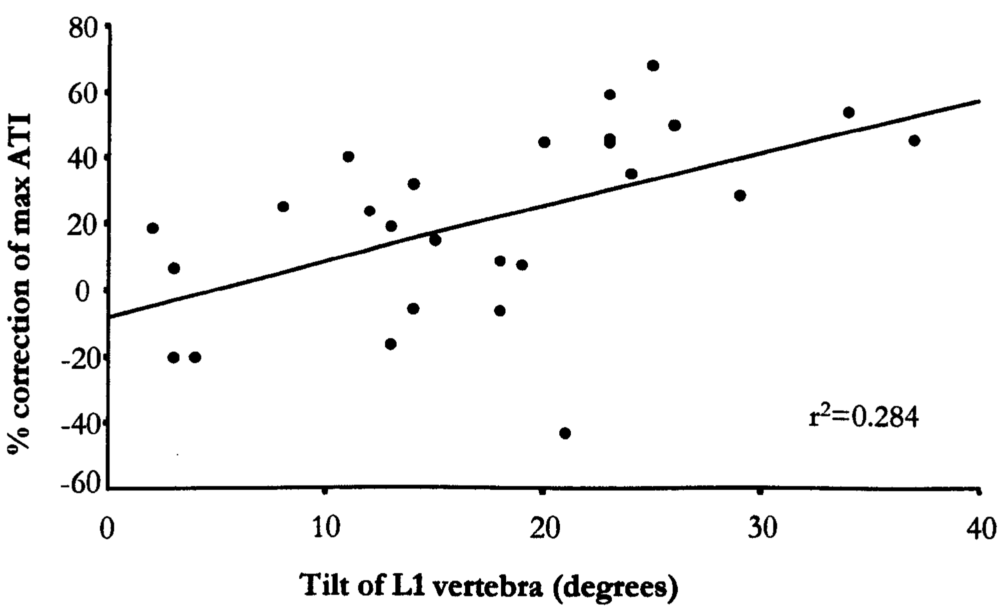


Figure 28. Percentage correction of maximum ATI at 2 years plotted against pre-operative tilt of L1 (n=27).

Table 17. Segmental concave rib-spine angles at pre-operative, 8-week, 1-year and 2-year assessments. Repeated measures multivariate analysis of variance for all assessments and for each assessment interval separately.

Source of variation	df	Sums of Squares	Mean Square	F	P
Concave RSA pre-op/8 weeks/1 year/2 years	3	2696	899	10	<0.001
Within+Residual	78	6853	88	_	_
Concave RSA pre-8/52	1	2182	2182	21	<0.001
Within+Residual	26	2764	106	_	_
Concave RSA 8/52-1 yr	1	87	87	1.9	0.182
Within+Residual	26	1198	46	_	_
Concave RSA 1- 2 years	1	13	13	0.38	0.543
Within+Residual	26	873	34	_	_

For abbreviations see Table 13, page 103.

Relationship between changes in ATIs and changes in Cobb angle, vertebral tilt, rotation, translation and rib-spine angles

Changes in maximum ATI correlate significantly with changes in each of Cobb angle and AVT from pre-operative to 8-week follow-up, from pre-operative to 2-year follow-up and from 8-week to 2-year follow-up (Spearman correlation coefficients, Table 18).

Table 18. Spearman's correlation matrix for <u>changes</u> in maximum angle of trunk inclination (ATI) against changes in Cobb angle, apical vertebral translation (AVT) and apical vertebral rotation (AVR) between corresponding follow-up intervals.

Variables (n=27)		**Maximum ATI**		
		pre-op - 8 weeks	**pre-op - 2 years**	**8 weeks - 2 years**
Cobb angle	r	0.49	0.63	-0.40
	P	0.009	<0.001	0.039
AVT	r	0.44	0.66	0.52
	P	0.023	<0.001	0.005
AVR	r	0.28	0.19	-0.04
	P	0.16	0.35	0.83

Where:

r = correlation

n = sample size

p = probability value

Segmental ATIs and segmental vertebral tilt

There is a significant linear relationship between changes in segmental ATI and segmental vertebral tilt from pre-operative assessment to 8-week follow-up (P=0.012, repeated measures MANOVA, Table 19), but not for repeated measures MANOVA of 8-week, 1-year and 2-year post-operative data (Table 20). The linear relationship between segmental ATI and vertebral tilt is not significant when all follow-up assessments are considered (P=0.083, repeated measures MANOVA).

Table 19. Segmental ATI at pre-operative and 8-week assessments. Repeated measures MANOVA incorporating each of segmental vertebral tilt, translation and rotation as covariates.

Covariate	Source of variation	df	Sums of Squares	Mean Square	F	P
	ATI pre - 8 weeks	1	109	109	5.8	0.024
tilt	regression	1	139	139	7.4	0.012
	Within+Residual	25	471	19	–	–
	ATI pre - 8 weeks	1	97	97	4.0	0.056
translation	regression	1	9.3	9.3	0.4	0.539
	Within+Residual	25	601	24	–	–
	ATI pre - 8 weeks	1	607	607	25	<0.001
rotation	regression	1	1.9	1.9	0.1	0.784
	Within+Residual	25	608	24	–	–

See Table 13, page103 for abbreviations.

Table 20. Segmental ATI at 8-week, 1-year and 2-year assessments. Repeated measures MANOVA incorporating each of segmental vertebral tilt, translation and rotation as covariates.

Covariate	Source of variation	df	Sums of Squares	Mean Square	F	P
	ATI 8/52, 1 & 2 years	2	546	273	7.2	0.002
tilt	regression	1	40	40	1.1	0.311
	Within+Residual	51	1928	38	–	–
	ATI 8/52, 1 & 2 years	2	166	83	2.7	0.076
translation	regression	1	411	411	13	0.001
	Within+Residual	51	1557	31	–	–
	ATI 8/52, 1 & 2 years	2	665	333	8.7	0.001
rotation	regression	1	16	16	0.4	0.519
	Within+Residual	51	1952	38	–	–

See Table 13, page 103 for abbreviations.

Segmental ATIs and segmental vertebral rotation

There is no significant linear relationship between segmental ATI and segmental vertebral rotation changes when either pre-operative assessment and 8-week follow-up data or 8-week, 1-year and 2-year post-operative data are analysed (Table 19 and Table 20).

Segmental ATIs and segmental vertebral translation

There is a significant linear relationship between segmental ATI and segmental vertebral translation (P=0.024, repeated measures MANOVA) if all assessments are considered (pre-operative, 8-week, 1-year and 2-year). However, changes in ATI over the study period are still significant (P=0.002, repeated measures MANOVA) if variation due to segmental vertebral translation is removed from the analysis. There is a significant correlation between segmental gain in ATI between 8-week, 1-year and 2-year assessments (rib-hump reassertion) and gain in segmental vertebral translation (P=0.001, Table 20).

Segmental ATIs and segmental rib-spine angles

Changes in segmental convex RSA do not correlate with *changes* in segmental ATI by repeated measures MANOVA (P=0.64) when all assessments are considered. Likewise, there is not a significant linear relationship between *changes* in segmental concave RSA and *changes* in segmental ATI (P=0.18, RMMANOVA). There was a weak linear relationship between segmental concave RSA and segmental ATI when only pre-operative and 8-week assessments were considered (P=0.033, RMMANOVA). Similar results were obtained when both concave and convex RSAs were considered in the analysis simultaneously. The analysis was repeated to include segmental vertebral rotation as a covariate, but this did not produce different results which is unsurprising as there is not a clear linear relationship between RSA and vertebral rotation, see *Effect of thoracic cage rotation on measurement of RSAs*, page 40.

Segmental ATIs and segmental sagittal vertebral tilt

There was no significant linear relationship between segmental ATI and segmental sagittal vertebral tilt (P=0.30, repeated measures MANOVA) if all assessments are considered (pre-operative, 8-week, 1-year and 2-year).

Analysis of data by King-Moe type

Analysis of data for King-Moe II and King-Moe III curves separately produced results similar to those described. Back shape improved after surgery and rib-hump reassertion occurred mainly from 8 weeks to 1 year in both groups. Patients with King-Moe II curves had an overall 19% correction of maximum ATI from pre-operative to 2-year follow-up, having 50% reassertion of rib-hump from 8 weeks to 2 years. Patients with King-Moe III curves had an overall 24% correction ATI after a 48% reassertion of rib-hump from 8 weeks to 2 years. The King-Moe type did not alter the relationship between surface and radiological measurements described above.

Relationships between segmental vertebral tilt, sagittal tilt, rotation, translation and rib-spine angles

Significant changes were found for changes in segmental vertebral tilt and translation between assessments (Table 14 and Table 15, pages 104 and 107), so further analysis was performed to determine if there were any linear relationship between changes in these and other segmental variables.

A significant relationship was found between changes in segmental vertebral tilt and translation (P=0.006), such that when this relationship was removed from the source of variation then the changes seen in segmental tilt and translation were no longer significant (P=0.56, repeated measures MANOVA, Table 21). There was a significant relationship between changes in segmental vertebral tilt and each of segmental sagittal vertebral tilt (P=0.03) and segmental vertebral rotation (P<0.001, repeated measures MANOVA, Table 21), neither of which accounted for the changes seen in segmental vertebral tilt between assessments. There was no significant relationship between changes in vertebral tilt and each of sagittal tilt and rotation for pre-operative and 8-week assessments analysed alone (repeated measures MANOVA).

Table 21. Segmental vertebral tilt for all patient assessments. Repeated measures MANOVA incorporating each of segmental vertebral translation, sagittal tilt and rotation as covariates.

Covariate	Source of variation	df	Sums of Squares	Mean Square	F	P
vertebral	tilt pre-; 8/52, 1, 2 yrs	3	35	12	0.7	0.562
translation	regression	1	135	135	7.9	0.006
	Within+Residual	77	1313	17	_	_
vertebral	tilt pre-; 8/52, 1, 2 yrs	3	643	214	12	<0.001
sagittal tilt	regression	1	85	85	4.7	0.033
	Within+Residual	77	1392	18	_	_
vertebral	tilt pre-; 8/52, 1, 2 yrs	3	545	182	9.9	0.036
rotation	regression	1	84	84	4.6	<0.001
	Within+Residual	77	1409	18	_	_

See Table 13, page 103 for abbreviations.

However significant relationships were found for the same analysis for 8-week, 1-year and 2-year assessments (tilt and segmental tilt; regression P=0.001, tilt and rotation; regression P=0.036, repeated measures MANOVA). [Performing this test for 3 assessments rather than 2 will improve the power of the MANOVA however, the result was still significant when 8-week and 2-year assessments were considered in the analysis]. Changes in vertebral tilt were still significant for the latter analysis once the effects of each of sagittal tilt and rotation were taken into account (P=0.007 when sagittal tilt controlled for, P<0.0001 for rotation, repeated measures MANOVA).

There was no significant relationship between changes in segmental vertebral tilt and convex or concave RSAs for corresponding levels (repeated measures MANOVA).

There was a significant relationship between changes in segmental vertebral translation and segmental vertebral rotation (P=0.04), and changes in segmental vertebral translation were still significant (P<0.001) when this relationship was considered in the analysis (repeated measures MANOVA, Table 22.). There was no significant relationship between changes in vertebral translation and rotation for pre-operative and 8-week assessments or for 8-week, 1-year and 2-year assessments when analysed alone (repeated measures MANOVA).

Table 22. Segmental vertebral translation for all patient assessments. Repeated measures MANOVA incorporating segmental vertebral rotation as a covariate.

Covariate	**Source of variation**	**df**	**Sums of Squares**	**Mean Square**	**F**	**P**
vertebral	translation, all asse'nts	3	372	124	47	<0.001
rotation	Regression	1	12	12	4.4	0.039
	Within+Residual	77	205	2.7	_	_

See Table 13, page 103 for abbreviations.

There was no significant relationship between changes in segmental vertebral translation and each of sagittal vertebral tilt, convex or concave RSAs for corresponding levels (repeated measures MANOVA).

Pre-operative factors which predict the outcome of surgery

Multiple linear regression analysis was used to select pre-operative variables which correlate most strongly with outcome (see *Statistical methods*, page 56 and *Data analysis*, page 96).

Pre-operative factors which predict the percentage correction of maximum ATI at 2-year follow-up

Pre-operative tilt of L1 most strongly predicts the percentage correction of maximum ATI at 2 years (Table 23). The scattergraph of percentage correction of maximum ATI at 2 years against pre-operative tilt of L1 is presented in Figure 28. As pre-operative tilt of L1 increases then a greater percentage correction of maximum ATI at 2 years may be expected, but the relationship is weak. When the effect of pre-operative tilt of L1 is removed from the analysis, the other variables significantly associated with outcome were pre-operative concave RSA of 5th rib (P=0.039), pre-operative concave RSA of 4th rib (P =0.044) and pre-operative convex RSA of 4th rib (P=0.049). The pre-operative concave RSA of the 5th rib has the strongest association and is selected in the analysis (Table 23) and a scattergraph is shown in Figure 29 where the horizontal axis is the product of pre-operative tilt of L1 and the concave RSA of the fifth rib. As the tilt of L1 increases and the droop of 5th concave rib lessens then a greater percentage correction of maximum ATI is observed.

Table 23. Factors predicting percentage correction of maximum ATI at 2-year follow-up. Stepwise multiple linear regression model for pre-operative variables with probability of F<0.05 to enter variable into analysis.

Step	Variable	Coefficient	SE	95% CI	R square	T	P
1	Tilt of L1	-0.02	0.005	-0.015 to -0.025	0.28	-3.9	0.001
2	Concave 5th RSA	0.01	0.004	0.012 to 0.004	0.40	2.2	0.039
_	Intercept	-0.81	0.35	_	_	_	_

Where:

Intercept = for the equation on the x-axis

Upper EVA = upper end-vertebra tilt

Concave RSA= concave rib-spine angle

AVR = apical vertebral rotation

Coefficient = mathematical weightings of the explanatory variables in the equation

SE = standard error of the coefficients

95% CI = 95% confidence intervals for the coefficients

R square = coefficient of multiple determination

T = square root of mean square regression divided by the mean square residual

P = P value

When the analysis is repeated using correction of maximum ATI by 2-year follow-up as an outcome measure rather than the percentage correction, similar results are obtained. The tilt of L1 is selected first in the analysis (R^2=0.268), followed by pre-operative convex RSA of 4th rib (P=0.020, R^2=0.418).

Pre-operative factors which predict the percentage correction of maximum ATI from pre-operative to 8-week follow-up

No pre-operative variables were predictive.

Pre-operative factors which predict the percentage reassertion of maximum ATI at 2-year follow-up

The strongest predictive factor of percentage reassertion of maximum ATI is the concave rib-spine angle of the 9th rib (Table 24). Patients with less droop of the 9th concave rib had less rib-hump reassertion. Other pre-operative factors that contribute to the prediction of percentage reassertion of maximum ATI are in the lumbar spine namely rotation of L4, rotation of L2 and tilt of L4 (Table 24). These lumbar spine factors act in conjunction with 9th concave RSA to predict up to 73% of rib-hump reassertion.

Table 24. Factors predicting percentage reassertion of maximum ATI from 8-week to 2-year follow-up.

Step	Variable	Coefficient	SE	95% CI	R^2	T	P
1	Concave 9th RSA	-0.03	0.01	-0.034 to -0.018	0.35	-3.3	0.0004
2	Rotation of L4	0.15	0.03	0.116 to 0.173	0.45	5.1	<0.001
3	Rotation of L2	-0.06	0.01	-0.071 to -0.046	0.60	-4.7	<0.001
4	Tilt of L4	-0.04	0.01	-0.051 to -0.027	0.73	-3.2	0.004
_	Intercept	2.3	0.66	(analysis terminated)			

See Table 23 for abbreviations.

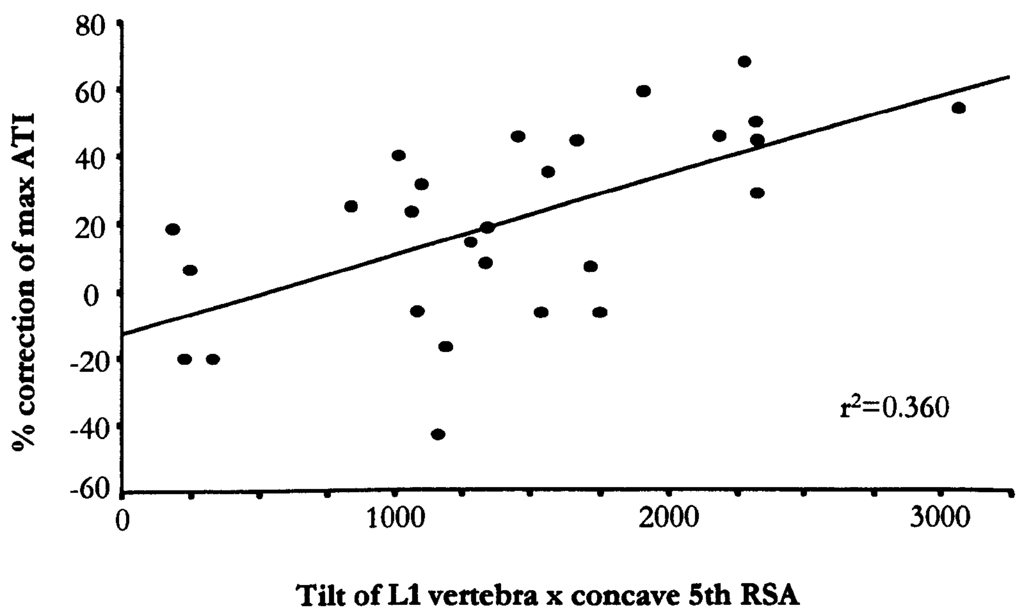


Figure 29. Percentage correction of maximum ATI at 2 years plotted against pre-operative tilt of L1 x concave RSA 5th rib (n=27).

The analysis was repeated for change in maximum ATI from 8 weeks to 2 years as the dependent variable. The concave 2nd RSA was predictive (P=0.001, R^2=0.36, coefficient=0.17).

Does rib-hump reassertion occur in response to any changes from pre-operative to 8-week assessments?

MLRA with percentage reassertion of maximum ATI from 8-week to 2-year follow-up as the dependent variable was performed, including only variables for *changes* in segmental ATI, vertebral tilt, rotation and translation and RSAs from pre-operative to 8-week assessments. The results are presented in Table 25.

Table 25. Changes in measurements from pre-operative to 8 weeks which predict percentage reassertion of maximum ATI from 8 week to 2 year follow-up.

Step	Change in	Coefficient	SE	95% CI	R^2	T	P
1	T6 vertebral rotation	0.04	0.01	0.030 to 0.044	0.24	3.6	0.001
2	ATI at level 6	0.08	0.02	0.054 to 0.102	0.47	3.2	0.004
_	Intercept	0.02	0.15	_	_	_	_

See Table 23 for abbreviations.

If pre-operative and pre-operative to 8-week change variables are included in the analysis, then the variables predicative of percentage reassertion of maximum ATI from 8-week to 2-year follow-up are (i) the concave 9th RSA (P=0.0004, R^2=0.35) and (ii) the change in ATI at level 8 down the back surface (P=0.036, R^2=0.46, MLRA).

Pre-operative factors which predict the percentage correction of Cobb angle at 2-year follow-up

The pre-operative tilt of L1 most strongly predicts the percentage correction of Cobb angle at 2 years (Table 26).

Table 26. Factors predicting percentage correction of Cobb angle at 2-year follow-up.

Step	Variable	Coefficient	SE	95% CI	R^2	T	P
1	Tilt of L1	-0.02	0.002	-0.018 to -0.013	0.46	-6.0	<0.001
2	ATI level 6	-0.01	0.004	-0.016 to -0.007	0.61	-3.0	0.007
_	Intercept	0.27	0.05	(analysis terminated)			

See Table 23 for abbreviations.

The analysis was repeated using correction of Cobb angle by 2-year follow-up as an outcome measure rather than the percentage correction, and similar results were found, with tilt of L1 (P<0.001, R^2=0.60), ATI at level 7 (P<0.001, R^2=0.75) and the convex 8th RSA (P=0.007, R^2=0.85, MLRA) being selected for the regression equation.

Pre-operative factors which predict the percentage correction of Cobb angle from pre-operative to 8-week follow-up

Tilt of L1 was the only independent variable entered into the linear regression equation as a predictor of percentage correction of Cobb angle from pre-operative to 8-week follow-up (P<0.005, R^2=0.28, coefficient=-0.008, MLRA).

The pre-operative Cobb angle predicts the correction of Cobb angle seen from pre-operative to 8-week follow-up (P<0.001, R^2=0.54, coefficient=0.70).

Pre-operative factors which predict the percentage reassertion of Cobb angle by 2-year follow-up

The vertebral rotation at T3 was entered into the linear regression equation (P=0.025, R^2=0.18), with a coefficient of 0.01.

The change in Cobb angle from 8-week to 2-year follow-up was predicted by pre-operative translation of L5 (P=0.008, R^2=0.21), pre-operative rotation of L4 (P=0.011, R^2=0.36) and tilt of L2 (P=0.022, R^2=0.49, MLRA).

Pre-operative factors which predict the percentage correction of maximum vertebral translation at 2-year follow-up

The pre-operative convex 5th RSA most strongly predicts the percentage correction of AVT at 2 years (P=0.031, R^2=0.21), with ATI at level 7 down the back (P=0.003, R^2=0.36) and tilt of L2 (P=0.011, R^2=0.52) being selected for the regression equation subsequently (MLRA). Patients with less droop of the 5th convex RSA had greater percentage correction of AVT.

Correction of AVT by 2-year follow-up was predicted by pre-operative tilt of L1 (P<0.001, R^2=0.51) and tilt of T9 (P=0.004, R^2=0.66, MLRA).

Pre-operative factors which predict the percentage correction of AVT from pre-operative to 8-week follow-up

Whether anterior surgery (release or growth arrest) was performed was the only variable entered into the equation (P=0.04, R^2=0.16), with a coefficient of 0.14. When the analysis was repeated for correction of AVT from pre-operative to 8-week follow-up, then tilt of L1 was the first variable entered into the equation (P<0.0001, R^2=0.61, coefficient=-0.11, MLRA).

Pre-operative factors which predict the percentage reassertion of AVT by 2-year follow-up

The convex 2nd RSA was entered into the equation (P=0.006, R^2=0.27), with a coefficient of -0.01. Similar results were obtained for reassertion of AVT (convex 2nd RSA, P=0.015, R^2=0.21).

Complications

Two of the 34 patients had the metalwork removed during the 2-year follow-up period. One had severe post-operative pain which did not improve after the metalwork was removed 18 months after the initial surgery. The other had upper thoracic pain and implant prominence which was solved with removal of the upper two pedicle hooks. Subsequently the rest of the instrumentation became infected and was removed.

Two patients had instrumentation failure. A pedicle screw slipped off the end of the rod in one case and in the other two pedicle screws pulled out.

One patient required extension of the instrumentation due to progression of the lumbar curve.

Eight patients complained of some mild pre-operative discomfort, either in the back (4) or in the right (3) or left (1) shoulder region. After 2 years, most patients had similar complaints to those preoperatively, though one patient thought the discomfort better, one developed new backache (not requiring analgesia) and one had severe back pain.

Discussion

Results determined by radiographic measurements

The assessment of the effects of surgery on scoliosis is generally by radiographic means, and almost universally by Cobb angle. Clinical decisions are based on Cobb angle and likelihood of its progression.

There is a wide range in results of instrumentation for AIS in the literature. Cobb angle correction after implantation of Harrington rods range from 22% to 55%[185,215]. Cobb angle correction after Cotrel-Dubousset instrumentation (CDI) vary from 47% to 71%[266,301]. This range of results is likely to be accounted for by (i) patient factors (such as curve type, severity, flexibility, patient age), (ii) surgical technique (such as number of fused levels, performing of anterior release or costoplasty, operator experience) and (iii) assessment techniques (outcome measures, length of follow-up).

The 2-year follow-up findings reported here show that USS results in a significant correction of each of Cobb angle (58° to 34°, 41%), AVR (26° to 20°, 23%) and apical vertebral translation (AVT) (4.5 to 2.4 cm, 48%) by 2-year follow-up (Table 10, page 98). Kyphosis, lordosis, FPB and SPB were unchanged by 2-year follow-up. These results, as assessed by radiographs, are consistent with those found for other systems[146,151,163,168,280,376]. Modern posterior instrumentation systems appear to be broadly equivalent[203], excepting the effects of CDI on frontal plane balance[321], especially in King-Moe type II curves[23,173,351].

Results determined by back surface measurements

Rib-hump reassertion has been documented after Harrington[49,364] and CDI[49,371,375] implantation. Weatherley et al[364] documented rib-hump progression after Harrington distraction instrumentation in 47 AIS patients with thoracic or thoracolumbar curves. They found no relationship between rib-hump progression and age, Risser sign, or vertebral rotation changes. CT scan data after CDI demonstrated a loss in rib-hump correction from 41% to 20%[375]. Similar findings are found using Scoliometer data after CDI, with a 39% initial correction reducing to 25% by 1 year after surgery[49,371]. The use of USS results in significant correction of maximum ATI by 2-year follow-up (17° to 13°, 22%) but half of the initial 42% correction of maximum ATI by 8 weeks is lost by 1 year (to 23%).

Analysis of segmental back surface data

Significant correction of segmental ATI occurs from pre-op to 8-week follow-up but partial loss of correction (reassertion of rib-hump) occurs from 8-week to 1-year follow-up. The difference between 1-year and 2-year follow-up is not significant (Figure 19, page 101 and Table 13, page 103).

Rib-hump reassertion was not related to age or Risser stage (P=NS, repeated measures MANOVA). In particular, 5 patients who had an anterior growth arrest also experienced rib-hump reassertion. This suggests that a crankshaft phenomenon[88] or anterior growth forces are not responsible for the rib-hump reassertion. I suggest that rib-hump reassertion between 8 weeks and 1 year is due to musculoskeletal tension induced in the thoracic cage by surgery. The ribs thus tend to spring back towards their original position after surgery. My study does not preclude growth forces acting to increase rib-hump deformity over the longer term, and a 5 to 10 year follow-up would be required to investigate these factors. Some long term evidence is now available for Harrington rods[171].

Analysis of segmental vertebral tilt, rotation and translation

Progression of radiological deformity occurs after the initial correction achieved using spinal instrumentation[82,88,146,155,170,226,299,375]. Progression may be due failure of the instrumentation, progression of the curve beyond the limits of the fusion, pseudarthrosis, and the crankshaft phenomenon. The crankshaft phenomenon is anterior spinal growth in the presence of posterior fusion causing progression of deformity. In practice it is difficult to measure directly. Sanders et al[299] defined it as the absence of any other cause for progression being present, which is pure supposition. Lapinsky and Richards, in their paper entitled 'Preventing the crankshaft phenomenon by combining anterior fusion with posterior instrumentation' defined the crankshaft phenomenon as being progression in curve magnitude greater than 10° and accompanied by an increase in rib-vertebra angle difference greater than 10°[170]. Again this definition does not distinguish a crankshaft phenomenon from any other cause of progression because only comparison of anterior spinal growth with posterior spinal growth can define a crankshaft phenomenon. Lapinsky and Richards concluded from their retrospective study of patients at Risser stage 0, 14 having anterior and posterior surgery and 12 having posterior fusion, that crankshaft was prevented in the former group. These groups were not comparable because the follow-up periods were different, being 37 months for the combined surgery and 64 months for posterior surgery. If the rib-vertebra angle difference greater than 10° is discounted on the grounds that this is a difference smaller than measurement error (see discussion of *Reproducibility of rib-spine angle measurement*, page 39), then two patients progressed in terms of Cobb angle>10° in the group having combined surgery. As progression is still seen after combined anterior and posterior instrumentation[155,170] then factors other than crankshaft are causing progression of deformity. Of 8 patients who were Risser stage 0 in Lapinsky's series, one had Cobb angle progression>10° and she did not have anterior surgery. It is unlikely that anterior spinal growth would be of a magnitude to cause the changes observed predominantly between 8-week and 1-year follow-up, a relatively short time span. This 2-year follow-up study would not exclude crankshaft as a mechanism for curve progression over a longer time span. Mullaji et al[226] retrospectively studied 30 AIS patients treated by posterior spinal fusion at Risser grade 0 who were followed until maturity (mean 7.8 years). They measured the ratio of disc to vertebral height in the fused segments on lateral spinal radiographs. 11 patients had progression of Cobb angle of 6° to 10° during follow-up and the ratio of anterior disc height to length of the fused area decreased by nearly one-half

(P<0.001). This was taken as evidence of vertebral body growth resulting in compression of intervening discs but it was evidently not possible to determine if differential growth had occurred between anterior and posterior spinal columns. They concluded that the increase in deformity was not enough to warrant the use of combined anterior and posterior fusion.

Changes in segmental vertebral tilt, vertebral rotation and vertebral translation in my study are shown in Figure 23, Figure 24 and Figure 25, pages 105 and 106. Significant correction of segmental vertebral tilt and vertebral translation occurs from pre-operative to 8-week follow-up (repeated measures MANOVA). From 8 weeks to 1 year there is a partial loss of correction for all these parameters. Only vertebral translation shows significant changes from 1-year to 2-year follow-up (repeated measures MANOVA). These changes are consistent with 'early stress relaxation of the spine, gradual maturation of the fusion mass, and realignment of the curve'[299].

Changes in segmental vertebral rotation are not significant (repeated measures MANOVA). Either USS does not affect vertebral rotation or the error in measuring vertebral rotation is large compared with the changes occurring with surgery and follow-up. I believe the latter is the more likely explanation. CT scan data for 22 patients with thoracic AIS revealed a mean 3.8° correction from pre-operative to 8-week assessment after implantation of posterior USS[67]. CT data in CDI also suggests the changes seen in vertebral rotation are small, only 2°to 5° initially[172,376], being lost with follow-up[375,383]. The amount of correction of vertebral rotation is small compared with the measurement error using the Perdriolle template. In addition, posterior instrumentation obscures vertebral landmarks making use of the Perdriolle template difficult[278,299].

Relationship between segmental ATI and segmental vertebral tilt, rotation, translation and rib-spine angles

Inspection of Figure 19 (page 101) reveals that rib-hump reassertion distributes to a lower level down the spine than the original rib-hump and lumbar trunk prominence does not recur. Changes in segmental vertebral tilt, rotation and translation on follow-up stay consistent with vertebral level (Figure 23, Figure 24 and Figure 25, pages 105 and 106). The loss of correction from 8-week to 2-year follow-up as a percentage of correction achieved from pre-operative to 8-week follow-up is 11% for Cobb angle, 0% for AVR, 21% for AVT, but 48% for maximum ATI. The magnitude of rib-hump reassertion is more than twice that for AVT and over four times that for Cobb angle. These observations suggest there is not a simple direct relationship between back surface changes and radiographic changes.

The *changes in segmental* ATI from pre-op to 8 weeks are related to *changes in segmental* vertebral tilt (Table 19, page 112). The *changes in segmental* ATI when considering the post-operative data (8 weeks, 1-year, 2 years) are related to *changes in segmental* vertebral translation (Table 20, page 113). One interpretation is that surgery corrects back surface shape through correction of vertebral tilt and that rib-hump reassertion causes post-operative increases in vertebral translation.

No convincing relationship was found between changes in segmental ATIs and segmental rib-spine angles. RSA measurement will reveal changes in the frontal plane but it is likely that rib-hump reassertion involves mainly rib changes in the transverse plane, as the convex ribs rotate posteriorly to produce the rib-hump. RSA measurement will not reveal these transverse plane changes and these findings for RSAs do not exclude a role for the thoracic cage in rib-hump reassertion or in curve progression.

Changes in segmental ATI are still significant if the effects of changes in either segmental vertebral tilt or translation or rotation are removed from the analysis (repeated measures MANOVA). In other words, as far as can be determined from the radiographic measurements, changes in segmental ATI have a significant component that is separate from changes in spinal morphology as measured from radiographs in this study. This may be because forces causing rib cage deformity are incompletely transmitted to the spine across costo-vertebral articulations.

No linear relationship was found between changes in segmental ATI and segmental vertebral rotation (Table 19, page 112), which casts doubt on the importance of de-rotating the spine to achieve back surface correction. Similar findings were found for the Harrington compression system[106]. Correction of vertebral rotation does not appear to be the mechanism by which rib-hump correction is attained in CDI[167,376]. Humke[146] suggested that Harrington instrumentation corrects rib-hump through correction of vertebral transposition.

Alternatively, it may be artificial to argue the importance of vertebral correction in one plane over the correction obtained in another plane in producing ATI correction. The joints, ligaments and muscles of the spine mean that all movements of vertebral bodies are coupled - it is not possible to have pure tilt without simultaneous vertebral rotation and translation. The apparent importance of movement in any one plane to bring about rib-hump correction may only be a reflection of the accuracy of the data that is obtained on PA spinal films, with poor reproducibility for rotation measurements but good reproducibility for measurement of vertebral tilt and vertebral translation (relative to the quantities measured).

Roaf[288] noted the poor relationship between correction of the lateral curve and correction of rib-hump deformity. Weatherley[364] presented prospective follow-up data showing progression of rib-hump deformity in some cases of AIS after Harrington instrumentation without changes in Cobb angle or apical vertebral rotation. Their observations can be explained by the findings reported above - neither the Cobb angle nor the vertebral rotation correlated with rib-hump reassertion. Moreover, a component of rib-hump reassertion is independent of vertebral changes.

It is implicit in the findings presented above that there is no radiographic substitute for the measurement of back shape to assess results of surgery and for patient information. This is time consuming so consideration should also be given to the measurement of vertebral translation. These data demonstrate that segmental vertebral translation is the best radiographic indicator of ATI, and especially of loss of correction in radiographic and surface measurements during follow-up. The measurement of *apical* vertebral rotation with a Perdriolle template, especially in the post-operative situation, is probably not fruitful. Although more sophisticated techniques such as 3-D reconstructions can detect the 'small but significant' changes in vertebral rotation with surgery[168], they demand special skills, equipment, time and higher cost.

Relationships between radiographic segmental measurements

Changes in segmental vertebral tilt and translation are related (Table 21, page 115), apparent on inspection of Figure 23, page 105 and Figure 25, page 106. Repeated measures MANOVA reveals that the changes in one are accounted for by the changes in the other, so it would seem likely that changes in vertebral tilt cannot occur without changes in vertebral translation and vice versa. The relationship for each of tilt and translation with vertebral rotation is weak and mainly exists during the post-operative follow-up period from 8 weeks to 2-year follow-up, which suggests that changes in vertebral orientation produced by surgery from pre-operative to 8-week follow-up are mainly in frontal plane tilt and translation while changes in the vertebral column after surgery (presumably adaptive to tensions induced by surgery in the tissue) are more closely linked in all planes (frontal and sagittal plane tilt, translation and rotation).

There is no significant linear relationship between changes in segmental vertebral tilt and translation and convex or concave RSAs. RSAs do not change significantly between assessments which may be because (i) there is poor linkage between vertebral and rib movements as costo-vertebral attachments are mobile or (ii) rib movements do not occur in the frontal plane but may be occurring in the transverse plane where they are not readily measured by radiographs but may be measured by ultrasound techniques[265].

Effect of USS on FPB

King-Moe type II curves (n=14)

USS results in frontal balance moving to the left from pre-operative to 8 weeks post-operative follow-up (Table 11, page 99, P=0.048, Spearman correlation coefficient). This change in frontal balance correlates with pre-operative thoracic apical vertebral rotation (P=0.01, Spearman correlation coefficient). From 8 weeks to 2-year follow-up, FPB moves back to the right (P=0.005), improving the magnitude of C7-S1 offset (P=0.007), so that FPB by 2 years is not different from pre-operative FPB (P=0.78). The improvement in frontal balance in patients with USS from 8 weeks to 2 years may be due to changes in the lumbar spine because the change in L1, L2, L3 and L5 tilt in the sagittal plane correlates with the change in frontal balance (P=0.035, P=0.007, P=0.003, P=0.006 respectively). As FPB moves back to the right, then L1, L2 and L3 become more vertical from a backwards tilted position and L5 becomes tilted more forward so that a significant increase in lordosis occurs (Table 11, page 99). Perhaps the thoracic derotation manoeuvre used with CDI results in rotation being transmitted to the lumbar spine which somehow inhibits correction of frontal balance through changes in the lumbar spine. The segmental translation manoeuvre used with USS still allows frontal balance correction by the lumbar spine.

King-Moe type III curves (n=11)

No significant changes in FPB are seen in King-Moe Type III curves (Table 12, page 100).

Effect of surgery on the sagittal plane deformity

Kyphosis and lordosis are reduced from pre-operative to 8-week follow-up (Table 10, page 98). On further follow-up to 2 years, both kyphosis and lordosis increase such that by 2 years there is not a significant difference when compared with pre-operative measurements. A similar pattern is observed for King-Moe Type II and Type III curves.

Sagittal plane balance changed from pre-operative to 8-week assessment (Table 10, page 98), such that the patients leaned forwards more. This could reflect the decrease in lordosis seen during the same period and the effect may be due to surgery causing pain or impaired paraspinal muscle function as a result of the surgical approach. By 2-year follow-up the sagittal plane balance is the same as at pre-operative assessment.

There was no change in segmental sagittal plane vertebral tilt when all assessments were considered in the analysis (P=NS, repeated measures MANOVA), and segmental sagittal plane vertebral tilt was not found to be a covariate for changes in segmental ATI, frontal plane vertebral tilt or translation .

Pre-operative factors which predict the outcome of surgery

Pre-operative factors which predict the percentage correction of maximum ATI

The strongest predictive factor of percentage correction of maximum ATI at 2 years is the pre-operative tilt of L1 (Table 23, page 117). As tilt of L1 increases, so a greater percentage correction of maximum ATI can be expected (Figure 28, page 109). L1 tilt accounts for approximately 28% of the variation in percentage correction of maximum ATI (Table 23, R^2 column). Pre-operative L1 tilt correlates with each of pre-operative Cobb angle (P=0.002), the number of instrumented levels (P<0.001), and the pre-operative maximum angle of trunk inclination (P<0.001, Spearman rank correlation). In the latter connection, a link between lumbar tilt and rib-hump in pre-operative patients was first noted by Wythers et al[390].

The second factor that predicts percentage correction of maximum ATI is the pre-operative concave RSA of the 5th rib. Approximately 40% of the variation in percentage correction of maximum ATI at 2 years is accounted for by L1 tilt and concave 5th RSA

(Table 23, page 117 and Figure 29, page 119). Patients with less droop of the 5th concave rib and greater tilt of L1 can expect a greater percentage of correction of maximum ATI at 2 years.

If the analysis is repeated using correction of maximum ATI by 2 years follow-up as an outcome measure rather than the percentage correction, then tilt of L1 is selected first in the analysis (R^2=0.268), followed by pre-operative convex RSA of 4th rib (P=0.020, R^2=0.418). That a convex rib factor is selected rather than a concave rib factor indicates that rib factors as a whole are of importance. Other factors with almost the same P values in the analysis were: pre-operative concave RSA of 2nd rib (P=0.022); concave RSA of 4th rib (P=0.021); concave RSA of 5th rib (P=0.021); convex RSA of 4th rib (P=0.020); ATI at level 1 (P=0.022) and ATI at level 7 (P=0.041).

The strongest predictive factor of percentage *reassertion* of maximum ATI is pre-operative concave 9th RSA (Table 24, page 118). This accounts for approximately 35% of the variation in rib-hump reassertion seen in these patients. Patients with less droop of the 9th concave rib can expect less rib-hump reassertion. The variables subsequently selected by the MLRA all related to the lumbar spine, namely rotation of L4, rotation of L2 and tilt of L4 (Table 24). When all factors are taken together they account for approximately 73% of the variation in rib-hump reassertion. These findings imply that thoracic cage factors and factors in the lumbar spine influence rib-hump reassertion. Further analysis did not reveal any clear relationship between pre-operative lumbar vertebral rotations or tilts and the magnitude of rib-hump reassertion (Spearman rank correlation).

I postulate that surgery could induce tensions in ligaments and soft tissues with spinal attachments and that these tensions could produce changes in body morphometry by acting on unfused vertebrae and the thoracic cage. Such tensions could produce rib-hump reassertion which would be most marked during the early post-operative period, as observed in these patients (Figure 19, page 101). To explore this postulate, differences were calculated for pre-operative and 8-week measurements which were taken to indicate the differences caused by surgery. These variables were entered into MLRA for rib-hump reassertion (Table 25, page 120). When pre-operative variables and variables for change as a result of surgery were entered into the analysis, then the concave 9th RSA was the strongest predictive factor and a better predictor than the change in rotation of T6 from pre-operative to 8-week follow-up (Table 25). The second factor entered was change in ATI at the 8th back surface level from pre-operative to 8-week follow-up, which replaces the lumbar factors in Table 24, page 118. In addition, the concave 9th RSA correlates with both the percentage change in maximum ATI from pre-operative assessment to 8 weeks follow-up (ρ=-0.540, P=0.002) and with percentage reassertion of maximum ATI (ρ=-0.532, P=0.004), and the percentage change in maximum ATI from pre-operative to 8 weeks and from 8-week to 2 years are also correlated (ρ=0.488, P=0.010, Spearman rank correlations). Taken as a whole, these findings would be consistent with the concave 9th RSA as a marker of potential tensions induced in the thoracic cage as a result of surgery which produce rib-hump reassertion, along with lumbar ATI changes as markers of lumbar tensions. For reasons which are unclear, the lumbar surface deformity does not reassert (Figure 19, page 101) perhaps owing to the lack of rib lever arms upon which induced tensions can act.

Pre-operative factors which predict the percentage correction of Cobb angle and correction of Cobb angle

The results of these two analyses (Table 26) were similar, with tilt of L1 being selected first, then ATI at the 6th or 7th level down the spine respectively. We may consider the result of surgery in terms of Cobb angle as being made up of two components, namely, the initial correction achieved with surgery minus any correction that is lost with time. The recurrence of deformity is not as evident for Cobb angle measurements after surgery as it is for ATI measurements (Table 10, page 98). L1 tilt is the only variable selected as a predictor of correction from pre-operative to 8-week assessment so it would seem reasonable that L1 tilt increases with those curve properties that prevent surgical correction. The second component, percentage correction lost with time, is predicted by T3 rotation but the relationship is weak (R^2=0.18). Cobb angle correction lost with follow-up is predicted by lumbar spine factors, analogous to the some of the factors found for reassertion of ATI.

Pre-operative factors which predict AVT and the percentage correction of AVT

A combination of spine (tilt of L2, L1, T9) and rib (convex 5th RSA) and back surface (ATI at level 7 down the back) were selected in the 2-year analysis of predictors of the percentage correction of AVT and correction of AVT (*Pre-operative factors which predict the percentage correction of maximum vertebral translation at 2-year follow-up*, page 121). The effect of surgery on AVT and percentage correction of AVT as measured by changes from pre-operative to 8-week assessments was predicted by tilt of L1 and whether anterior surgery was performed or not respectively. The extent of loss of AVT correction from 8 weeks to 2-year follow-up was predicted by the 2nd convex RSA. In general terms, it would appear that spine factors more strongly influence correction of deformity seen from pre-operative to 8 weeks assessment while rib factors more strongly influence the loss of deformity correction in terms of AVT.

Taking all the above into account, in broad terms the initial correction of deformity is, in terms of the variables I have assessed, more strongly influenced by spine factors, most especially evidenced by the tilt of L1. Subsequent loss of correction of deformity seen in all outcome measures from 8-week assessment to 2-year assessment is more strongly influenced by rib factors, and by association back surface parameters, in conjunction with some contribution by factors in the lumbar spine.

To some extent it is artificial to talk about these variables as independent of each other, as they are all inter-related by virtue of being measurements taken on the same individual. The usefulness of each of the variables discussed is in some part dependent on our ability to measure them (hence vertebral rotation being difficult to measure is not found to be a significant factor) and our ability to perceive them - I would expect variables pertaining to surface deformity of greater importance to patients than radiological measurements.

Analysis of outcome by King-Moe type

Review of results by King types II and III (Table 11 and Table 12, pages 99 and 100) does not reveal any obvious differences in terms of correction of spinal or surface parameters achieved with surgery. King type was not selected as a predictor of the surgical results when this group of patients was analysed as a whole (see *Pre-operative factors which predict the outcome of surgery*, page 116).

Reanalysis of the data for each of King-Moe Type II and III curves separately did not reveal any significant differences in results for either plots of segmental measurements by assessment or RMMANOVA.

Significance for surgical treatment - rib interventions

The findings for the 5th and 9th pre-operative concave rib-spine angles imply a role for the thoracic cage in determining correction of surface deformity achieved with surgery. Rib factors have also been implicated in a 5-year study of surgical treatment of IIS[270], see Section I. Drooping concave ribs may indicate a more rigid thoracic cage that acts to (i) brace the spine in position and (ii) return it towards its original shape after surgery. The observation that rib-hump reassertion occurs mainly in the first post-operative year and has a component independent of vertebral changes is consistent with the interpretation that surgery has induced tensions in the rib cage which produce the recurrence of deformity as the viscoelastic properties of vertebro-costal ligaments are overcome. These findings suggest the use of costoplasty to (i) reduce thoracic cage resistance to correcting forces and (ii) decrease rib-hump reassertion.

Costoplasty has been advocated to improve spinal correction[330]. Gaines advocated rib osteotomy after observing no correlation between rib-hump correction and vertebral derotation using the Harrington compression system[106]. Mann et al[194] reported the use of concave costoplasty with Harrington distraction instrumentation and sub-laminar wiring in patients with less flexible thoracic AIS. Costoplasty increased Cobb angle correction compared with that expected from side bending films but resulted in increased pulmonary morbidity when compared with patients with flexible curves not treated with costoplasty[194]. Barrett et al showed convex costoplasty is more effective when performed at the time of surgery[21], which is consistent with the rib cage acting as a spinal brace, and it produced satisfactory results[245,332].

Conclusions

Implantation of USS in 27 patients with right thoracic AIS produced a 41% correction of Cobb angle, 23% correction of AVR and a 48% correction of AVT, similar to results for other modern instrumentation systems[146,151,163,168,266,280,301,376]. Frontal plane balance moved leftwards by 8-week follow-up but was restored by 2 years. Maximum ATI was corrected by 42% by 8-week follow-up but half of this was lost by 2 years (rib-hump reassertion). Ease and familiarity of use will likely determine surgeon preference for any one instrumentation system.

Segmental radiographic and segmental surface measurements

Rib-hump reassertion occurs mainly from 8 weeks to 1 year and its magnitude is not related to age or Risser stage which suggests that growth and the crankshaft phenomenon[88] is not the cause. Significant changes occur in segmental vertebral tilt (P=0.012) and translation (P=0.004) from 8 weeks to 1 year. Segmental translation alone changes from 1-year to 2-year follow-up (P<0.001). There is a linear relationship between *changes in segmental* ATI and *changes in segmental* vertebral tilt from pre-operative to 8 weeks (P=0.012). There is a linear relationship between *changes in segmental* ATI and *changes in segmental* vertebral translation when considering the post-operative data (8-week, 1-year and 2-year follow-up) (P=0.001). However changes in segmental ATI are still significant if changes in vertebral translation are allowed for (P=0.02). Rib-hump reassertion is not explained by changes in spine radiographic measurements during 2-year follow-up.

No change occurred in segmental vertebral rotation between any assessments probably because errors with use of the Perdriolle template are large when compared with the small changes in rotation being measured in the instrumented spine, especially at levels other than the apex.

The acquisition of multiple level surface data is recommended to assess the results of spinal surgery for scoliosis and it is suggested that vertebral translation is a sensitive measure of spine deformity.

Factors predicting results of surgery at 2 years

Pre-operative tilt of L1 and the rib spinal angle of the 5^{th} concave rib account for approximately 40% of the variation in percentage correction of maximum ATI. It is concluded that spine and rib factors are important in determining surface correction of surgery. Further work is required to evaluate tilt of L1 and concave RSAs as predictors of surgical results, and their possible usefulness in curve classification.

One approach to improve the surface results of surgery would be through addressing mechanisms of rib-hump reassertion possibly using finite element analysis. The findings reported here suggest rib-hump reassertion is due to elastic forces stored in the rib cage deformed with surgery. The thoracic cage unwinds on the spine especially during the first post-operative year. It is suggested this mechanism is best addressed surgically by concave or convex costoplasty.

SECTION IIii: CHANGES IN SURFACE AND RADIOGRAPHIC DEFORMITY AFTER ANTERIOR UNIVERSAL SPINE SYSTEM FOR THORACOLUMBAR ADOLESCENT IDIOPATHIC SCOLIOSIS

Overview

I performed an analysis of pre-operative, 8-week and 1-year data from patients with AIS treated with anterior USS instrumentation with the aim of comparing these results with those obtained from Section IIi.

20 patients were treated with anterior USS instrumentation between 1994 and 1996. 17 had complete prospective back surface and radiological appraisal. Of these, data from the 10 patients who had thoracolumbar curves were analysed in more detail.

Rib-hump reassertion at 10 back surface levels occurred between 8 weeks and 1 year and correlated with changes in vertebral translation at 10 equivalent vertebral levels ($P<0.001$ repeated measures MANOVA). Significant changes in kyphosis, lordosis, sagittal plane balance and segmental vertebral rotation were found which were not found for patients with thoracic curves treated by posterior instrumentation (see Section IIi).

Both spine and rib factors are implicated in the prediction of percentage correction of maximum ATI by 1 year.

Introduction

There is evidence that thoracolumbar curves differ from thoracic curves in natural history, response to treatment and surface deformity. Thoracolumbar curves are half as likely to progress as thoracic curves[85,326] and progression during adulthood is less common and less severe[31,69,366]. Anterior instrumentation for thoracolumbar and lumbar curves may produce greater correction of deformity while sparing motion segments when compared with posterior instrumentation[185,305], but this is a matter of dispute when considering modern instrumentation systems[28,138]. Few authors have published results in terms of surface correction[68,135]. Data from this centre on 16 patients with thoracolumbar curves treated with anterior Zielke VDS showed an initial 63% correction in maximum ATI[68], with no significant loss of back surface correction on follow-up. Patients who were treated for AIS using anterior USS were studied using the same methods as described in Section IIi. There were insufficient numbers for 2-year follow-up but, as there was little change seen between

1-year and 2-year assessments for patients with thoracic curves, I felt it was acceptable to present 1 year results.

Material and Methods

Patients

20 patients with AIS[124] treated using anterior USS instrumentation were recruited between 1994 and 1996. Of these, one patient had incomplete surface measurements. Two patients did not have lateral radiographic films. This left 17 patients with complete surface and radiographic records for analysis. Of these, 4 had thoracic curves (2 left sided and 2 right sided), 3 had lumbar curves (2 left sided and 1 right sided), and 10 had thoracolumbar curves (5 left sided and 5 right sided). There were insufficient numbers to make a meaningful analysis of the thoracic and lumbar curves. Data from patients with thoracolumbar curves are presented below.

Operative procedure

Anterior USS was implanted according to the manufacturer's instructions[3]. A thoracolumbar approach was used to the convex side. After removal of inter-vertebral discs and bone grafting, a rod contoured appropriately was applied to the convex side, held by screws into the vertebral bodies.

Patient assessment

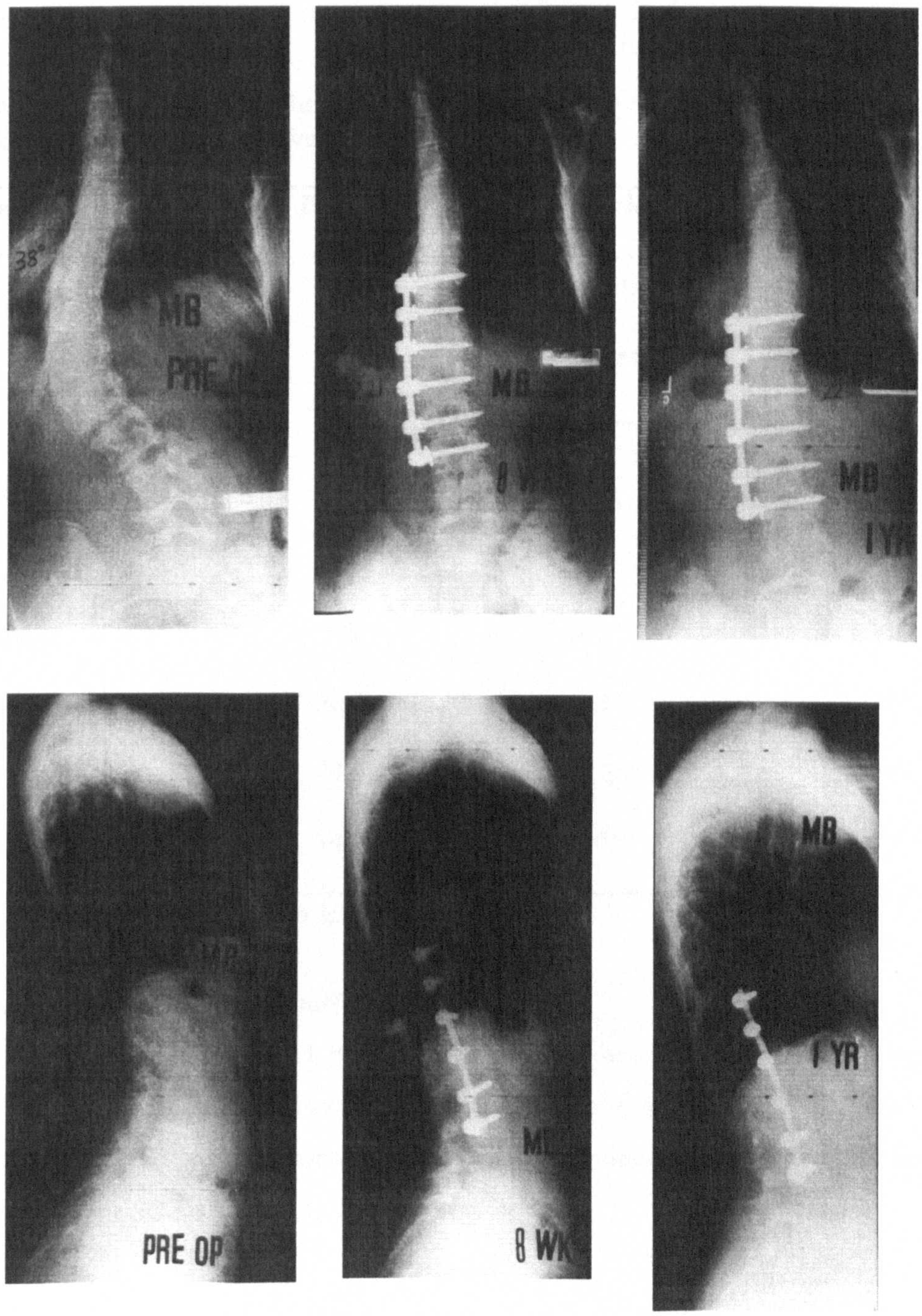
See General Methods section, page 32.

Data analysis

See Data analysis, page 96, Section IIi.

Results

8 females (4 left sided curves, 4 right sided curves) and 2 males had anterior USS implanted for thoracolumbar AIS. The mean age at operation was 17.3 years (13.0 to 25.6 years) and the mean Risser stage was 3.9 (0-5). Between 4 and 6 vertebrae were instrumented (mean=5.4). Mean Cobb angle correction on side-bending films was 65% (38%-91%). A typical example of the radiographic results is shown in Figure 30.



	preop	8 weeks	1 year
Cobb	64°	21°	22°
AVR	38°	4°	3°
kyphosis	14°	25°	29°
lordosis	64°	46°	53°
SPB (cm)	-0.2	+2.3	+0.5

Figure 30. Example of anterior USS instrumentation, pre- and post-operative films for patient MB.

Results from pre-operative to 1-year follow-up are summarised in Table 27 (Wilcoxon signed-ranks test).

Table 27. Surface and radiographic results of surgery: Mean findings for anterior USS in thoracolumbar curves (10 patients).

Measure	Pre-op	8 weeks	1 year
Cobb angle (degrees)	53.1	18.4**	21.5**†
AVR (degrees)	30.5	10.2**	11.4**
AVT (cm)	4.8	1.3**	1.5**
FPB (cm)	1.0	0.1	-0.1
FPB (cm)(abs)	2.8	3.7	2.3†
SPB (cm)	1.3	3.2**	1.2††
Kyphosis (degrees)	26.7	36.6**	35.4**
Lordosis (degrees)	49.6	33.2**	40.5*†
Max ATI (degrees)	14.0	8.0**	7.4**

See Table 10, page 98 for abbreviations.

Analysis of segmental back surface measurements

The changes in segmental ATI between assessments shown in Figure 31 are significant (P<0.001, Table 28). The statistically significant surgical correction of deformity between pre-operative and 8-week assessment is followed by significant rib-hump reassertion by 1-year assessment (RMMANOVA, Table 28).

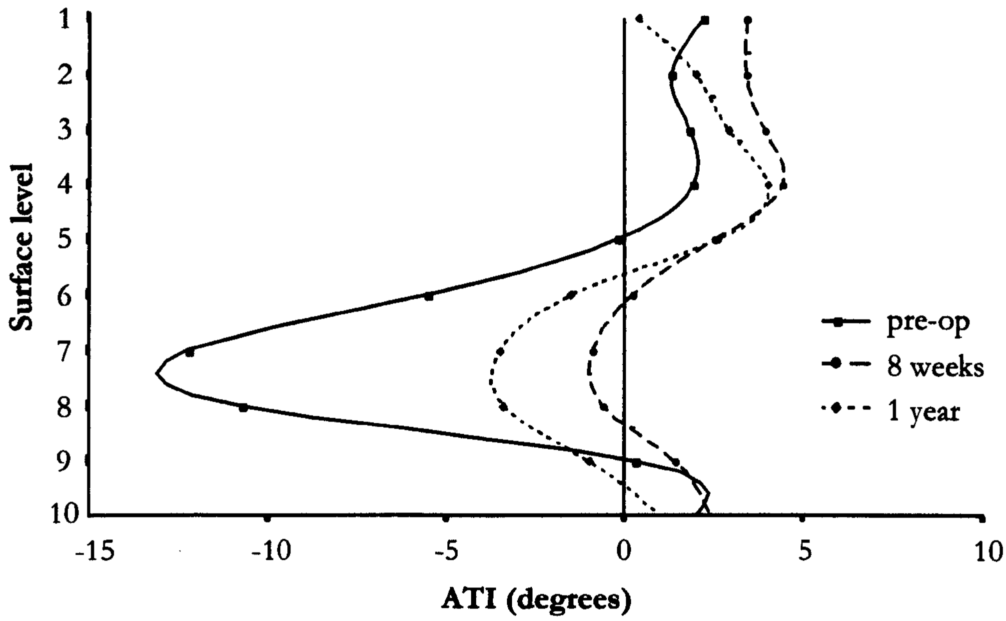


Figure 31. Mean ATI plotted against surface level for patients treated using anterior USS (n=10).

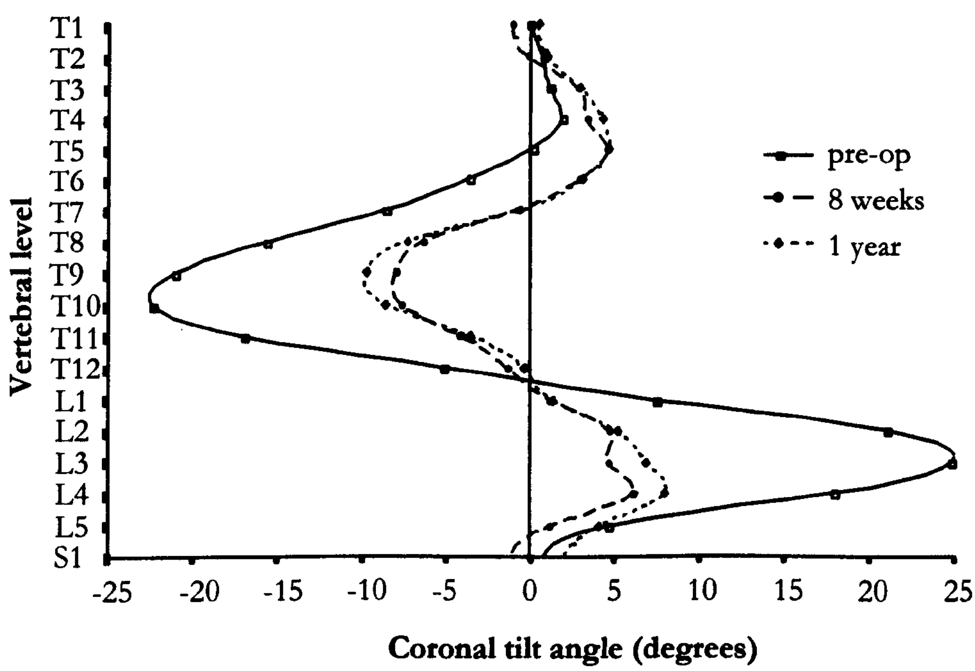


Figure 32. Mean vertebral tilt plotted against vertebral level (anterior USS, n=10).

Table 28. Segmental ATI at pre-operative, 8-week and 1-year assessments. Repeated measures multivariate analysis of variance for all assessments and then for each assessment interval separately.

Source of variation	df	Sums of Squares	Mean Square	F	P
ATI pre/8 weeks/1 yr	2	774	387	19	<0.001
Within+Residual	18	363	20	_	_
ATI pre - 8 weeks	1	768	768	31	<0.001
Within+Residual	9	221	25	_	_
ATI 8 weeks - 1 year	1	138	138	8.0	0.020
Within+Residual	9	154	17	_	_

For abbreviations see Table 13, page 98.

Analysis of segmental vertebral tilt, rotation and translation

Graphs of vertebral level by each of vertebral tilt, vertebral rotation and vertebral translation for three assessments are shown in Figure 32, Figure 33 and Figure 34 respectively. A similar pattern is observed in all three, namely an initial surgical correction of radiographic deformity which is partially lost on follow-up. Significant changes occurred in segmental vertebral tilt (P=0.01), rotation (P=0.002) and translation (P<0.001, RMMANOVA) between assessments.

When only pre-operative and 8-week assessments were considered in the analysis, then changes in segmental vertebral rotation (P=0.002) and segmental vertebral translation (P=< 0.001, RMMANOVA) were statistically significant. The change in segmental vertebral tilt from pre-operative to 8-week follow-up was not statistically significant (P=0.094, RMMANOVA). When 8-week and 1-year assessments were considered in the analysis, then the change in segmental vertebral tilt was statistically significant (P=0.017, RMMANOVA). The change in segmental vertebral rotation (P=0.541, RMMANOVA) and segmental vertebral translation (P=0.175, RMMANOVA) from 8-week to 1-year follow-up were not statistically significant.

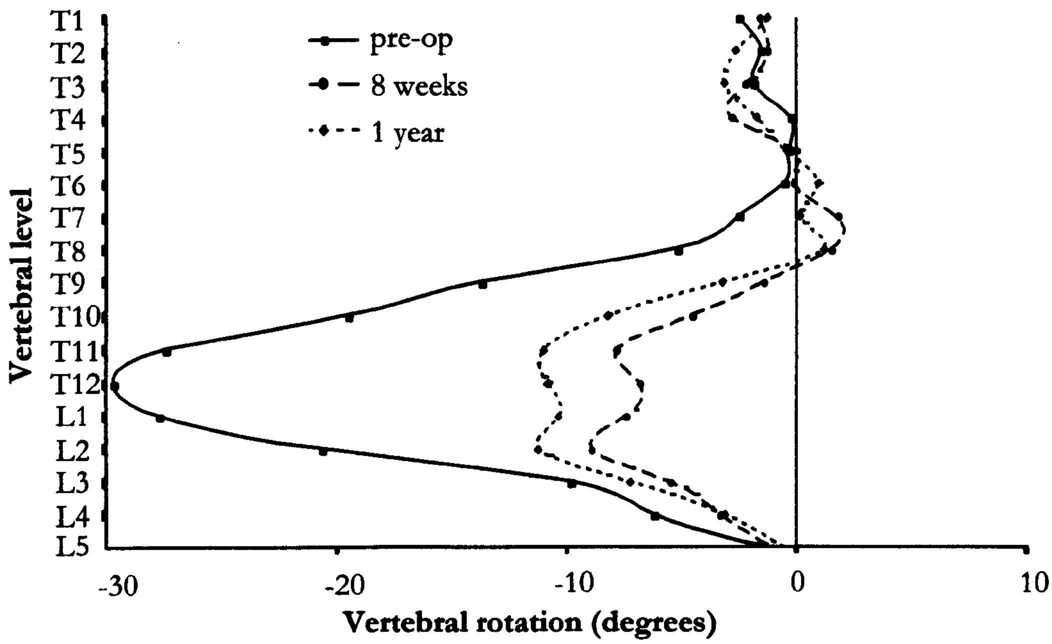


Figure 33. Mean vertebral rotation plotted against vertebral level (anterior USS, n=10).

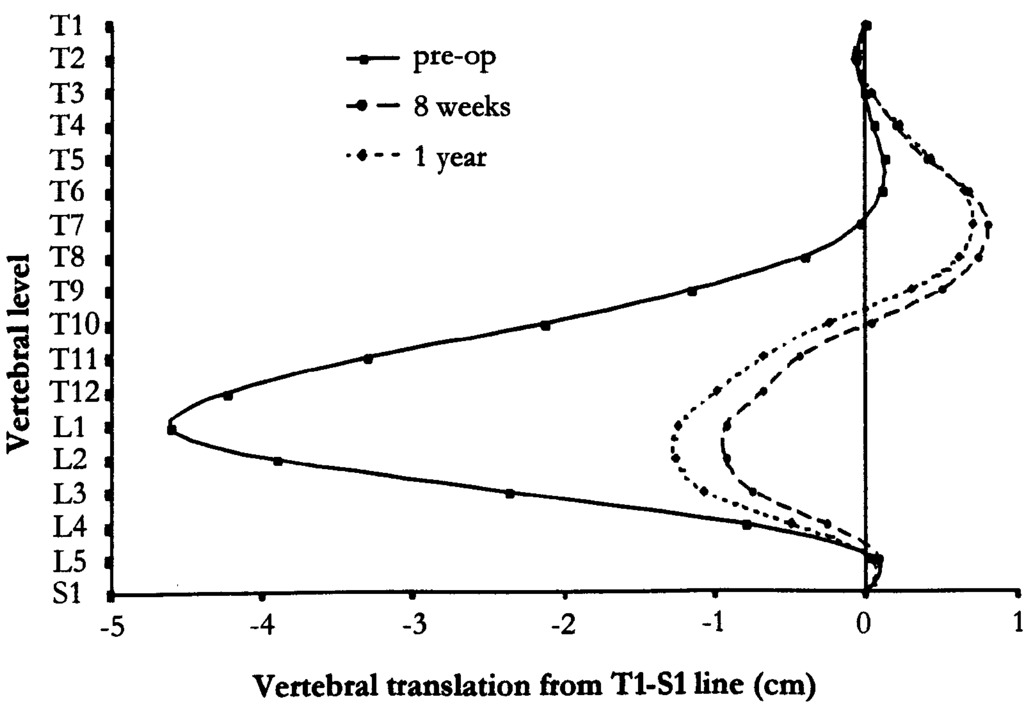


Figure 34. Mean vertebral translation plotted against vertebral level (anterior USS, n=10).

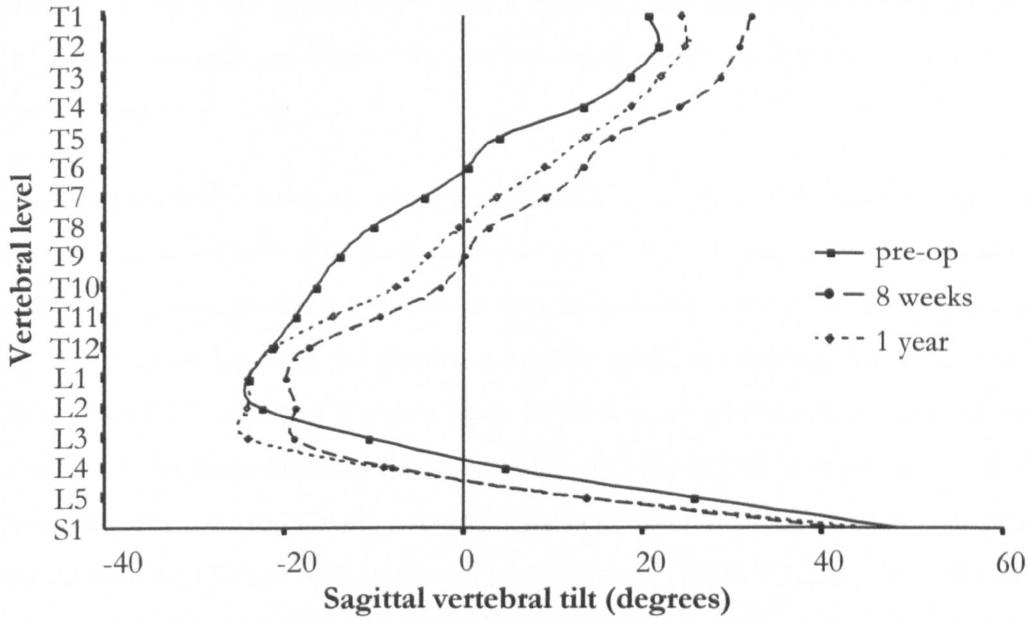


Figure 35. Mean sagittal vertebral tilt plotted against vertebral level (anterior USS, n=10).

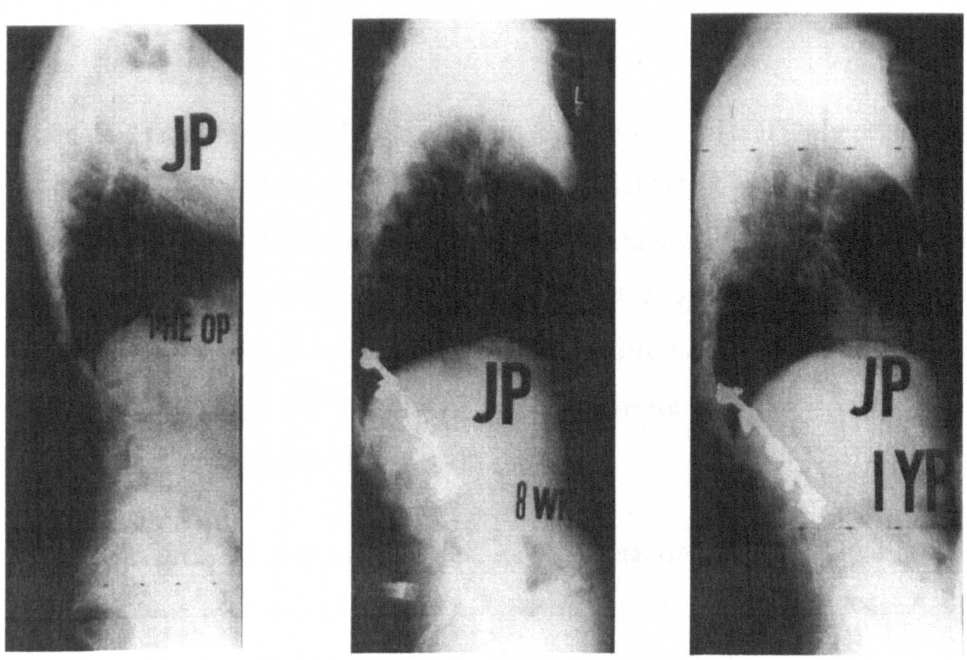


Figure 36. Severe kyphosis developing at the upper end of the instrumentation following anterior USS.

Analysis of sagittal plane segmental vertebral tilt

The changes in segmental sagittal vertebral tilt between pre-operative and 8-week and 8-week and 1-year assessments (Figure 35) are statistically significant ($P<0.001$ and $P=0.002$ respectively, RMMANOVA).

Inspection of Figure 35 reveals that the tilt of vertebrae from T1 to T11 increases (becomes more inclined in an anterior direction) from pre-operative to 8-week assessment and then decreases by the 1-year assessment but not to the pre-operative values. The thoracic spine is moving *en bloc*. From L3 to S1 the vertebrae become more inclined backwards with time. The T12, L1 and L2 vertebrae become more inclined in an anterior direction from pre-operative to 8-week assessments and then become more posteriorly inclined from 8 weeks to 1 year, with the inclination being restored to pre-operative values. The changes in these vertebrae mirror the changes seen in sagittal plane balance (Table 27, page 139). There is a linear relationship between changes in sagittal balance and changes in sagittal vertebral tilt at L1 ($P=0.003$, RMMANOVA).

Inspection of post-operative radiographs revealed that five patients developed a progressive kyphosis at the upper end of the instrumentation to varying degrees, as demonstrated in Figure 36. Two patients were offered further surgery to correct their sagittal spine alignment.

Pre-operative kyphosis was found to predict the difference in sagittal tilt between the upper instrumented vertebra and the vertebra above it ($P=0.0004$, $R^2=0.64$, MLRA) by 1-year follow-up. It appeared from the lateral radiographs that the contouring of the anterior USS rod was inappropriate in some cases because account was not taken of the change in sagittal profile from kyphosis to lordosis across the thoracolumbar junction. Patients with greater pre-operative kyphosis were less able to tolerate this and appear at risk of developing progressive kyphotic deformities.

Analysis of concave and convex rib spinal angles measured from T1 to T12

Graphs of concave and convex rib spinal angles (RSAs) by vertebral level for each assessment are shown in Figure 37. Both segmental convex and concave RSAs change between assessments ($P=0.024$ and $P<0.001$ respectively, RMMANOVA), with the changes occur predominantly between pre-operative and 8-week assessments ($P=0.016$ and $P=0.002$ respectively, RMMANOVA). The changes in convex and concave RSAs from 8-

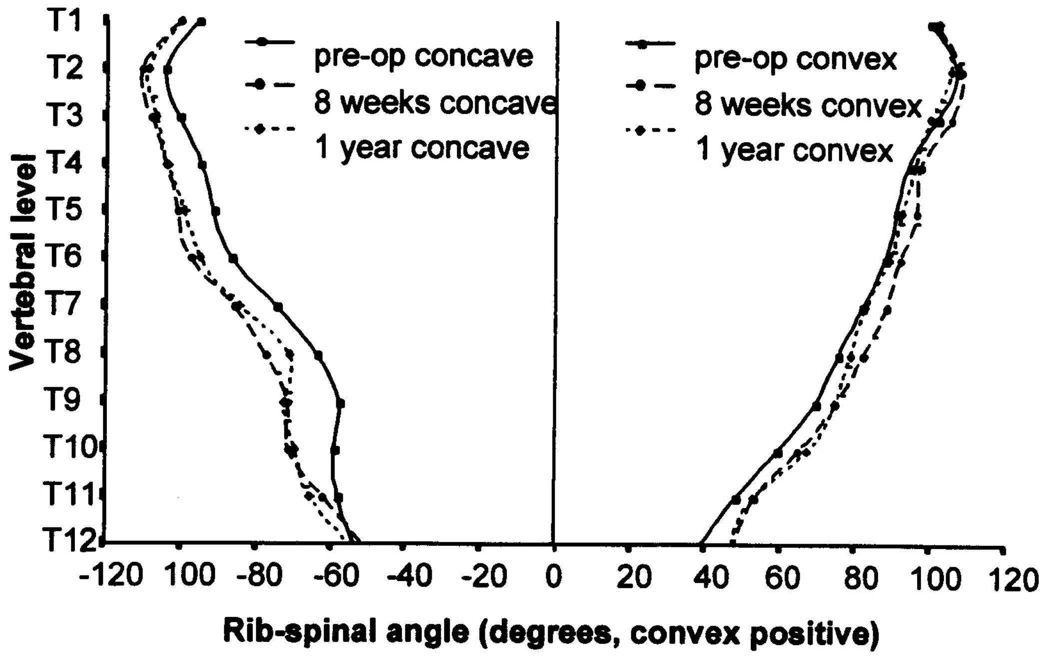


Figure 37. Concave & convex RSA plotted against vertebral level (anterior USS, n=10).

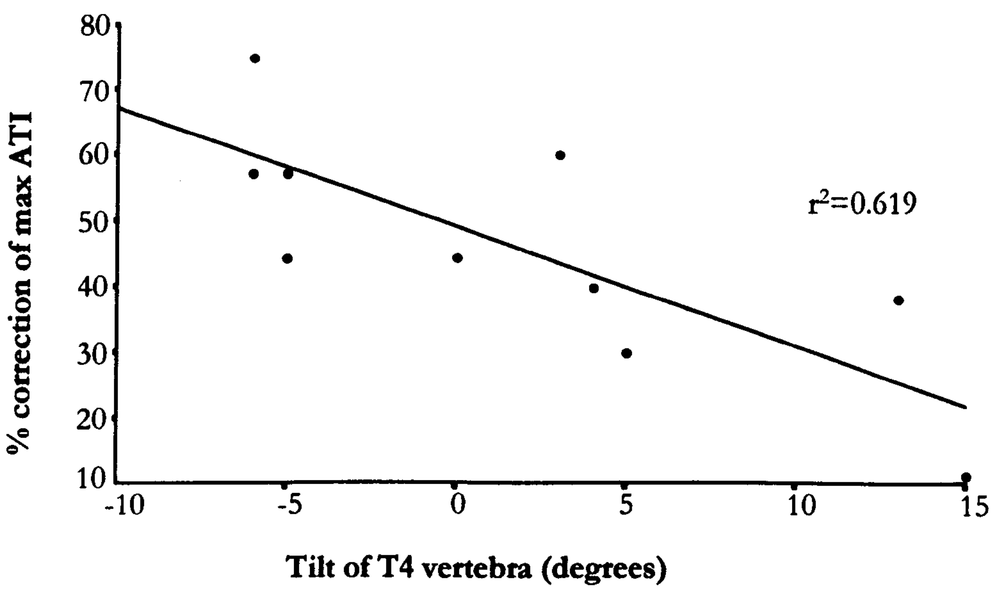


Figure 38. Percentage correction of maximum ATI at 1 year plotted against pre-operative tilt of T4 (n=10).

week to 1-year follow-up were not statistically significant (P=0.166 and P=0.309 respectively, RMMANOVA). The analysis was performed for 11 ribs as 2 patients did not have 12th ribs.

Relationship between changes in segmental ATIs and changes in segmental vertebral tilt, sagittal vertebral tilt, rotation, translation and rib-spine angles

There is a linear relationship between the changes in segmental ATI and the changes in segmental vertebral translation at vertebral levels corresponding to surface levels when pre-operative, 8-week and 1-year assessments are considered (P<0.001), but changes in segmental ATI are still significant once the effect of vertebral translation has been allowed for (P=0.025, RMMANOVA, Table 29). This linear relationship between segmental ATI and vertebral translation is statistically significant for analysis of pre-operative and 8-week assessments and 8-week and 1-year assessments (Table 29).

Table 29. Segmental ATI at pre-operative, 8-week and 1-year assessments. Repeated measures MANOVA incorporating segmental vertebral translation as a covariates for all assessments and for each assessment interval separately.

Covariate	Source of variation	df	Sums of Squares	Mean Square	F	P
	ATI pre-op/8-week/1-year	2	80	40	4.6	0.025
translation	regression	1	214	214	25	<0.001
	Within+Residual	7	149	8.8	_	_
	ATI pre - 8 weeks	1	0.97	0.97	0.1	0.795
translation	regression	1	114	114	8.6	0.019
	Within+Residual	8	107	13	_	_
	ATI 8 weeks - 1 yr	1	35	35	6.0	0.040
translation	regression	1	107	107	18	0.003
	Within+Residual	8	47	5.9	_	_

See Table 13, page 103 for abbreviations.

No linear relationship was found between changes in segmental ATIs and changes in segmental vertebral tilt, sagittal vertebral tilt, rotation and concave and convex rib-spine angles when all assessments were considered in the analysis.

Relationships between segmental vertebral tilt, sagittal tilt, rotation, translation and rib-spine angles

No significant linear relationships were found between the above segmental variables for these 10 patients.

Pre-operative factors which predict the outcome of surgery

Pre-operative factors which predict the percentage correction of maximum ATI at 1-year follow-up

Pre-operative tilt of T4 most strongly predicts the percentage correction of maximum ATI at 1 year (MLRA, Table 30). The scattergraph of percentage correction of maximum ATI at 1 year against pre-operative tilt of T4 is presented in Figure 38. This scattergraph shows that patients with a 'negative' tilt of T4 have more correction of the rib-hump with surgery. The data for these patients has been converted to refer to side as concave or convex, as half had left sided curve and half had right sided curves. In this context, a 'negative' tilt means that the transverse axis of the vertebra is inclined such that the convex side is cranial and vice versa (Figure 39). Patients who have a compensatory thoracic curve above the thoracolumbar curve and hence 'positive' tilts of T4 have less percentage correction of the rib-hump with surgery. When the effect of pre-operative tilt of T4 is removed from the analysis, the other variable significantly associated with outcome was the pre-operative convex RSA of 3rd rib (Table 30). Convex here refers to the side of the thoracolumbar curve and not the side of any compensatory thoracic curve (if there is a compensatory thoracic curve then this convex rib will in fact be on the concave side of the compensatory curve). As the tilt of T4 increases (more 'positive') and the droop of 3rd concave rib increases then less percentage correction of maximum ATI is observed (R^2=0.86 for the regression equation -0.02 × Tilt of T4 vertebra + 0.007 × convex 3rd RSA, Figure 40).

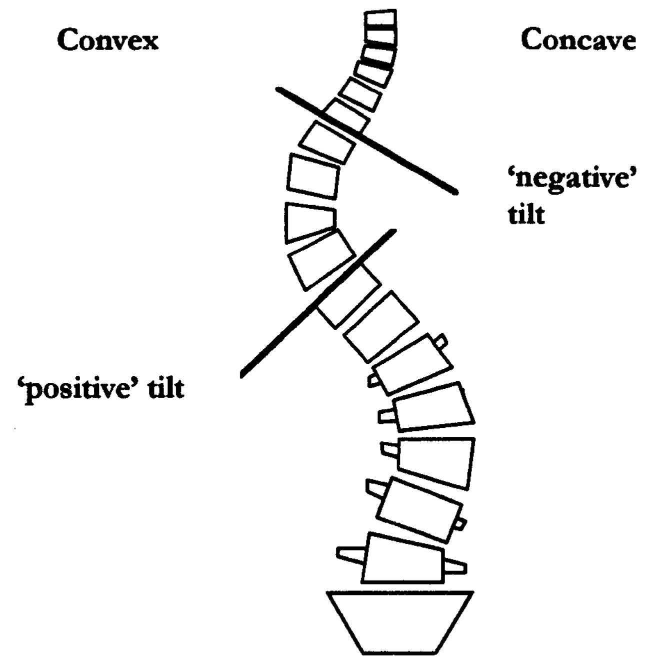


Figure 39. Illustration of positive and negative vertebral tilts.

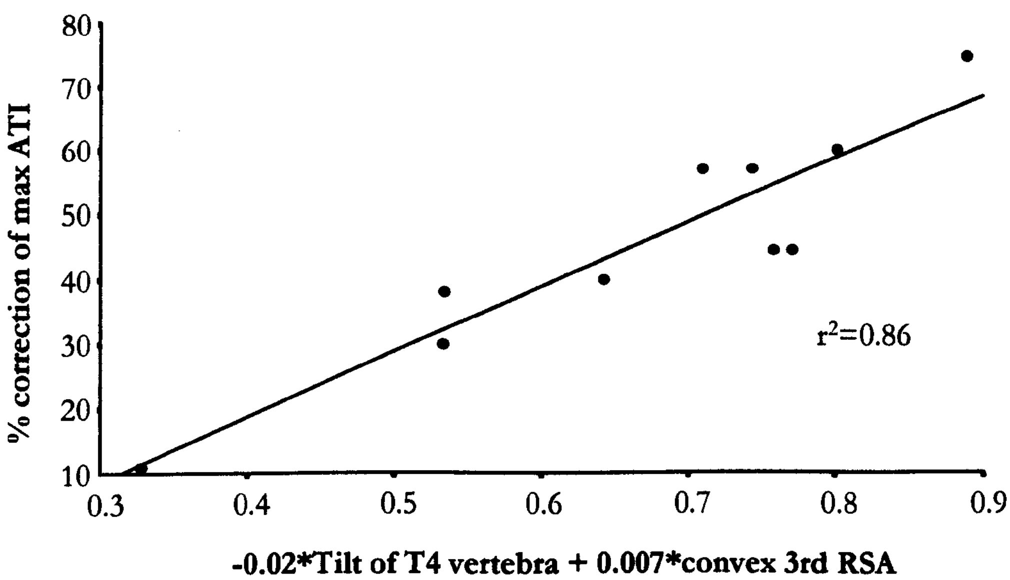


Figure 40. Regression equation for correction of maximum ATI (%) at 1 year (n=10).

Table 30. Factors predicting percentage correction of maximum ATI at 1-year follow-up. Stepwise multiple linear regression model for pre-operative variables with probability of F<0.05 to enter variable into analysis.

Step	Variable	Coefficient	SE	95% CI	R^2	T	P
1	Tilt of T4	-0.02	0.003	-0.017 to -0.023	0.62	-5.9	0.001
2	Convex 3rd RSA	0.01	0.002	0.005 to 0.009	0.86	3.4	0.011
_	Intercept	-0.21	0.21	analysis terminated			

For abbreviations see Table 23.

No factors were predictive of the percentage reassertion of maximum ATI from 8 weeks to 1-year follow-up.

Pre-operative factors which predict the percentage correction of Cobb angle at 1-year follow-up

Age at operation most strongly predicts the percentage correction of Cobb angle at 1 year (R^2=0.46, P=0.001), followed by ATI at level 9 (R^2=0.79, P=0.001) and vertebral translation of T9 (R^2=0.92, P=0.021, MLRA).

Pre-operative factors which predict the percentage reassertion of Cobb angle between 8-week and 1-year follow-up

The vertebral tilt at T4 (P<0.001, R^2=0.61) and the translation of T9 (P=0.004, R^2=0.89) predicted the percentage reassertion of Cobb angle by 1-year follow-up (MLRA).

Pre-operative factors which predict the percentage correction of apical vertebral translation at 1-year follow-up

The 6th convex RSA (P=0.006, R^2=0.44) and the translation of T7 (P=0.04, R^2=0.70) predicted the percentage correction of apical vertebral translation at 1-year follow-up (MLRA).

Pre-operative factors which predict the percentage correction of apical vertebral translation (AVT) from pre-operative to 8-week follow-up

No factors were selected for this analysis.

Pre-operative factors which predict the percentage correction of apical vertebral rotation (AVR) at 1-year follow-up

The 6th convex RSA ($P=0.006$, $R^2=0.40$) and the rotation of L2 ($P=0.01$, $R^2=0.77$) predicted the percentage correction of apical vertebral rotation (AVR) by 1-year follow-up (MLRA).

Complications

One patient required further surgery. One patient had Scheuermann's kyphosis associated with her AIS and also developed a kyphosis above the anterior USS instrumentation. Another patient developed a kyphosis above his instrumentation but declined to have further surgery (Figure 36, page 143).

Four of ten patients complained of backache at longest follow-up, usually associated with prolonged sitting or standing and one patient occasionally required analgesia for this. One patient had pre-operative backache.

Three patients noticed that their foot or leg on the side of the curve was warm after the operation and this effect persisted. These effects were likely due to surgical damage to the ipsilateral sympathetic trunk.

Discussion

These results for a small group of thoracolumbar curves instrumented with anterior USS indicate that the responses of these curves to surgery differ in several ways from the results presented in Section IIi for thoracic AIS instrumented with posterior USS. These differences are discussed below.

Results determined by radiographic measurements

Treatment of thoracolumbar curves with anterior USS results in a 60% correction of Cobb angle, a 63% correction of AVR and a 69% correction of AVT by 1-year follow-up (Table 27, page 139), after a mean of 5.4 vertebrae were instrumented. The corresponding percentage corrections for thoracic AIS instrumented by posterior USS were 41%, 23% and 48% respectively for Cobb angle, AVR and AVT, after a mean of 10 vertebrae were instrumented. I suggest that the radiographic deformity of thoracolumbar curves is corrected more than that of thoracic curves because (i) the thoracolumbar junction is less constrained by the ribs than the thoracic vertebrae so there may be less resistance to surgical correction and (ii) an anterior approach allows full release of anterior discs and ligaments.

The graphs for segmental vertebral tilt, rotation and translation (Figure 32, Figure 33 and Figure 34, pages 140 and 142) show that some loss of the correction achieved with surgery is seen between 8-week and 1-year follow-up. This is statistically significant for segmental vertebral tilt when these 10 patients are considered (P=0.017, RMMANOVA). The general pattern of changes is similar to those for thoracic curves (Figure 23, Figure 24 and Figure 25, pages 105 and 106). These findings suggest that the crankshaft phenomenon is not a cause of early reassertion of deformity because loss of deformity correction is found despite anterior instrumentation[27,28,341].

The reassertion of spinal deformity is greater for thoracolumbar AIS. Around 3° of Cobb angle and 1° AVR reassertion is seen from 8-week to 1-year follow-up for thoracolumbar curves, compared with 2° and 0.5° for thoracic curves over the same follow-up period. Several factors may explain this observation: (i) greater correction of spinal deformity induces greater reassertion of deformity (ii) the thoracolumbar region is more mobile than the thoracic spine so lower forces for a given reassertion of deformity are required (iii) fewer levels are instrumented in thoracolumbar curves allowing reassertion of deformity above and below the instrumentation.

Kyphosis was increased and lordosis was decreased after anterior USS implantation for thoracolumbar AIS while they were unchanged in thoracic curves after posterior USS. Anterior instrumentation systems have been noted to produce an increase in kyphosis over the instrumented segments[182]. This is probably due to the loss of anterior spinal height after intervertebral disc removal.

Sagittal plane balance moves forward from pre-operative to 8-week assessment and then reverts to normal for both anterior USS in thoracolumbar curves and posterior USS in thoracic curves (Table 10 and Table 27, pages 98 and 139). *En bloc* movement of the thoracic spine is seen after anterior surgery in thoracolumbar curves (Figure 35, page 143) in the sagittal plane with statistically significant changes in sagittal segmental vertebral tilt between pre-operative and 8-week and 8-week and 1-year assessments ($P<0.001$ and

P=0.002 respectively, repeated measures MANOVA). Further analysis reveals that the changes in sagittal plane tilt of L1 regress with the changes in SPB for both thoracic (P<0.001, RMMANOVA) and thoracolumbar curves (P=0.003, RMMANOVA). The findings above suggest that changes in lumbar lordosis compensate for changes in spinal balance after instrumentation.

Five of the 10 patients presented here developed a kyphosis at the upper end of the instrumented spine which increased between 8-week and 1-year assessments. Two factors appear to be important. Firstly, patients who developed a progressing kyphosis at the upper end of the instrumented spine had an anterior rod implanted which was contoured into lordosis along its full length, as seen in Figure 36, page 143. This does not reproduce the normal sagittal contour across the thoracolumbar junction. Appropriate contouring of the anterior rod is shown in Figure 30, page 138. Compensation for inappropriate sagittal contouring of the anterior rod to restore sagittal plane balance could take place either below or above the instrumented spine and a progressive kyphosis above the fused segment may be the result. Secondly, the pre-operative kyphosis predicts the difference in sagittal tilt between the upper instrumented vertebra and the vertebra above it (P=0.0004, R^2=0.64, MLRA) by 1-year follow-up. Patients with greater pre-operative kyphosis were more likely to develop progressive kyphosis above the instrumentation. It is possible that these patients are already achieving sagittal plane balance through their thoracic kyphosis and are unable to compensate through decreasing lumbar lordosis so they compensate through production of a progressive kyphosis.

Results determined by back surface measurements

Anterior USS results in a 47% correction of *maximum* ATI by 1-year follow-up, which compares with 23% correction of ATI in thoracic curves.

Analysis of segmental back surface data

Consideration of *segmental* back surface data shows that after the initial surgical correction of surface deformity, rib-hump reassertion occurs from 8-week to 1-year follow-up (P=0.02, RMMANOVA). Comparison of Figure 19 (page 101) and Figure 31 (page 140) suggests that the magnitude of reassertion is less for thoracolumbar than thoracic curves, being roughly 25% for the former and 50% for the latter. Reassertion of maximum ATI after instrumentation of thoracic curves is predicted by rib and spine factors (Table 24, page

118). Significant changes in both segmental convex and concave RSAs occur between assessments of thoracolumbar curves (P=0.024 and P<0.001, RMMANOVA) which suggests that the thoracic cage in thoracolumbar scoliosis is compliant and RSAs are altered by the surgery. Superimposition of RSAs for thoracic curves (black) over RSAs for thoracolumbar curves (red) shows that the convex ribs in thoracic curves are more drooped in the region of the apex of the thoracic curve (Figure 41). I postulate that this pattern of RSAs indicates a stiffer, less compliant, thoracic cage in thoracic AIS. The more compliant thoracic cage in thoracolumbar AIS means ATIs are more easily corrected and lower forces are induced in the thoracic cage for rib-hump reassertion. In addition, only the lower part of the rib cage can act to brace or buttress the thoracolumbar curves. The lower 2 ribs are floating ribs which would mean that T11 and T12 are braced by the ribs as much as the vertebrae above.

This contrasts with the observations for reassertion of radiographic deformity in thoracic and thoracolumbar AIS. There is greater correction of radiographic deformity for thoracolumbar AIS from pre-operative to 8-week follow-up and concomitant greater reassertion of radiographic deformity. Percentage reassertion of Cobb angle is predicted by spine factors for both thoracic (vertebral translation of T5, rotation of L5 and tilt of L2, page 121) and thoracolumbar curves (vertebral tilt of T4 and translation of T9, page149) and the thoracic cage is not implicated.

Relationship between segmental ATI and segmental vertebral tilt, rotation, translation and rib-spine angles

The changes in segmental ATI are related to the changes in segmental vertebral translation when pre-operative, 8-week and 1-year assessments are considered (P<0.001, RMMANOVA, Table 29, page 146), but changes in segmental ATI are still significant once the effect of vertebral translation has allowed for (P=0.025, RMMANOVA, Table 29). This indicates that the changes in surface deformity are not fully accounted for by changes in spinal deformity as assessed by vertebral translation and similar findings were found when thoracic curves were considered in Section IIi. Segmental vertebral translation may be the best radiographic indicator of ATI, as was suggested for thoracic curves.

No clear relationship was demonstrated between changes in segmental RSAs and changes in segmental ATI suggesting that either there is poor linkage between vertebral and rib movements or the rib movements relating to ATI are not occurring in the coronal plane.

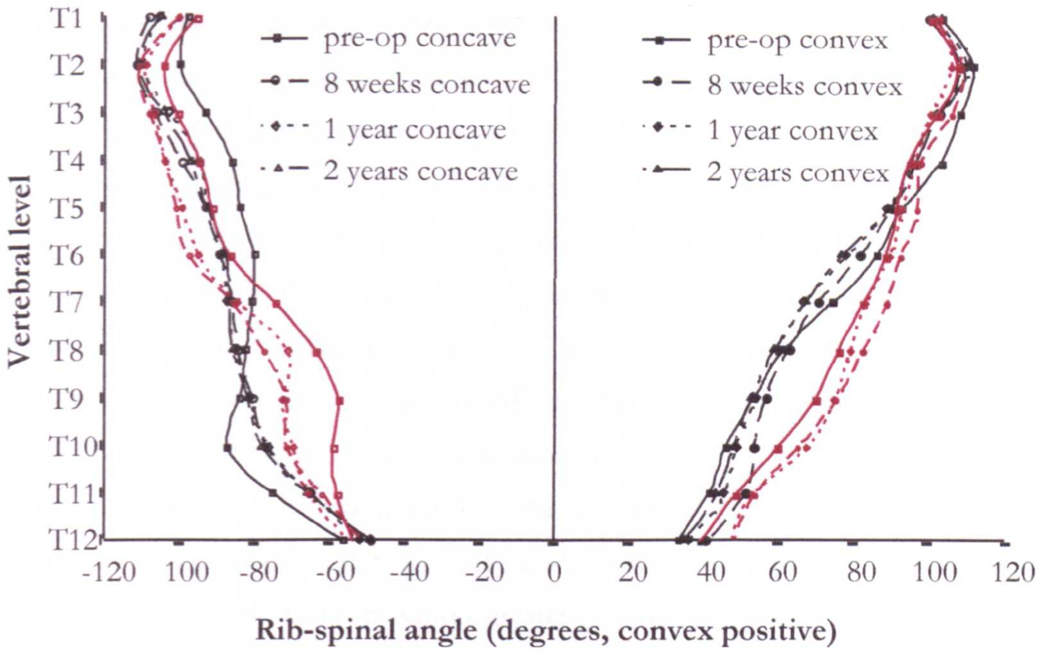
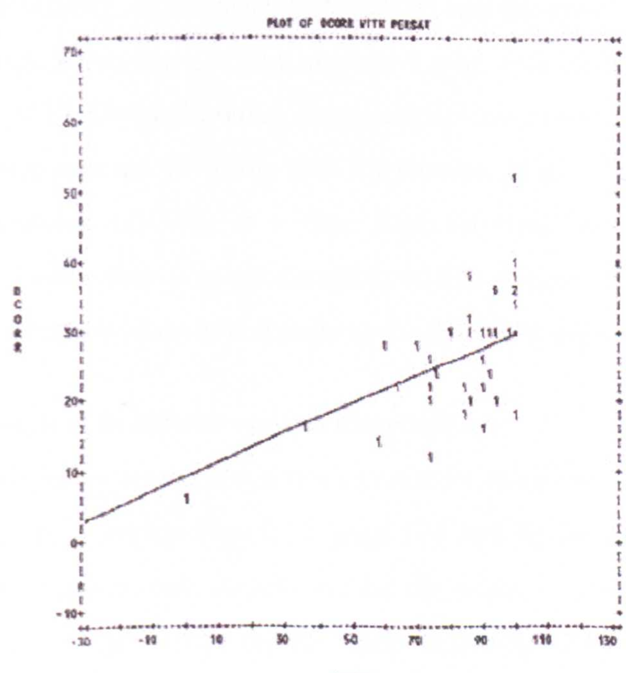


Figure 41. Concave & convex RSA plotted against vertebral level (black-thoracic AIS, red-thoracolumbar AIS)



Patient satisfaction versus Cobb angle correction for 33 studies

r = 0.628

Figure 42. Data presented by Haher et al to show that patient satisfaction is predicted by Cobb angle correction.

from Haher et al Spine 20(14) p1575-84

Pre-operative factors which predict the outcome of surgery

Pre-operative factors which predict the percentage correction of maximum ATI

Coronal tilt of T4 (P=0.001) and the degree of 3rd concave rib droop (P=0.011) predict the percentage correction of maximum ATI by 1 year (R^2=0.86, MLRA). As was the case for thoracic curves, both spine and rib factors are implicated in the prediction of back surface deformity after surgery. If T4 tilts in the opposite direction to the vertebra immediately above the apex i.e. T4 is part of a thoracic compensatory curve, then the correction of the maximum ATI is less. Conversely, if T4 tilts in the same direction as the vertebra immediately above the apex i.e. T4 is part of the upper thoracolumbar curve, then the correction of the maximum ATI is more. The more drooping the convex 3rd RSA (convex with respect to the primary curve), the less the correction of the maximum ATI. An interpretation of these results is that any *compensatory* thoracic curve above a thoracolumbar curve is less compliant and hence produces greater counter tensions as a result of surgery which then leads to reassertion of deformity on further follow-up.

Other pre-operative factors which predict the radiographic outcome

Age at operation (P=0.001), ATI at level 9 (P =0.001) and the translation of T9 (P=0.021) predict the percentage correction of Cobb angle at 1 year. The 6th convex RSA (P=0.006) and the translation of T7 (P=0.04) predict the percentage correction of AVT at 1 year. The 6th convex RSA is also selected (P=0.006) with the rotation of L2 (P=0.01) as predictors of the percentage correction of AVR at 1 year. Each of these radiological outcomes is predicted by rib and spine factors in combination, which supports the postulate that both rib and spine factors are important in determining the deformity after surgery in AIS.

Significance for surgical treatment - costal interventions

The magnitude of rib-hump reassertion is not as great for thoracolumbar lumbar curves as it is for thoracic curves (compare Figure 19, page 101 and Figure 31, page 140) possibly because the thoracic cage can only directly act on the upper part of the curve. Thus the absolute effect of any costoplasty on the rib-hump deformity and in reducing the forces induced by surgery for reassertion of deformity may be less, and may not be indicated for these curves in terms of the extra morbidity associated with a further surgical procedure.

Conclusions

Similar changes occur with surgery and on follow-up after surgery when thoracolumbar and thoracic AIS are studied. The differences that occur are mainly quantitative. Correction of Cobb angle, AVR, AVT and maximum ATI are produced by anterior instrumentation for thoracolumbar AIS. Reassertion of both spinal and rib-hump deformity occur between 8-week and 1-year assessments. Greater correction of radiographic and surface deformity is seen for thoracolumbar curves when compared with thoracic curves. This is postulated to be because both spine and thoracic cage are more compliant in thoracolumbar scoliosis and so easier to correct with surgery. Greater reassertion of radiographic deformity is seen for thoracolumbar curves possibly because fewer vertebral levels are instrumented when compared with thoracic curves. Less reassertion of surface deformity is seen for thoracolumbar curves because the thoracic cage is more compliant so lesser forces for rib-hump reassertion are induced in it, and the thoracic cage can only act directly through the ribs on then upper part of the curve. Significant changes in vertebral rotation are found for thoracolumbar curves in contrast to the findings for thoracic curves, which may be due greater rotational mobility in the lower thoracic spine and lack of buttressing of the curve by the lower ribs and presence of a more compliant lower thoracic cage. The convex ribs in thoracolumbar curves do not droop as much as in thoracic curves, which are postulated to indicate a more compliant thoracic cage. *En bloc* movement of the thoracic spine is seen after anterior surgery in thoracolumbar curves in the sagittal plane producing changes in sagittal plane balance which returns to normal by 1-year follow-up.

Segmental vertebral translation may be the best radiographic indicator of ATI, as was suggested for thoracic curves.

Both spine (pre-operative tilt of T4, P=0.001) and rib (convex 3rd RSA, P=0.011, MLRA) factors predict the results of surgery in terms of percentage correction of maximum ATI. Patients with a compensatory thoracic curve and drooping convex ribs and by implication a less compliant thoracic cage have less percentage correction of maximum ATI.

Implications for surgical interventions in thoracolumbar AIS

The thoracic cage of patients with thoracolumbar AIS is postulated to be more compliant than in the thoracic cage of patients with thoracic AIS so the expected effects of costal interventions would be less and may not be justified in most patients.

The development of a kyphosis above the instrumented vertebrae was found to be a significant problem, which can likely be avoided by appropriate contouring of the rod especially in patients with large pre-operative thoracic kyphosis.

SECTION IIiii: PATIENT AND PARENTAL PERCEPTION OF ADOLESCENT IDIOPATHIC SCOLIOSIS (AIS) BEFORE AND AFTER SURGERY, AND COMPARISON WITH SURFACE AND RADIOGRAPHIC MEASUREMENTS.

Overview

Patients with AIS being treated with either posterior of anterior instrumentation of their curves filled in questionnaires at pre-operative and 2-year assessments. Parents filled in their own questionnaire. Prospective back shape, anthropometric and radiographic data were obtained. The aim of the study was to describe the relationship between patient and parental perception of AIS, and back-shape and radiographic measurements before and after surgery.

39 patients with AIS filled in questionnaires at pre-operative and 2-year assessments after implantation of either anterior (n=23) or posterior (n=16) instrumentation. 26 parents had filled in their forms (anterior n=17, posterior n=9).

Most patients experienced aching or throbbing back pain, rated 18% on visual-analogue score (VAS). Pre-operative maximum Angle of Trunk Inclination (ATI) and pre-operative apical vertebral translation (AVT) correlated with each of pre-operative VAS (P=0.001) and Oswestry Disability Index (P=0.001, Spearman correlation coefficient). There was no significant change in the Short-Form McGill pain scale, intensity and site of pain or Oswestry Disability Index by 2 years after surgery (Wilcoxon signed-ranks test). The psychological distress domain of the Psychosocial Adjustment to Illness Scale (PAIS) was higher at 10 days before surgery than at 2 years after surgery (P=0.001, Wilcoxon signed-ranks test). In order of importance, patients expected surgery to correct spinal curvature, address the rib-hump and stop progression of the curve. Rib prominence, shoulder and hip and waist asymmetry, lean to one side, spinal curvature and progression were perceived as less by 2 years after surgery (P<0.005, Wilcoxon) but 6 of the 39 patients still perceived their rib-hump as a moderate or severe problem, despite significant correction of ATI (P<0.0001, Wilcoxon).

Parents (n=26) rated scoliosis problems more severely than their children (P<0.0001, repeated measures MANOVA). Parents perceived fewer problems after surgery, including rib-hump prominence when compared with their perception of problems prior to surgery children (P<0.0001, repeated measures MANOVA).

Introduction

There are a large number of scales available for the measurement of subjective patient attributes such as pain, satisfaction with treatment, response to illness, illness behaviour, social interaction, personality and attitude. The selection of a particular scale for use will depend on whether it is appropriate, valid and reproducible (*see Material and methods section, Questionnaires*, page 43).

Several scales have been applied to the study of patients with AIS, but have mainly taken the form of retrospective surveys. Areas examined include pain[65,69,82,95,184,199,215,223,264], self-perception[123], function[70] and pre-operative concerns of parents and patients[38]. Haher et al published a meta-analysis of surgical outcome in 11,000 AIS patients[137] which claimed to link patient satisfaction with degree of Cobb angle correction. This conclusion was reached based on 33 studies (2926 patients) and the plot of percentage of satisfied patients against Cobb angle correction (Figure 42, page 155). Inspection of Figure 42 from Haher's paper reveals that if just one or two outlying studies are removed then the statistically significant correlation disappears. This analysis takes no account of curve type, method of treatment or the era when the study was performed. Thus I do not consider that this data establishes the importance of Cobb angle correction as a determinant of patient satisfaction. However, the lack of a standardised measure for satisfaction was noted and subsequently Haher et al published the Scoliosis Research Society instrument for the evaluation of surgical outcome in AIS[136] with validation on 244 patients. Reliability was assessed on 26 controls. One month later White et al published the results of its use on 168 patients[373], again as a retrospective survey. There is a lack of prospective studies to evaluate the surgical treatment of AIS[36]. Koch et al demonstrated the importance of psychological factors in patient satisfaction with surgery in a prospective study of 42 patients with AIS within 5 to 11 months follow-up after surgery[162]. They found 'neutral/dissatisfied' patients (n=11) were more likely to have lower body mass index, be younger in menarchal status, to have preoperative psychological difficulties and have unmet expectations regarding postoperative cosmesis. Differences between the 'satisfied' and 'neutral/dissatisfied' groups for factors such as rib rotation correction (19% vs 8%, figures calculated from data presented) were not of statistical significance at this sample size but may nevertheless be confounding factors.

The purpose of my study was to evaluate patients' pain, their self-image, their disability and their perception of deformity before and 2 years after surgery. The parents' perception of their child's deformity was also assessed.

Material and Methods

Patients

59 patients with AIS treated using either anterior or posterior USS instrumentation were given questionnaires to complete before surgery and at 2 years after surgery. Patients were recruited between July 1995 and March 1999. Of these, 5 pre-operative and 10 2-year sets of questionnaires were missing.

Some patients and a greater number of parents did not complete the current problems section, especially at 2-year assessment, despite filling in the rest of the questionnaires. It was decided to retain questionnaires when the self-perception, pain, PAIS and ODI sections were complete. Three patients did not fully complete the self-perception, pain, PAIS and ODI sections. Two patients did not attend the 2-year follow-up assessment. This left 39 patients with complete self-perception, pain, PAIS and ODI sections for analysis. 35 of 39 patients had completed pre-operative and 2-year current problems sections. 26 of 35 parents had completed their pre-operative and 2-year current problems sections.

Questionnaires

See General Methods section, *Questionnaires*, page 43.

Patient assessment

All patients had a full back surface appraisal at pre-operative, 8-week, 1-year and 2-year assessments, see General Methods section, *Back surface appraisal*, page 32. The difference between left and right acromial height measurements gave the acromial height difference. Eight patients had missing lateral films but were included in the analysis. The radiological data obtained were curve type, King type, Risser grade, upper and lower end-vertebrae, the instrumented vertebrae, Cobb angle, AVR, apical vertebral translation, T1 to S1 distance, frontal plane balance, and where possible sagittal plane balance, kyphosis and lordosis. The methods of radiographic measurement are described in the General Methods section, page 32.

Data analysis

See *Data analysis*, Section IIi, page 96 and *Statistical Methods*, page 56. Non-parametric methods of analysis were applied to data from questionnaires. The P-value required for significance was adjusted (Bonferroni's correction) when multiple comparisons were performed on related data to reduce the chance of a Type I error. Analysis of results by curve type (either thoracic or thoracolumbar) was performed using a Mann-Whitney U Test. Repeated measures MANOVA was used to compare changes in multiple measures with follow-up according to curve type.

Angles of trunk inclination (ATI) at each of 10 levels down the back were measured in all patients at each assessment using a Scoliometer. The maximum ATI was used in analysis for comparison with questionnaire data. However maximum ATI only gives information about back shape at one back surface level. Patients with a given maximum ATI can have an extensive unilateral hump or a short thoracic rib-hump which continues caudally as a smaller contralateral lumbar back surface asymmetry. Patients and their parents may perceive a unilateral rib-hump to be more severe than a thoracic rib-hump with a compensatory lumbar hump. To incorporate 10 levels of surface data into a single measurement that may better reflect back shape, A.A. Cole has suggested that a Surface Asymmetry Score (SAS) be calculated (personal communication). The SAS is, on a plot of ATI by surface level, the area between the curve and the X axis, as shown in Figure 43. The value may range from 0 to 270.

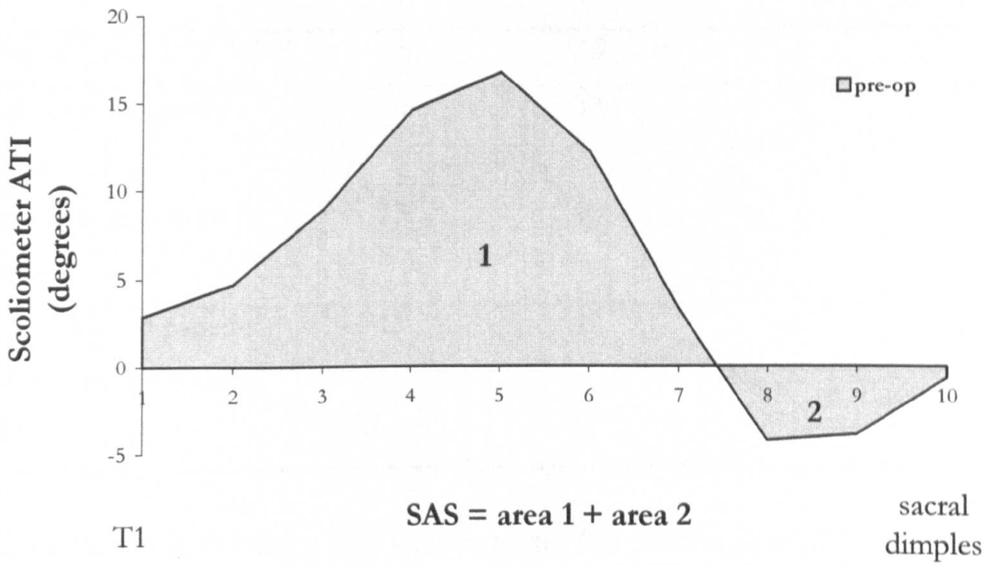


Figure 43. Example of calculation of Surface Asymmetry Score (SAS) for 1 patient.

Results

35 females and 4 males with AIS had either posterior USS (n=16) or anterior USS instrumentation (n=23) implanted (Table 31).

Table 31. Curve type and instrumentation implanted, with number of completed questionnaires for patients and parents.

	Thoracic	Thoracolumbar	Lumbar	Total
Posterior USS	15	1	0	16
Anterior USS	6	14	3	23
Total	21	15	3	39
Ste-Justine/pain/ODI/PAIS	21	15	3	39
Patients' aims & current problems	20	15	0	35
Parents' aims & current problems	13	13	1	27
Both parents' and patients' aims & current problems complete	13	13	0	26

Where:

Ste-Justine/pain/ODI/PAIS - refers to the first four sections of the questionnaire at pre-operative and 2-year assessment

Aims & current problems - refers to the pre-operative aims of surgery section and the 2-year current problems section

One thoracic, nine thoracolumbar and two lumbar curves were left sided. The mean age at operation was 16.1 years (11.7 to 25.6 years) and the mean Risser stage was 3.4 (0 to 5). The pre-operative Cobb angle was 56^0 (36^0-88^0), the pre-operative apical vertebral rotation (AVR) was 30^0 (7^0-45^0) and apical vertebral translation (AVT) from the T1-S1 line was 4.8 cm (2.6-7.8). Kyphosis measured 28^0 (1^0-54^0) and lordosis measured 42^0 (13^0-59^0), n=31. 3 to 14 vertebrae were instrumented (mean=7.6). Mean Cobb angle correction on side-bending films was 51% (3%-91%). The mean maximum rib-hump measured with a Scoliometer was 17^0 (9^0-28^0).

Cobb angle corrected to 30^0 (range 13^0-54^0) by 2-year follow-up. AVR corrected to 20^0 (range 3^0-35^0), AVT corrected to 2.2 cm (range 0.2-4.9) and maximum ATI corrected to 10^0 (range 2^0-25^0) by 2-year follow-up (for all, $P<0.0005$, Wilcoxon matched-pairs signed-ranks test).

Analysis of questionnaire data

The results are presented for each section of the questionnaire in order, namely the self-perception section, the pain section, the Oswestry Disability Index, the Psychosocial Adjustment to Illness Scale, the pre-operative aims of surgery, the 2-year realisation of aims and the results of surgery section. These results are then compared with radiographic and surface measurements.

The analysis is then repeated for thoracic and thoracolumbar curves separately.

The self-perception section (Figure 5, page 51)

The mean pre-operative total score was 37.3, which was not significantly different from the total score at 2-year follow-up which was 38.5 ($P=0.2$, Wilcoxon matched-pairs signed-ranks test). The individual breakdown of results giving the numbers of patients responding in the most positive way to each question is given in below. The proportions of subjects in the Ste-Justine AIS Cohort Study[123] with the most positive perception is also given, calculated from data presented in that paper, corrected to the proportion of males to females in my study. No statistical comparison is performed as the Ste-Justine subjects are approximately 10 years older than Nottingham patients and are not strictly comparable.

Table 32. Numbers of patients giving most positive response to each question (n=39), the corresponding percentage and the equivalent percentages from the Ste-Justine AIS Cohort Study AIS and control groups (adjusted n=1439 & 1264 respectively).

Most positive responses:	Number		Percentage		Ste-Justine percentage	
Question:	Pre-op	2-year	Pre-op	2-year	AIS	Control
I have a good figure for my age	*3*	*5*	7	13	26.6	22.4
I am in good shape for my age	*5*	*3*	13	7	13.8	15.0
I try to look my best	*11*	*10*	28	26	47.6	37.7
I like the way I look	*3*	*5*	7	13	24.9	20.8
I like who I am	*6*	*7*	15	18	35.7	33.4
Other people find me attractive	*1*	*2*	3	5	27.4	20.5
I hate parties and social occasions	*33*	*33*	85	85	32.6	34.1
I like meeting new people	*9*	*10*	23	26	45.8	43.3
I am comfortable being around people	*10*	*9*	26	23	31.7	29.9
I'm not as well dressed as most	*18*	*25*	46	64	11.0	15.6
I'm a failure at everything I try to do	*29*	*29*	74	74	6.8	9.4
I give up too easily	*17*	*15*	44	38	11.0	13.1
I usually feel quite lonely	*25*	*30*	64	77	16.6	18.6

There was no significant difference between pre-operative and 2-year responses at P=0.003 (Bonferroni's correction, Wilcoxon matched-pairs signed-ranks test).

The pain section (Figure 5, page 51)

Patients marked the intensity of their pain on a visual analogue scale (VAS) which was 10 cm long. The mean pre-operative VAS was 2.4 cm (range 0-7.8 cm) which was not significantly different from the post-operative VAS of 1.8 cm (range 0-8 cm, P=0.2, Wilcoxon matched-pairs signed-ranks test). Six patients had no pain at pre-operative assessment and 11 patients had no pain at 2-year follow-up. The pain was worst in either back or buttock or hip region in approximately 70% of patients for each assessment. 6 of

30 patients indicated that they had pain on the front view of the pain diagram at pre-operative assessment.

Short-form McGill pain questionnaire

The breakdown for the numbers of patients who responded to each of the descriptors at pre-operative and 2-year assessment are given in Table 33 below:

Table 33. Numbers of patients who responded to each of the descriptors at pre-operative and 2-year assessment, with sensory, affective and total scores and their comparison between assessments.

N=39	Pre-operative				S/A	2-year follow-up				S/A	
Descriptor	None	Mild	Mod	Sev	**Score**	None	Mild	Mod	Sev	**Score**	***P***
Throbbing	30	7	2			33	6				
Shooting	30	9				30	8	1			
Stabbing	33	5	1			36	1	2			
Sharp	30	6	2	1		31	5	2	1		
Cramping	31	4	2	2	**3.28**	31	6	2		**3.08**	***0.57***
Gnawing	34	3	2			36	1	2			
Hot burning	39					36	2	1			
Aching	8	13	13	5		10	17	9	3		
Heavy	36	2	1			39					
Tender	32	7				29	7	3			
Splitting	32	7				39					
Tiring-exhausting	26	7	4	2		29	6	4			
Sickening	38		1		**0.72**	38	1			**0.41**	***0.20***
Fearful	37	2				38	1				
Punishing-cruel	37	1	1			39					
Total Score:					**4.00**					**3.49**	***0.39***

Where:

S = sensory component of the short-form McGill pain questionnaire, first 12 descriptors

A = affective component of short-form McGill pain questionnaire, last 5 descriptors

Mod = moderate

Sev = severe

P = P value for comparison of sensory, affective and total scores, Wilcoxon matched-pairs signed-ranks test

There was no change in scores between assessments (Wilcoxon matched-pairs signed-ranks test). Most patients described their pain as a 'tiring-exhausting' 'aching' pain. Other common descriptors were 'throbbing', 'shooting', 'sharp' and 'cramping' with 'tender' being selected at 2-year follow-up.

6 pre-operative and 3 patients at 2-year assessment marked down one or more of the descriptors as 'severe'.

Oswestry Disability Index (ODI) (Figure 6, page 52)

The mean pre-operative ODI was 9.2 (0-44.4) and ODI at 2-year follow-up was 6.9 (0-44.4), there being no significant difference between the two (P=0.2, Wilcoxon matched-pairs signed-ranks test).

4 of 39 patients at pre-operative assessment and 3 of 39 patients at 2-year assessment scored over 25 points.

Psychosocial Adjustment to Illness Scale (PAIS) (Figure 7 and Figure 8, pages 53 and 54)

The scores for each subsection of the modified PAIS questionnaire used in this study are given in below:

Table 34. Scores for subsections of PAIS, comparing pre-operative and 2-year assessment results.

N=39 **Section**	**No of questions / original**	**Pre-op**	**2-year**	**P**
health care orientation	8 / 8	19.2	19.3	0.89
vocational environment	6 / 6	10.6	11.0	0.25
domestic environment	2 / 8	5.8	5.8	0.53
social environment	3 / 6	5.4	5.5	0.62
psychological distress	7 / 7	15.0	17.5	0.001

Where:

P = P value for comparison of section scores, Wilcoxon matched-pairs signed-ranks test, for significance P<0.01, Bonferroni's correction for 5 comparisons

The scores for the psychological distress section indicate that patients were more distressed (lower scores) before surgery than at 2 years after surgery (P=0.001). The questionnaires were administered a mean of 10 days prior to surgery (range 1-62 days). These results probably indicate the stress of impending surgery on these patients.

Pre-operative aims of surgery (patients and parents) and 2-year realisation of aims (Figure 9, page 55)
Two patients did not complete the *aims of surgery* section of their questionnaires at pre-operative assessment and a different 2 patients did not complete the equivalent *current problems* section of their questionnaires at 2-year follow-up. This left 35 patients and the numbers of patients rating each descriptor as no problem, mild, moderate or severe problem are presented in Table 35 below. Details of the scoring method are given on page 50.

Table 35. Patient responses to problems section of questionnaire.

N=35	Pre-operative				2-year follow-up				P
Descriptor	None	Mild	Mod	Sev	None	Mild	Mod	Sev	
Rib-hump/prominence	14	5	11	5	25	5	2	3	0.005
Shoulders not level	13	13	9	0	27	6	2		0.003
Hips not symmetrical	14	7	9	5	28	6	1		0.0001
Waist not symmetrical	13	9	9	4	30	3	2		0.0003
Front of chest not symmetrical	21	10	2	2	27	5	3		0.14
Leaning over to one side	13	13	6	3	27	5	3		0.0006
Being teased at school	32	1	1	1	34	1			0.2
Large curve of the spine	3	6	16	10	29	4	1	1	<0.0005
Getting worse in the future	4	7	11	13	26	6	2	1	<0.0005
Total scores (range)	9.9 (1 - 20)				2.5 (0 - 20)				<0.0005

Where:

Mod = moderate

Sev = severe

P = P value for comparison scores, Wilcoxon matched-pairs signed-ranks test, for significance P=0.005 (applied Bonferroni's correction for individual statements).

Patients' responses to the 9 'current problems' statements were different by 2-year follow-up when total scores for all 9 statements were compared (P<0.0005, Wilcoxon matched-pairs signed-ranks test).

35 parents completed the *aims of surgery* section at pre-operative assessment and 30 parents filled in the equivalent *current problems* section of their questionnaires at 2-year follow-up. 27 parents had filled in both pre-operative and 2-year sections (Table 36).

Table 36. Parent responses to problems section of questionnaire.

N=27	**Pre-operative**				**2-year follow-up**				**P**
Descriptor	None	Mild	Mod	Sev	None	Mild	Mod	Sev	
Rib-hump/prominence	9	1	14	3	17	7	1	2	0.001
Shoulders not level	6	9	11	1	20	5	2		0.0001
Hips not symmetrical	6	7	4	10	17	8	2		0.0002
Waist not symmetrical	8	3	9	7	24	2	1		0.0002
Front of chest not symmetrical	14	4	7	2	25	2			0.0012
Leaning over to one side	10	5	7	5	21	2	3	1	0.0033
Being teased at school	19	5	2	1	26		1		0.06
Large curve of the spine		3	6	18	16	7	2	2	<0.0005
Getting worse in the future	4		6	17	17	5	3	2	0.0001
Total scores (range)	13.4 (3 - 21)				3.3 (0 - 17)				<0.0005

See Table 35 for abbreviations.

The total scores for parents responses at pre-operative and 2-year assessment were different (P<0.0005, Wilcoxon matched-pairs signed-ranks test).

Each patient and parent were asked to rank in order of importance the features of scoliosis that they would most like to see improved after surgery. The three most common responses for the top three ranks are given in Table 37 below:

Table 37. Features of scoliosis that patients and parents most wanted to be corrected by surgery.

Rank	Feature	Number of patients (n=35)	Number of parents (n=27)
1	Large curve of the spine	14	16
	Rib-hump/prominence	10	9
	Getting worse in the future	8	9
2	Rib-hump/prominence	9	10
	Getting worse in the future	6	8
	Waist not symmetrical	6	6
3	Large curve of the spine	8	7
	Hips not symmetrical	6	4
	Waist not symmetrical	5	4

The parents' and patients' perceptions of problems associated with scoliosis at pre-operative and 2-year assessment are compared below, using Wilcoxon matched-pairs signed-ranks test, where P=0.005 for significance (Bonferroni's correction).

Table 38. Comparison of parents' and patients' grading of the common problems associated with scoliosis for each of pre-operative and 2-year assessments.

n=26	Pre-operative scores			2-year follow-up scores		
Descriptor	**Pt**	**Par**	**P**	**Pt**	**Par**	**P**
Rib-hump/prominence	27	36	0.037	14	15	0.832
Shoulders not level	26	32	0.227	8	9	0.773
Hips not symmetrical	31	44	0.022	4	11	0.165
Waist not symmetrical	28	41	0.008	5	4	1.000
Front of chest not symmetrical	14	22	0.101	7	2	0.096
Leaning over to one side	24	31	0.342	10	11	0.862
Being teased at school	4	10	0.034	1	2	0.655
Large curve of the spine	53	66	0.006	8	17	0.116
Getting worse in the future	51	60	0.095	10	17	0.277

Where:

Pt = summated patient score

Pa = summated parent score

P = P value for comparison scores, Wilcoxon matched-pairs signed-ranks test, for significance P=0.005 (applied Bonferroni's correction for individual statements).

When total scores are compared, parents perceived the severity of the problems associated with scoliosis to be greater than their children did at pre-operative assessment (P=0.0009, Wilcoxon matched-pairs signed-ranks test) but there was no difference at 2-year assessment (P=0.6, Wilcoxon matched-pairs signed-ranks test, n=26).

Results of surgery section

34 patients completed this section. Most of the problems associated with scoliosis were reported to be 'fully corrected'. This may be because patients ticked the 'fully corrected' option by default if they did not perceive the statement concerned to be a problem before surgery. The three most important problems according to patients (Table 37) had more varied responses, namely the *Rib-hump/prominence*, *large curve of the spine* and *getting worse in the future*. To reduce the effect of default answers of 'fully corrected', only answers from patients who had ranked the descriptor in the top four for importance were selected. The number of patients selected for each descriptor and their responses are detailed below:

Table 39. Results of surgery. Only responses from patients who had ranked the concerned descriptor in the top four of problems at pre-operative assessment were considered.

Descriptor	N	Fully corrected	Moderately improved	Mildly improved	Made no difference
Rib-hump/prominence	20	7	10	2	1
Shoulders not level	11	9	1	1	0
Hips not symmetrical	15	9	5	1	0
Waist not symmetrical	14	10	4	0	0
Front of chest not symmetrical	6	4	1	0	1
Leaning over to one side	9	6	2	1	0
Being teased at school	0	0	0	0	0
Large curve of the spine	23	12	11	0	0
Getting worse in the future	18	13	5	0	0

Where:

n = number of patients who had pre-operatively ranked the descriptor in the top four of problems most desired to be corrected by surgery.

No patients had considered teasing at school to be in the top four of problems to be corrected by surgery.

Comparison between radiographic and surface measurements and responses to questionnaire items

Radiographic measurements and responses to questionnaire items

Pre-operative Cobb angle, AVR and AVT were correlated with pre-operative questionnaire results and the correlation coefficients and P values are given in Table 40 below:

Table 40. Results from pre-operative questionnaire correlated with radiographic measurements of Cobb angle, AVR and AVT.

Pre-operative		**Radiographic Measurements**		
Variables (n=39)		**Cobb angle**	**AVR**	**AVT**
St Justine	r	-0.12	-0.33	-0.30
Body Image	P	0.485	0.041	0.068
VAS	r	0.32	0.31	0.44
	P	0.048	0.058	0.005
ODI	r	0.38	0.40	0.53
	P	0.018	0.011	**<0.0005**
SF - McGill	r	0.40	0.33	0.49
	P	0.011	0.040	**0.002**
PAIS	r	-0.11	-0.33	-0.45
	P	0.502	0.038	0.004

Where:

r = correlation coefficients

n = sample size

p = probability value, Spearman correlation coefficients, for significance P < 0.003 (Bonferroni's correction for 15 comparisons)

Inspection of Table 40 reveals there is a significant correlation between curve magnitude measured by apical vertebral translation and both ODI and the short-form McGill pain questionnaire.

There were no significant correlations between the same radiographic and questionnaire variables derived from the 2-year follow-up data.

There were no significant correlations between Cobb angle and either the patients' or parents' grading of *large curve of the spine* as a current problem of scoliosis for pre-operative and 2-year assessment. The change in Cobb angle between assessments did not correlate with the change in grading of *large curve of the spine* for either the patients or their parents. There were likewise no correlations found between pre-operative and 2-year grading of *leaning over to one side* and radiographic frontal plane balance or correlation between changes in these quantities between assessments.

Surface measurements, anthropometry and responses to questionnaire items

There was a statistically significant correlation between each of pre-operative maximum ATI and SAS and each of the questionnaire pain measures, namely ODI, VAS and short-form McGill (Table 41).

Table 41. Correlation of questionnaire results with Maximum ATI and Scoliometer Surface Asymmetry Score for pre-operative and 2-year assessments.

		Pre-operative		2-year assessment	
Variables (n=39)		**max. ATI**	**SAS**	**max. ATI**	**SAS**
St Justine	r	-0.15	-0.07	0.09	0.04
Body Image	P	0.362	0.674	0.586	0.823
VAS	r	0.53	0.47	0.22	0.25
	P	**0.001**	**0.003**	0.187	0.132
ODI	r	0.50	0.48	0.09	0.04
	P	**0.001**	**0.002**	0.598	0.803
SF - McGill	r	0.44	0.46	0.06	-0.01
	P	0.006	**0.003**	0.736	0.932
PAIS	r	-0.30	-0.39	-0.03	0.03
	P	0.063	0.016	0.874	0.839

See Table 40 for abbreviations.

The grading of the rib-hump by patients (n=35) and parents (n=27) were correlated with maximum ATI and SAS for pre-operative and 2-year assessments. The correlation between *pre-operative* SAS and the patients' grading of the severity of their rib-hump was statistically significant (r=0.445, P=0.007). There was no correlation between surface measurements of rib-hump and the patients' grading of their results for the 20 patients who ranked the rib-hump as one of the top 4 aspects of scoliosis that surgery should correct.

There were no significant correlations between the anthropometric measurement of acromial height difference (see *General anthropometric methods*, page 36) and either the patients' or parents' grading of *shoulders not level* as a current problem of scoliosis for pre-operative and 2-year assessment. The change in shoulder height asymmetry between assessments did not correlate with the change in grading of *shoulders not level* for either the patients or their parents. There were likewise no correlations found between pre-operative and 2-year assessments for *leaning over to one side* and measurement of plumb-line (see Methods section, General anthropometric methods, page 36.)

Results by sex, curve type and operation

The analysis above was repeated excluding the 4 male patients and similar results were obtained.

Results by curve type

There was no difference in total scores for the Ste-Justine scale, VAS, short-form McGill, PAIS, ODI and current problems sections between thoracic and thoracolumbar curves for either pre-operative or 2-year follow-up. No differences were found for sex, operation age, Risser grade, upper and lower end-vertebrae, AVR, AVT and where possible sagittal plane balance between curve types.

Patients with thoracic AIS differed from patients with thoracolumbar AIS in the operation performed (Table 31, page 164, P=0.0001), the number of instrumented vertebrae (9.5 and 5.8, P=0.0001), pre-operative frontal plane balance (1.1 cm and 2.9 cm, P=0.0003), Cobb angle at 2-year follow-up (36.3^0 and 23.3^0, P=0.0005), kyphosis at 2-year follow-up (23.4^0 and 35.7^0, P=0.007) and lordosis at 2-year follow-up (40^0 and 30.3^0 respectively, P=0.006, alpha level set to P=0.001 for significance using Bonferroni's correction).

The analysis for changes between pre-operative and 2-year assessments was repeated for patients with thoracic and thoracolumbar curves separately. The results were essentially similar with statistically significant corrections in Cobb angle, AVR, AVT, maximum ATI and SAS by 2-year follow-up for thoracic and thoracolumbar curves (Wilcoxon matched-pairs signed-ranks test). There was no significant change in kyphosis or lordosis in patients with thoracic curves. Lordosis was reduced by 2-year follow-up in patients with thoracolumbar curves (P=0.001, n=13).

Analysis of questionnaire data

No changes in the self perception section, VAS, short-form McGill, ODI and PAIS were found between pre-operative and 2-year assessments for either thoracic or thoracolumbar curves.

Patients and parents perceived fewer problems associated with scoliosis by 2-year follow-up (thoracic AIS: P<0.0005 for parents and patients, thoracolumbar AIS: P=0.002 for patients and P=0.001 for parents, Wilcoxon matched-pairs signed-ranks test). Parents ranked the pre-operative problems as more severe when compared with patients (thoracic AIS: P=0.03, thoracolumbar AIS: P=0.008).

There were differences in how the scoliosis was perceived. Results of the *current problems* sections for parents and patients by curve type are given in Table 42 and Table 43. The scores of patients with thoracic curves for the problems of *rib-hump/prominence*, *large curve of the spine* and *getting worse in the future* were lower by 2-year follow-up (P=0.002, P=0.0002, P=0.001 respectively, Table 42). The scores of patients with thoracolumbar curves for the problems of *hips not symmetrical*, *large curve of the spine* and *getting worse in the future* were lower by 2-year follow-up (P=0.001, P=0.002, P=0.002 respectively, Table 42).

Table 42. Assessment of current problems associated with scoliosis by patients according to curve type.

Mean scores	**Thoracic (n=20)**			**Thoracolumbar (n=15)**		
Descriptor	**Pre-op**	**2-year**	**P**	**Pre-op**	**2-year**	**P**
Rib-hump/prominence	1.79	0.65	0.002	0.73	0.47	0.459
Shoulders not level	0.79	0.20	0.068	1.07	0.27	0.015
Hips not symmetrical	0.68	0.15	0.020	1.87	0.27	0.001
Waist not symmetrical	0.79	0.10	0.015	1.67	0.33	0.008
Front of chest not symmetrical	0.84	0.40	0.206	0.47	0.20	0.395
Leaning over to one side	0.95	0.30	0.026	1.13	0.33	0.015
Being teased at school	0.32	0.00	0.109	0.00	0.07	0.317
Large curve of the spine	2.11	0.25	0.0002	1.93	0.33	0.002
Getting worse in the future	1.79	0.35	0.001	2.20	0.40	0.002

Where:

P = P value for comparison scores, Wilcoxon matched-pairs signed-ranks test, for significance P=0.005 (applied Bonferroni's correction for individual statements).

Parents gave lower scores for *shoulders not level*, *large curve of the spine* and *getting worse in the future* by 2-year follow-up if their children had thoracic curves (P=0.005, P=0.002, P=0.004

respectively, Table 43). Parents gave lower scores for *hips not symmetrical, waist not symmetrical, large curve of the spine* and *getting worse in the future* by 2-year follow-up if their children had thoracolumbar curves (P=0.001, P=0.003, P=0.002, P=0.005 respectively, Table 43).

Table 43. Assessment of current problems associated with scoliosis by parents according to curve type.

Mean scores	Thoracic (n=13)			Thoracolumbar (n=13)		
Descriptor	**Pre-op**	**2-year**	**P**	**Pre-op**	**2-year**	**P**
Rib-hump/prominence	1.89	0.64	0.006	1.21	0.64	0.083
Shoulders not level	1.42	0.29	0.005	1.14	0.57	0.014
Hips not symmetrical	0.84	0.43	0.160	2.36	0.64	0.001
Waist not symmetrical	0.95	0.14	0.037	2.29	0.29	0.003
Front of chest not symmetrical	1.37	0.14	0.007	0.71	0.14	0.066
Leaning over to one side	1.11	0.36	0.065	1.43	0.64	0.040
Being teased at school	0.63	0.00	0.066	0.36	0.14	0.408
Large curve of the spine	2.32	0.71	0.002	2.71	0.71	0.002
Getting worse in the future	2.37	0.57	0.004	2.36	0.86	0.005

Where:

P = P value for comparison scores, Wilcoxon matched-pairs signed-ranks test, for significance P=0.005 (applied Bonferroni's correction for individual statements).

Analysis of the changes in responses to the current problems section between pre-operative and 2-year assessments for patients reveals significant differences between thoracic and thoracolumbar curves (P < 0.0005 RMMANOVA, using curve type as a between subjects factor, Table 44).

Table 44. Responses to *current problems* statements at pre-operative and 2-year assessments. Repeated measures multivariate analysis of variance for patients with thoracic or thoracolumbar curves, using curve type as between-subjects factor (n=33).

Source of variation	**df**	**Sums of Squares**	**Mean Square**	**F**	**P**
Responses to each statement	8	57	7.2	13	<0.0005
Curve type by response	8	21	2.6	4.7	<0.0005
Within+Residual	248	138	0.56	_	_
Pre-op/ 2-year follow-up	1	107	107	67	<0.0005
Curve type by follow-up	1	0.96	0.96	0.62	0.438
Within+Residual	31	48	1.56	_	_

Where:

Source of variation	= Source of variations in the response variable
df	= degrees of freedom
Sums of Squares	= magnitudes of differences between repeated measures
Mean Square	= sums of squares divided by the degrees of freedom; estimates the variation in the data
F	= test statistic for the F distribution - equals the mean square for each factor divided by the mean square of the error term
P	= P value, the significance of changes in the response variable with repeated measurement

The interpretation of the results presented in Table 44 is that significant differences exist between the responses to each statement, differences exist between pre-operative and 2-year assessments and responses to the statements vary according to curve type. However, curve type is not a factor for the changes that occur between assessments.

The analysis was repeated for parents (n=26) with the same results and interpretation.

Inspection of Table 42 and Table 43 reveal that the differences in perception relate predominantly to rib-hump and hip and waist asymmetry. According to the mean scores for each statement, patients with thoracic curves and their parents were most concerned about, in order, *Large curve of the spine*, *Getting worse in the future* and *Rib-hump/prominence*. Patients with thoracolumbar curves and their parents were most concerned about *Getting worse in the future*, *Large curve of the spine* and the *hips and waist not being symmetrical*. The same factors were those that were perceived to have improved after surgery.

Comparison between radiographic and surface measurements and responses to questionnaire items

A P-value of 0.003 was taken as significant to reduce the chance of a Type I error occurring when multiple comparisons are made (Bonferroni's correction).

Thoracic curves

The strongest correlation between questionnaire results and radiographic measurements for patients with thoracic curves was between ODI and AVT (P=0.039, Spearman correlation coefficient) at pre-operative assessment and between ODI and AVR (P=0.003) and ODI and AVT (P=0.006) at 2-year assessment. Maximum ATI and SAS correlated with each of VAS (P=0.005, P=0.017 respectively), ODI (P=0.002, P=0.001 respectively), and short-form McGill (P=0.004, P=0.022 respectively, Spearman correlation coefficient) at pre-operative assessment.

Patients' grading of the severity of their *shoulders not being level* correlated with acromial height difference (P=0.002) and pre-operative frontal plane balance correlated with parents' grading of *leaning over to one side* (P=0.008).

Of 15 patients who indicated the site of their pain, 11 said it was worst in the thoracic spine, 3 said it was worst in the low back/buttock region and one said the pain was worst in the neck.

Thoracolumbar curves

AVT correlated with each of VAS (P=0.033, not significant with Bonferroni's correction), ODI (P=0.006), and short-form McGill (P=0.001, Spearman correlation coefficient) at pre-operative assessment. There was no correlation between pre-operative maximum ATI and SAS and each of Ste-Justine Body Image, ODI and short-form McGill. The correlation of pre-operative maximum ATI and SAS with VAS (P=0.055 and P=0.011 respectively) was not significant once a Bonferroni's correction is applied.

Of 13 patients who indicated the site of their pain, 10 said it was worst in the low back/buttock region, 2 said it was worst in the thoracic spine and one said the pain was worst in the neck.

Discussion

Most studies of scoliosis focus on radiographic outcome measures. Studies using patient-based outcome questionnaires are less common and are usually of a cross-sectional or retrospective design. There are few prospective studies in AIS[162,243].

The self-perception section

There was no change in perception of self between pre-operative and 2-year follow-up when questions used in the Ste-Justine study were given to the Nottingham patients (P=NS, Wilcoxon matched-pairs signed-ranks test for total scores, RMMANOVA for simultaneous comparison of individual questions). There was no difference in perception of self found by curve type when total Ste-Justine Body Image scores were compared (P=0.1 for pre-operative data, P=0.1 for 2-year follow-up data, Mann-Whitney U Test using curve type as the grouping variable). However mean scores were lower in the thoracolumbar patients.

The Ste-Justine AIS cohort study assessed the effect of AIS on health and well-being in adulthood. It was a comparative retrospective study of 1476 subjects and 1755 population-based age-matched controls with results published in four parts[122,123,199,264]. Around 30% of the AIS patients had surgical treatment in the past[122]. Goldberg et al found that AIS subjects a minimum of 10 years after referral, when compared with the age-matched control group, perceived themselves to be less healthy, had a poorer perception of body image, had more difficulty with physical activities and had more days ill[123]. Nevertheless, they had a more positive perception of self.

There were some striking differences between the responses our patients made to some questions and the responses of the Ste-Justine Cohort Study AIS and control subjects (Table 32, page 166). For example, 85% of Nottingham patients gave a positive response to the statement 'I hate parties and social occasions' compared with around 33% of Ste-Justine Cohort Study AIS and control subjects. 74% of the Nottingham patients gave the positive response to 'I'm a failure at everything I do' compared with around 5-10% of Ste-Justine Cohort Study AIS and control subjects. This probably reflects the different age of the populations being studied. The Ste-Justine Cohort subjects were mainly in their fourth decade whilst the Nottingham patients were mainly in their second decade.

White et al[373] administered the Scoliosis Research Society outcomes instrument[136] to 168 patients who had spinal instrumentation for JIS or AIS. They found patients with thoracolumbar and lumbar curves reported higher self-image scores but the type of instrumentation used was a confounding variable in that only one of the thoracolumbar and lumbar curves was treated with Harrington instrumentation, compared with 22 thoracic curves.

The pain section

Pre-operative assessment

My study found that at *pre-operative* assessment, pain intensity as measured by VAS and the short-form McGill were significantly correlated with curve severity measured by each of Cobb angle, AVT, maximum ATI and SAS (Table 40 and Table 41, pages 173 and 175). Correlation with Cobb angle was the weakest of the four measures of curve severity. 33 of 39 patients had some pain at pre-operative assessment (85%), though the level of pain was low (VAS=2.4 cm and mainly rated 'mild'). The most common type of pain was mild back ache.

Reported prevalences of back pain in normal adolescents are lower, varying from 17% to 39%[15,16,35,100,231,235,342]. A recent study of Danish schoolchildren found thoracic and lumbar pain was equally common amongst 14-16 year olds, with 38% reporting some consequences of the back pain[231]. Nissinen et al found the 1 year (from 12.8 to 13.8 years) incidence of LBP in 408 girls and 451 boys in Finland was 18.4% in girls and 16.9% in boys[235]. They also found that trunk asymmetry was a significant predictor of low back pain. Their screening question for pain was 'Have you ever had pain in your lower back?'.

Ramirez et al performed a retrospective study of 2442 patients with IS and found 560 had back pain and of these, 48 had an underlying pathological cause[273]. Part III of the Ste-Justine Cohort study assessed the frequency and duration of episodes of back pain during the previous year and any current back pain in AIS and controls[199]. 44% of subjects had current back pain compared to 24% of controls. The intensity of pain was greater for patients who had surgery and for patients whose curves were grouped in the 1-19 degree category than that experienced by controls. Other studies on untreated scoliosis have found a 30% to 60% incidence of back pain[11,32,164,228,366], similar to that in the general adult population[366]. Retrospective studies of IS have found that patients treated by fusion (n=91) had less back pain than those left unfused (n=77)[95] and that surgically treated IS patients reported a greater decrease in pain and increase in function since operation when compared with patients who declined operation[83].

There was no change in VAS and short-form McGill scores from pre-operative assessment to 2 years after surgery in the Nottingham patients. There are few other prospective studies of back pain in AIS. A Medline search from 1980 onwards using search terms 'Idiopathic scoliosis' [Complication, Rehabilitation, Epidemiology, Surgery, Etiology, Therapy] AND 'pain' produced 51 papers, none of which had prospective data for back pain in AIS.

At 2-year assessment, 11 patients had no pain (28%), and the 72% who did have pain rated it mainly as 'mild' (mean VAS=1.8 cm).

Lenke et al reported that 38% of 63 patients with AIS treated by CDI at 5 to 10 year follow-up had some degree of back pain[175]. Dickson et al[82] found that 84% of scoliosis subjects treated with Harrington rods (surgery from 1961 to 1963) had back pain when compared with 52% of non-scoliosis controls. The scoliosis group had more pain in the inter-scapular and thoracolumbar regions compared with the control group[82]. Cochran et al[65] reported that the prevalence of back pain among those surgically treated (65%) was not greatly different from a control series of hospital employees and outpatients attending for treatment of minor injuries.

There was no correlation between curve severity and pain severity at 2-year follow-up for the Nottingham patients, and no correlation was found between extent of fusion and back pain measurements in the current study. However, it should be noted that the low number of patients in each group means the power to detect such associations would be low. The fourth part of the Ste-Justine Cohort study[264] studied back pain in patients treated with

Harrington rods (555 of 723 respondents). They found little variation in back pain by pre-operative Cobb angle, curve type or side, number of vertebrae fused and level of fusion.

Several other retrospective studies also found no association between extent of the fusion and back pain[82,184,215,223]. However, Cochran et al[65] found more back pain in patients fused to L4 or L5 and Fabry et al[97] found that lower fusions are prone to give more back pain based on a retrospective study of 182 IS patients.

Recently Haher et al in a cross sectional evaluation of the Scoliosis Research Society Instrument for the evaluation of AIS on 244 patients found that satisfaction with surgery correlated most strongly with the pain domain[136]. My study would indicate that it may not be possible to reliably decrease the amount of pain a patient experiences at 2 years after surgery, given that the most usual complaint is of a mild back ache.

Oswestry Disability Index (ODI) - Use in teenagers and AIS

My mean results for ODI of 9.2 and 6.9 for pre-operative and 2-year assessments are compatible with that from the normal adult population considered in Fairbank and Pynsent's review of the literature[99]. Four of 39 patients at pre-operative assessment and 3 of 39 patients at 2-year assessment scored over 25 points (7-10%). For these patients scores were of the order normally associated with spondylolisthesis, neurogenic claudication and chronic back pain[99].

The Ste-Justine study of back pain in AIS[199] compared ODI scores of 650 patients with AIS (259 having had surgery) with 418 population-based controls. Total mean scores were a few points higher in the scoliosis group. Difficulty with managing pain, lifting, walking and socialising was associated with Cobb angle. Women with scoliosis were significantly more limited than unaffected women in their ability to lift heavy objects, to walk long distances, to travel, to sit or stand for long periods and to enjoy social activities. For men, the results were statistically significant for sitting. They concluded that the 'results of this study suggest that back pain is responsible for a considerable amount of disability and handicap in later life'. Unfortunately they scored the ODI out of 6 for each section instead of 5. Fairbank and Pynsent[99] reviewed the literature and found the ODI administered to a normal population results in a score of 10.19 (one standard deviation range 2.2-12, n=461), while AIS patients scored 13.81 (SD 9.2-13, n=1264). I think it is overstating the case to say that there is 'considerable amount of disability and handicap in later life' due to back pain in patients with AIS[199]. The figures that the Ste Justine group present indicate that between 2 and 20% have 'considerable' problems depending on which section of the ODI is considered[199]. Mayo published scores for the ODI using scoring from 0 to 5 in a subsequent letter and qualified their initial conclusion with '...indeed, a sizeable proportion of the scoliosis population is doing very well'[198].

At pre-operative assessment disability as measured by ODI was significantly correlated with curve severity measured by Cobb angle, AVT, AVR, maximum ATI and SAS (Table 40 and Table 41, pages 173 and 175). These findings are in keeping with those of the Ste-Justine study[199].

Psychosocial Adjustment to Illness Scale (PAIS)

The current study demonstrated no change in sections 1 (health care orientation), section 2 (vocational environment) or the shortened sections 3 and 4 (domestic and social environment respectively) between pre-operative and 2-year assessments. No control data was available. There was a significant reduction in the score for section 5 (psychological distress, P=0.001, Wilcoxon matched-pairs signed-ranks test) which is probably because the questionnaires were administered a mean of 10 days prior to surgery (range 1-62 days). The anticipation of major surgery is likely to be causing psychological distress in these patients. The adverse psychological impact of surgery[141,230] and brace treatment[8,126] for scoliosis has been shown, and usually disappears with time[8,126,141,223].

Cadman et al[55] studied the psychosocial characteristics of parents and families of children with chronic illness or physical disability (chronic health problems), compared with control families (n=1869 families). Significant positive findings included increased rates of parental treatment for 'nerves' and increased maternal negative affect scores (P<0.001). They concluded that families of children with chronic health problems including physical disability do not suffer a marked excess of dysfunction, although some indicators of parental psychosocial problems were modestly elevated in some individuals.

Pre-operative aims of surgery (patients and parents) and 2-year realisation of aims

Analysis of my data reveals that at pre-operative assessment the four most severe problems were, *large curve of the spine, getting worse in the future, hips not symmetrical and rib-hump/prominence,* (most severe first) for both parents and patients (Table 38, page 171). The latter concerns were different according to curve type, with *rib-hump/prominence* being of concern to those with thoracic curves and *hips not symmetrical* being of concern to those with thoracolumbar curves. It is not clear from the data the extent to which patients' and parents' concerns are influenced by what had been told to them by medical staff. Patients were assessed a mean of 10 days prior to surgery (range 1-62 days) by which time they will have been told the aims and expected results of surgery. There are no studies of patients' concerns performed prior to contact with surgeons. Bridwell et al[38] studied 91 patients' and their parents' concerns and expectations at pre-operative assessment. They found that the possibility of neurologic deficit after surgery caused greatest concern, and location and appearance of the scar were of the least concern. Again, they could not determine the extent to which patients' and parents' concerns were influenced by friends, the primary care physician, the Internet or clinic staff[38].

Patients' and parents' ranking of problems associated with scoliosis were compared at pre-operative and 2-year assessments (n=26). At pre-operative assessment, parents rated the problems to be more severe than the patients did (P=0.0009, Wilcoxon matched-pairs signed-ranks test) but there is no difference at 2-year assessment. Bridwell et al also found that generally parents' concerns were higher, and their expectations were greater than that of the patients'[38].

The total scores for current problems associated with scoliosis were significantly lower at 2-year follow-up when compared with pre-operative assessment for both parents (n=27) and patients (n=35) (P<0.0005, Wilcoxon matched-pairs signed-ranks test). This finding may be explained in two ways. Firstly, surgery has caused a reduction in the perceived problems associated with scoliosis. Secondly, imminent surgery artificially increases perception of scoliosis problems. With time the perception of problems reduces to a baseline level again. If the second explanation was true then the perception of scoliosis problems may be expected to be greater the closer to surgery the pre-operative assessment was performed. No such relationship was demonstrated (patients P=0.7, parents P=0.5, Spearman rank correlation). As yet there are no other prospective studies with which to compare these results.

Patients were not very critical in the responses they gave in the results of surgery section. 'Fully corrected' was often indicated for aspects of scoliosis that the patient previously did not consider a problem, for example *being teased at school*. Such responses make surgery seem more successful than it is. 'Fully corrected' seemed to be selected by default. A more logical response would be 'made no difference'. This questionnaire section should be revised to include a neutral default response. Similar incongruities can be found in other studies. Moskowitz and Trommanhauser studied 13 adolescents and 19 adults with lumbar and thoracolumbar curves by retrospective questionnaire. They report that, regarding cosmetic results, 26 of 27 patients were satisfied with the cosmetic results of surgery, even though 7 of 26 patients had no cosmetic complaints prior to surgery. Despite the high level of satisfaction, only 17 of 27 had no difficulty wearing a bathing suit and 22 of 27 had no objection to the clinical appearance of the scar[224]. 'Satisfaction' appears to be a relative term, and does not mean the patient has no problems or is completely happy, which might be our initial impression.

Comparison between radiographic and surface measurements and responses to questionnaire items

At pre-operative assessment pain and disability as measured by VAS, short-form McGill and ODI was correlated with curve severity measured by AVT, maximum ATI and SAS (Table 40 and Table 41, pages 173 and 175). ODI was most strongly correlated with AVT, which supports the routine use of this measurement in scoliosis assessment. VAS and short-form McGill were most strongly correlated with maximum ATI, which raises the possibility that the magnitude of the rib-hump may be causative in the production of pain. No correlations were statistically significant for 2-year follow-up data.

No significant correlation was found between parents' and patients' grading of *large curve of the spine* as a current problem and Cobb angle for both assessments. No significant correlation was found between *leaning over to one side* and each of radiographic frontal plane balance and plumb-line. No significant correlation was found between *rib-hump / prominence* and maximum ATI. No significant correlation was found between *shoulders not level* and the anthropometric measurement of acromial height difference. There were no correlations between changes in parents and patients perceptions of the above parameters between pre-operative and 2-year assessments and changes in the corresponding radiographic and anthropometric measurements. This is likely to be explained by large intra-observer variations between patients and between parents. The implication is that patients' and parents' perception of the results of surgery is influenced by factors other than the physical effects of surgery on the above radiographic or anthropometric measurements, as suggested by Koch et al[162].

Only pre-operative SAS correlated with the patients' grading of the severity of their rib-hump (r=0.445, P=0.007). This supports the use of a measure of back surface asymmetry on the grounds that it bears a relationship to the patients' grading of the severity of their rib-hump.

There has been no other study to-date that has prospectively compared radiographic and surface measurements and responses to questionnaire items.

Results by curve type

Some significant differences between thoracic (n=21) and thoracolumbar (n=15) curves were found. Concern regarding the large curve of the spine and future progression were a common theme. Patients with thoracic curves and their parents were concerned about the rib-hump. Patients with thoracic curves complained predominantly of thoracic back pain and VAS and short-form McGill scores correlated with maximum ATI (p=0.005 and p=0.004 respectively, Spearman rank correlation) at pre-operative assessment. Disability (ODI) correlated with both maximum ATI and SAS (P=0.002, P=0.001 respectively). One possible explanation of these significant correlations may be that the rib-hump prominence impinges on the scapula leading to thoracic back pain.

Patients with thoracolumbar curves and their parents were concerned about hip and waist asymmetry rather than rib-hump prominence. Hip and waist asymmetry is implicit in thoracolumbar curves on account of the level of the apex. The rib-hump may be less noticeable with thoracolumbar curves compared with thoracic curves because only the lower part of the thoracic cage is involved. Pre-operative frontal plane balance was significantly worse in patients with thoracolumbar curves (P=0.0003) which may accentuate the hip and waist asymmetry. Moskowitz and Trommanhauser found that the most common pre-operative cosmetic complaint (18 of 26) was of uneven hips[224].

Patients with thoracolumbar curves predominantly complained of low back pain and both ODI and short-form McGill scores correlated with pre-operative AVT (p=0.006, p=0.001 respectively, Spearman rank correlation). The reason for this relationship is unclear.

Nissinen et al studied a population of pubertal schoolchildren and found that trunk asymmetry was a modest predictor of lower back pain[233,235].

Conclusions

There have been no published prospective studies examining the relationship between patients' perceptions of self-image, pain, disability and problems associated with scoliosis and back surface and radiographic measures of deformity, before and after surgery.

Preoperative assessment

The most important features of scoliosis that both parents and patients wanted surgery to correct were (i) the spinal curvature and (ii) the prospect of curve progression. The parents' ratings of problems associated with scoliosis were greater than the patients'. The incidence of back pain (85%) was higher than that reported for normal adolescents. The mean pre-operative ODI was similar to that of a normal adult population. Patients' grading of the severity of their rib-hump correlated significantly with SAS. This supports the use of a measure of back surface asymmetry for assessment of cosmesis. No other significant correlations between subjective (patient / parent) and objective (radiographic / anthropometric) measurements were found.

Differences between thoracic and thoracolumbar curves

The third feature of scoliosis that both parents and patients wanted surgery to correct was the rib-hump prominence for those with thoracic curves, while those with thoracolumbar curves wanted hip and waist asymmetry to be addressed. Patients with thoracic curves had predominantly mild thoracic back pain, and each of VAS, short-form McGill score and ODI correlated with maximum ATI. Patients with thoracolumbar curves had predominantly mild low back pain, and both ODI and short-form McGill score correlated significantly with AVT.

Results by 2-year follow-up

There was no detectable change in self-image, pain and ODI between pre-operative and 2-year assessments. Correction of AVT and maximum ATI by surgery did not result in a reduction of pain. The period prior to surgery was psychologically distressing for patients. Problems specifically related to scoliosis were perceived as being less at 2 years after surgery by both patients and parents.

CONCLUSION OF RESULTS OF STUDIES ON IDIOPATHIC SCOLIOSIS

This thesis is concerned with the results of observational studies of surgery and follow-up on patients with IIS, JIS and AIS. These types of IS are distinct based on age, and have differing prognoses, sex distribution, side distribution and curve morphologies. However, some elements of curve behaviour after surgery are similar.

Results of studies of methodology

The reproducibility of vertebral translation and vertebral tilt was better than that for axial vertebral rotation when considered in proportion to the deformity being measured. Indeed, Benson et al concluded that measurement of vertebral rotation on PA radiographs would never be accurate enough[25]. This was reflected in the clinical results, in that major findings for thoracic curves did not concern vertebral rotation. CT scanning demonstrates the changes in vertebral rotation with surgery are a mean of 3.8° correction from pre-operative to 8-week assessment after implantation of posterior USS[67] and thus comparable to the error in measurement from PA radiographs.

Reproducibility of the Scoliometer was superior to ISIS. The best position for measuring surface deformity was the standing forward bending position. This information on back shape cannot be extrapolated from the findings of radiographic measurements and it is only measures of back shape that were found to correlate with patients' perception of their body-image.

Results of studies of IIS and JIS

The concave rib-spine angle and the upper end-vertebra tilt predicted Cobb angle at 5-year follow-up in patients treated with convex epiphysiodesis and Luque trolley. If the resultant Cobb angle at 5 years is thought of consisting of the immediate effect of surgery (change in Cobb angle from pre-operative assessment to 8-week follow-up) and the changes during follow-up, then the concave rib-spine angle is most important in determining the correction effected by surgery. Growth in the instrumented segment was predicted by pre-operative Cobb angle.

The curves of patients having Luque trolley alone all progressed, but 5 of 7 entered the adolescent growth spurt during the 5-year follow-up period. The effect of the adolescent growth spurt on those treated with convex epiphysiodesis and Luque trolley has not yet been fully evaluated.

Factors associated with outcome were therefore (i) pre-operative concave rib-spine angle and (ii) upper end-vertebra tilt. Other factors which are probably important in outcome studies are the adolescent growth spurt, the effect of which was not fully evaluated in these patients, and convex epiphysiodesis. It was not possible to determine the relative importance of these latter factors as those patients who did not have a convex epiphysiodesis were older and entering the adolescent growth spurt during follow-up.

The combination of the Luque trolley and convex epiphysiodesis was enough to prevent progression and even to result in partial curve resolution; but once the growth capacity of the Luque rods was exceeded both resolving curves then worsened. Thus these were not naturally resolving curves incorrectly identified as progressive curves.

Implications for pathomechanisms of curve progression

The upper end-vertebra tilt predicted Cobb angle at 5-year follow-up in patients with IIS treated with Luque trolley and CE. The importance of this factor is partly in determining the correction achieved with surgery but more so in determining the progression of the curve after surgery. Empirically, the curves with the worst outcome had marked and sudden angulation at the upper end of the curve, while those curves with the best results had smooth curves with a gradual progression of vertebral tilt down the spine. This suggests that if factors for curve progression are acting on a small section of the spine, then their potential for producing curve progression is greater. Equally, these observations could be the result of a breakdown in homeostatic mechanisms. Whatever factors produce the changes in the upper end-vertebra, once established it is easy to conceive that a greater proportion of growth will be directed to cause curve progression in those curves with more deformity.

Even within the small group studied, differences in curve morphology by upper end-vertebra tilt could be distinguished. Some curves were characterised by smoother thoracolumbar 'C' shaped curves, while the malignant ones had a sharp thoracic scoliotic angulation. These differences in morphology may represent different underlying causes of IIS.

The concave RSA was found to be most important in determining the correction of the Cobb angle achieved with surgery. The balance of the evidence suggests the thoracic cage is acting as a brace resisting deformation of the spine produced by surgery. The biomechanical role of the thoracic cage in stabilising the thoracic spine has been demonstrated in canine thoracic cage specimens[242]. It is possible that the thoracic cage might resist pathomechanisms for curve progression also, or that it may cause progression itself. However, in the relative short term it resists the effects of surgery. Information on how it may be implicated by growth mechanisms, as suggested by Sevastik, has yet to be gathered and would require 10 to 15 years of follow-up study.

Implications for further surgical management

There were problems with the Luque trolley instrumentation system, namely of wire breakage and growth in excess of that allowed by the rods. Possible solutions included repeated surgery to implant longer rods or using some form of telescoping system. One possible design is given in Figure 18, page 89.

Growth only occurred along the Luque rods if the Cobb angle was corrected to 30 degrees or less after surgery. The two patients who did not have their IIS corrected to 30 degrees or less after Luque trolley and CE had no growth in the direction of the Luque rods by 5-year follow-up implying that the post-operative curve magnitude was such that the resultant vector of growth was not sufficiently parallel to the Luque rods for spinal growth along the rods to occur.

The data suggest the importance of the upper part of the curve and the concave ribs in determining outcome after surgery. One approach to improve the correction achieved with surgery would be to interrupt the structural integrity of the thoracic cage through costoplasty. Concave rib costoplasty with or without convex epiphysiodesis might be sufficient to control scoliosis progression without use of instrumentation. Children with severe upper end-vertebra tilt and drooping apical concave ribs would be expected to require early instrumentation, costodesis and convex epiphysiodesis. Further follow-up of these children will be essential.

Results of studies of AIS

Thoracic AIS treated using posterior USS

Comprehensive back surface measurements allowed study of the rib-hump both before and on follow-up after surgery. Almost half of initial back-surface correction was lost during follow-up. These changes were not completely reflected in changes in radiographic parameters, but were most closely reflected in changes in segmental vertebral translation (see *Relationship between segmental ATI and segmental vertebral tilt, rotation, translation and rib-spine angles*, page 126). Measurement of vertebral axial rotation on PA radiographs was not found to be informative of changes occurring in back shape and I believe that measurement of vertebral translation in the assessment of IS should be routine. However, the apparent importance of movement in any one plane to bring about rib-hump correction may only be a reflection of the accuracy of the data that is obtained on PA spinal films or CT scans rather than implying pathomechanisms.

Rib-hump reassertion occurred regardless of age, mainly between 8 weeks and 1 year and was predicted by concave 9th RSA. The results of surgery in terms of rib-hump were predicted by spine (pre-operative frontal plane tilt of L1) and rib (concave 5th RSA) factors, which implies an interplay between the thoracic cage and the spine as found in patients with IIS. The percentage correction of Cobb angle was predicted by pre-operative tilt of L1 and ATI at level 6 down the spine.

After concerns about the spinal curvature and the prospect of curve progression, patients with thoracic curves and their parents were most concerned about the rib-hump prominence and wished it to be corrected. The intensity of the predominantly mild thoracic back pain correlated with maximum ATI and SAS and it was postulated that the rib-hump may be causative in this, but correction of the rib-hump with surgery did not improve back pain. Surgery was perceived to address the issues of spinal curvature, the prospect of curve progression, the rib prominence, shoulder and hip and waist asymmetry and the lean to one side.

Implications for surgical interventions

As spine and thoracic cage factors determined results of surgery, surgical disruption of the thoracic cage by costoplasty may improve the initial correction of Cobb angle achieved with surgery, prevent rib-hump reassertion and have the added cosmetic effect of reducing the size of the rib-hump. The latter effect has been demonstrated at the Twin Cities Scoliosis Spine Center, where convex costoplasty to improve the rib-hump correction is performed[110].

Previous work on the effect of costoplasty

Modern instrumentation systems can produce good corrections of scoliosis in terms of spinal deformity but the studies in this thesis have demonstrated that the correction of the rib-hump is less in percentage terms and tends to be lost in the first post-operative year.

Volkmann first described the use of rib resection in the treatment of scoliosis in 1889[361]. Rib resection was used in the context of preventing scoliosis progression[261,345] but long term results were disappointing[18]. Other workers have described their techniques of costoplasty, with the aim of improving the cosmetic results of scoliosis surgery[21,39,79,140,174,195,332] and most of these techniques have utilised excision of the most prominent convex ribs. Owen et al recognised the improved correction of scoliosis that resulted after convex costectomy was performed[245]. However, few of these studies adequately documented the improvement in back surface correction that was achieved with convex costoplasty. That was demonstrated by Geissele et al[110].

There is little work on use of concave costoplasty in the treatment of scoliosis. Concave costoplasty alone was inadequate to prevent scoliosis progression[18,261] but its use is being advocated for selected patients once more[315]. Results of concave costoplasty with posterior instrumentation for rigid adult scoliosis have recently been reported[214]. A rib-hump improvement of 3.5 cm was reported, the technique involving allowing an overlap of the sectioned concave ribs over the ipsilateral spinal rod. In view of the findings of this thesis implicating the concave ribs, then the logical treatment of thoracic AIS should be concave costoplasty combined with posterior instrumentation.

The disadvantages of performing costoplasty are that the operating time is increased and that pulmonary complications may occur. Steel et al documented that the pulmonary function returned to normal at three years after surgery in adolescents[332], Lenke et al found similar findings except that adults did not regain their previous pulmonary function 2 years after costoplasty[174] and urged caution in older patients with below average respiratory function.

Changes in frontal and sagittal plane balance

Frontal plane decompensation has been well documented for King-Moe type II curves treated by CDI[23,37,173,202,220,260,279,300,321,351]. Suggested reasons for this include over-correction of the thoracic curve[37,202,272], use of the derotation manoeuvre[279,351], inappropriate distraction across the thoracolumbar junction[321] and incorrect hook and rod bend placement[173]. Although there is an initial change in frontal plane balance to the left in right thoracic curves treated by USS, this corrects by 2-year follow-up. This correction correlates significantly with changes in the lumbar spine (sagittal plane vertebral tilt). This may relate to differences in surgical technique used to implant CDI and USS respectively. The thoracic derotation manoeuvre used with CDI could result in rotation being transmitted to the lumbar spine so preventing lumbar spine compensatory mechanisms for that correction of frontal balance. The segmental translation manoeuvre used with USS still allows frontal balance correction by the lumbar spine. No significant changes in FPB where seen in King-Moe Type III curves.

Compensation by 2 years follow-up also occurred for the changes in sagittal plane balance, lordosis and kyphosis which occurred after surgery for both King-Moe Type II and III curves.

Anterior USS for thoracolumbar curves

Patients with thoracolumbar curves and their parents were most concerned about the spinal curvature, the prospect of curve progression and asymmetry of the hips and waist. Patients experienced predominantly low back pain, related in intensity to the AVT, which is postulated to be of musculoskeletal origin. Surgery was perceived to address these issues except that back pain was unchanged.

One way in which the structure of a thoracolumbar curve differs from that of a thoracic curve is that the apex of a thoracolumbar curve is not constrained by fixed ribs. If the thoracic cage acts as a brace to the spine as suggested by the results for IIS and thoracic AIS, then it should be easier to correct a thoracolumbar curve with surgery and the forces for reassertion of deformity should be less. This is confirmed by the results from Section IIii (see page 136) for thoracolumbar curves treated by anterior instrumentation which show greater correction of back shape and Cobb angle compared with that obtained for thoracic curves and less reassertion of the rib-hump. Rib-hump reassertion was again related to changes in segmental vertebral translation. The percentage correction of maximum ATI by 1 year is predicted by spine (tilt of T4) and rib (3rd concave RSA, where concave refers to the side of the thoracolumbar curve) factors (Figure 40, page 148, regression equation R^2=0.86). This demonstrates the influence of the thoracic spine and thoracic cage in influencing the results for surgery on thoracolumbar curves. Less correction is achieved in patients with *compensatory* thoracic curves with drooping convex (of the compensatory thoracic curve) ribs. This implies that these thoracic spines above the thoracolumbar junction are more resistant to the deforming forces produced by surgery.

Implications for surgical interventions

Given the smaller quantitative reassertion of back surface deformity for thoracolumbar curves then the absolute effect of costoplasty on the rib-hump deformity and in reducing the forces induced by surgery for reassertion of deformity may be less, and may not be indicated for these curves in terms of the extra morbidity associated with a further surgical procedure. In addition, patients with thoracolumbar curves and their parents were more concerned about hip and waist asymmetry rather than the rib hump. Care should be taken to contour the rod correctly in the sagittal plane across the thoracolumbar junction especially in patients with large pre-operative thoracic kyphosis to prevent the development of a kyphosis above the instrumented vertebrae.

Other differences between thoracolumbar and thoracic curves

There was more reassertion of spinal deformity (vertebral tilt) in thoracolumbar curves compared with thoracic curves from 8 weeks to 1-year follow-up and this was attributed to the shorter length of spinal fusion for thoracolumbar curves.

Statistically significant correction of vertebral rotation occurs after anterior surgery for thoracolumbar curves, which was not found after posterior surgery for thoracic curves. This finding was unexpected as rotational movement should be constrained by the orientation of the facet joints of lumbar vertebrae. The results indicate that this cannot be the dominant determinant of rotational changes in thoracolumbar curves. Much larger changes in vertebral rotation occur in thoracolumbar curves with surgery, which may be due to factors such as (i) the orientation of the facet joints in the lower thoracic spine allowing derotation to occur, (ii) a lack of buttressing of the curve by the lower ribs and (iii) surgical release of anterior discs and ligaments.

Parental and patient perception of scoliosis

Patients present with one or more of the external manifestations of scoliosis and surgery is performed ostensibly to address these issues, but there has been no prospective studies examining the relationship between the results of surgery as perceived by doctors and what the patients perceive as the results.

Patients expected surgery to correct spinal curvature, address the rib-hump and stop progression of the curve. Rib prominence, shoulder and hip and waist asymmetry, lean to one side, spinal curvature and progression were perceived as less by 2 years after surgery and to that extent surgery was successful. Parents rated scoliosis problems more severely than their children and perceived fewer problems after surgery. There was no change in perception of body image or back pain after surgery.

Pre-operative SAS correlated with the patients' grading of the severity of their rib-hump and this finding supports the use of a measure of back surface asymmetry on the grounds that it bears a relationship to the patients' grading of the severity of their rib-hump.

The behaviour of thoracic and thoracolumbar curves after surgery is distinct though the postulated role of the thoracic cage as a brace is demonstrated for both. The effect of the thoracic cage in thoracic curves probably indicates costal interventions in the further surgical management of scoliosis, but the same does not apply for thoracolumbar curves. It is attractive to study subgroups of scoliosis to look for underlying causes but practically this approach will require multi-centre collaboration and resources. The earlier prediction of progressive scoliosis and possible modification of spinal growth with implantation of instrumentation that allows this growth to counteract progression is one gaol but long term studies of 10 to 15 years duration will be needed to study the effect of growth modification on scoliosis.

Acknowledgements

The author wishes to thank Professor R.G. Burwell for his unstinting guidance, advice, help and encouragement, Mr J K Webb who kindly allowed access to his patients, the AO foundation without whose financial support the studies would not have been possible and Fiona, my wife, who has cheerfully supported me ever since she left those antipodean shores.

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