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Scoliosis

Surgical versus Nonsurgical Treatment

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This article reviews the nonoperative and operative decision making process in idiopathic scoliosis in the adolescent and adult with additional comments about degenerative scoliosis. Because knowledge of the natural history of idiopathic scoliosis is essential for decision making, this will be covered first, as will the current knowledge concerning the long term outcomes of nonoperative and operative treatment. With the natural history as a background, I will discuss how the factors that are important in natural history effect decision making in the adolescent and adult. By using an evidence-based approach, hopefully a better decision-making process will result in improved outcomes. Additional treatment decisions regarding the choice of the specific nonoperative treatment methods as well as surgical decisions (fusion levels, approach, choice of implants) will not be covered.

Level of Evidence: Therapeutic study, level V (expert opinion). See the Guidelines for Authors for a complete description of the levels of evidence.

Any decision regarding the treatment (nonoperative or operative) of any condition is based on the premise that the treatment alters the course or natural history of that condition. To make these decisions a knowledge regarding the natural course of the untreated condition is compared with the results of treatment in the short and long term. In order to be regarded as effective the treatment must alter the natural history favorably; in addition, the treatment should have no long-term adverse consequences.

In idiopathic scoliosis, the long-term effects of the untreated scoliosis is well documented in earlier studies[54,58] with mixed diagnoses, but has been clarified with more recent studies.[83–85] The most important factor in the natural history of adolescent idiopathic scoliosis is related to curve progression; the factors related to curve progression in the adolescent and adult are well documented.[2,11,30,41,44,69] Authors of studies on the long-term effects of treatment have been reported from Canada[31,32,48,64] and Sweden[16–20] and show excellent function after brace or surgical treatment compared with a control group of subjects without scoliosis.

I will provide information on background studies on untreated scoliosis, the factors related to progression in adolescents and adults, and untreated adolescent idiopathic scoliosis in adulthood. Nonoperative and operative decision making will be reviewed in the adolescent and adult using an evidence-based approach. The basic treatment decision (observation, nonoperative, operative) will be covered without details as to the nonoperative treatment plan or the technical details of surgery.

Natural History of Untreated Idiopathic Scoliosis

Adolescents

By definition, adolescent idiopathic scoliosis is a structural lateral curvature of the spine that occurs at or near the onset of puberty for which no cause has been established to date. By the Scoliosis Research Society (SRS) definition, it includes cases of idiopathic scoliosis that are diagnosed after the age of 10 years. It is diagnosed with asymmetry on forward bending combined with a curve of at least 10° as measured by the Cobb technique on a standing radiograph of the spine with vertebral rotation.[37] By this definition the prevalence of adolescent idiopathic scoliosis with curves greater than 10° in children 10 to 16 years old is about 2% to 3%.[3,8–10,38,43,52,59,69,71,75,86] The male-to-female ratio of patients with small curves is about equal, but with curves of larger magnitudes there is an overwhelming female preponderance[3,8,9,38,43,87,90] (Table 1). As the curve magnitude increases the prevalence decreases so that the prevalence of curves greater than 30° is 0.1% to 0.3%[10,38,69,71,86,87] (Table 1). Some authors indicate that less than 1% of the screened population and less than 10% of those with curves greater than 10° require treatment.[9,44,69,87]

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TABLE 1. Prevalence of Adolescent Idiopathic Scoliosis

Cobb Angle (degrees)	Female-to-Male Ratio	Prevalence (%)
> 10	1.4–2:1	2–3
> 20	5.4:1	0.3–0.5
> 30	10:1	0.1–0.3
> 40	Not applicable	< 0.1

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TABLE 2. Incidence of Progression

Authors	Number of Patients	Progression (%)	Curve
Brooks[9]	134	5.2	Not applicable
Rogala et al[76]	603	6.8	Not applicable
Clarisse[15]	110	35	10–29°
Fustier[36]	70	56	< 30°
Bunnell[13]	326	20	< 30°
		30	> 30°
Lonstein and Carlson[51]	727	23	5–29°

Reprinted with permission from Lonstein JE. Risk of progression in idiopathic scoliosis in skeletally immature patients. *Spine: State of Art Reviews.* 1987;1:183–193.

The perception of the effects of untreated scoliosis has been based on the earliest long-term studies of Nachemson[54] and of Nilsonne and Lundgren,[58] who reported higher mortality rates with marked complaints of back pain and other psychosocial effects. These authors studied patients with mixed types of scoliosis and had no radiographic data for reference; therefore these studies alone cannot be used to form the basis of decisions in adolescent idiopathic scoliosis. Most of the long-term followup natural studies are retrospective and have many of the problems of retrospective studies: particularly lost patients, small numbers, and inclusion of early onset scoliosis. These other diagnoses and the inclusion of scoliosis onset in the infantile or juvenile years cannot be compared with a group of patients with adolescent idiopathic scoliosis. In addition many studies have incomplete data on curve patterns, curve magnitude, and maturity factors like the Risser sign[66] and menarche, which make comparisons difficult.

In thinking about the natural history of a patient with adolescent idiopathic scoliosis, the most important question is: will this curve progress if no action is taken, and what are the adverse effects of a curve of this amount in adulthood? To attempt to answer this, curve progression in adolescence and adulthood will be discussed with the factors identified to date that have an effect on progression. In addition the current knowledge of the effects of scoliosis in the adult years will be covered.

Natural History and Progression in Adolescents

The incidence of progression varies (Table 2) and depends on the curve magnitude analyzed and the author's definition of progression (ie, 5 or 10°). It must be remembered that these series are on smaller curves usually detected on school screening. The risk for progression has been found to be related to growth potential (age, menarchal status, Risser sign), and to specific curve factors (pattern, magnitude).

It is well known that there is a relationship between the adolescent growth spurt and progression of scoliosis as shown by Duval-Beaupere[25] with a rapid increase at the onset of the adolescent growth spurt and appearance of secondary sex characteristics—Tanner Grade 2.[77] The patients in her study were patients who had had polio as well as idiopathic scoliosis; authors of other studies only of patients with idiopathic scoliosis have shown an increased progression in younger adolescents.[11,12,14,44]

Progression was found to be less common after the onset of menarche in the series of Lonstein and Carlson.[44] In their series 32% of children with progressive curves and 68% of those with nonprogressive curves have reached menarche by the first visit.

The Risser iliac apophysis ossification sign[66] relates to progression. The prevalence of progression has been shown to decrease as the Risser sign increases.[12,14,44]

The prevalence of progression has been shown to be related to the curve pattern.[12,14,30,44] In general, double curve patterns progress more frequently then single curves, with the lowest progression seen in single lumbar curves.

The risk of progression increases with increasing curve magnitude.[12,14,30,44,63,83]

Progression is more common in girls with comparable curves, as evidenced by the near equal male-to-female ratio with smaller curves, and the preponderance of girls with larger curves[2,3,11,12,14,24,55,57,69,80,84–86,91] (Table 1).

Many other factors and radiographic measurements have been analyzed as possible factors correlating with or predicting progression, but theses have been found not to correlate with progression. These include radiographic measurements including Mehta's Rib Vertebral Angle Difference (RVAD),[1,12,14,44,49] electromyography of paraspinal muscles, rotational prominence, and vertebral rotation.

The factors above that correlate with progression have been combined to give useful reference tables for progression. Lonstein and Carlson[44] calculated the probability of progression using curve magnitude and Risser sign (Table 3) while Nachemson and Peterson[56] used curve magnitude and age (Table 4). These two tables use the important

TABLE 3. Probabilities of Progression Based on Risser Sign and Curve Magnitude at Detection of Scoliosis

Risser Grade	Curve Magnitude	
	5°–19°	*20°–29°*
0–1	22%	68%
2–4	1.6%	23%

Reprinted with permission from Lonstein JE, Carlson JM. The prediction of curve progression in untreated idiopathic scoliosis during growth. *J Bone Joint Surg Am.* 1984;66:1061–1071.

correlations above; that is, the younger the child (as measured by age or Risser sign) and the larger the curve, the greater the incidence of progression.

Others[20,61,73] have found that there is a loss of thoracic kyphosis accompanying thoracic scoliosis. No correlation has been found between thoracic hypokyphosis or true thoracic lordosis and curve progression, but thoracic lordosis has been shown to affect pulmonary function adversely.[74] In addition, thoracic hypokyphosis has a bearing on nonoperative and operative decision making.

It must be appreciated that the correlations and predictions shown above only speak to the likelihood of a curve progressing in adolescence. They are only averages and correlations and do not answer a basic question in decision making: how much is the curve going to progress? Because they are averages they do not apply to an individual patient. Every 35° curve in a growing child once was 25°; the curve has progressed to 35°, but we cannot tell if the progression will stop at 38° or continue to 60°.

Natural History and Progression in Adults

Various authors have shown that untreated scoliosis in the adult, especially when severe, has deleterious effects as related to curve progression, pain, reduced pulmonary function, mortality, pregnancy, and psychosocial effects.[29,54,58,60] In addition, how do adults who were treated as adolescents for idiopathic scoliosis fare? This knowledge is essential in making treatment decisions in the adolescent and in the adult.

TABLE 4. Probabilities of Progression Based on Curve Magnitude and Age

Curve Magnitude at Detection	10–12 (%)	Age (years)	
		13–15 (%)	*16 (%)*
< 19°	25	10	0
20–29°	60	40	10
30–39°	90	70	30
60°	100	90	70

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Early studies of Nachemson,[54] Nilsonne and Lundgren,[58] Pehrsson et al,[60] and Fowles et al[29] gave a grim prognosis for untreated scoliosis with increased mortality rates mainly related to cor pulmonale and back pain, increased disability, and socioeconomic effects on work and marital status. These studies are involved patients with mixed causes of scoliosis, and the cases of idiopathic scoliosis mainly were of infantile and juvenile types (early onset). Conclusions about the adverse effects of adolescent idiopathic scoliosis cannot be drawn form these studies, and only studies that involve adolescent idiopathic scoliosis alone are applicable to this discussion. It must be noted that these long-term studies that physicians base decisions on are few in number and involve small numbers of patients and a small percentage of the original cohort.

Curve progression has been shown to occur after skeletal maturity.[15,24,84,85] The best studies are those in which Weinstein et al[85] followed up on a cohort of 353 patients originally reported by Ponseti and Friedman,[65] reporting on the curve progression on 102 patients at an average followup of 40 years and the treatment outcome at 50 years on 117 patients (94). Ascani et al[2] reported on 187 patients with an average followup of 34 years. The results of these studies were very similar, showing an average of 13° to 15° increase at followup. Curves that were 30° at skeletal maturity tended not to progress in adulthood regardless of curve pattern. Many curves progress in adulthood, especially thoracic curves of 50° to 80° at maturity, the lumbar component of double thoracic and lumbar curves, and thoracolumbar curves. Weinstein et al[82,84] also found that in the lumbar and thoracolumbar curves, vertebral rotation and rotatory subluxation was related to curve progression. These findings should be noted and assessed with the awareness that the reviewed series of patients comprise less than 30% of the original cohort.

The overall incidence of back pain in the series of adult patients with scoliosis has been shown to be the same as that found in the general population.[82,84] Authors of long-term studies in Sweden also have shown no greater number of patients with scoliosis on disability benefits compared with those without scoliosis.[35,54,58] This is in sharp contrast to the fact that the most common indication for surgery in the adult with scoliosis is back pain. It has been estimated that 1% of patients with scoliosis eventually will require surgery specifically for back pain, a rate similar to that for the general population.[53]

Differences have been found in the scoliosis patients in the studies by Weinstein and Ponseti.[84] Although the incidence of back pain was the same in patients with scoliosis as it is in the general population, the incidence of current or chronic back pain is more common[83] as is the incidence of frequent or daily back.[84] The latter occurred more frequently in patients with lumbar or thoracolumbar curves, especially with rotatory subluxation at the lower end of the curve, when compared with other curve patterns. Are these differences in the frequency and intensity of the pain in patients with scoliosis true differences, or are patients with scoliosis more aware of their backs and more aware of any back pain they may have?

Pulmonary function only is reduced in thoracic curves, with a direct correlation between increasing curve magnitude and decreasing vital capacity.[4,33,34,36,42,47,72,85,92] This effect can be measured with thoracic curves greater than 60° and is more pronounced in curves greater than 100°.[85] There are more complaints of shortness of breath in these patients.[83] In patients with these thoracic curves restrictive pulmonary disease was found, with vital capacity, forced respiratory volume in 1 second (FEV1), and PaO_2 decreasing with increasing curve magnitude.[85] The presence of thoracic lordosis also has been shown to affect the pulmonary function adversely in patients with curves of lesser magnitude, with considerable lordosis having a marked effect on pulmonary function.[89]

The mortality rate for patients with adolescent idiopathic scoliosis is comparable to that in the general population.[86] Authors of previous long-term studies suggested a higher mortality rate especially from cor pulmonale in patients older than 40 years with thoracic scoliosis.[54,58] The patients in these studies had mixed diagnoses and the patients with idiopathic scoliosis had the early-onset infantile and juvenile types.

There has been considerable controversy as to whether curves progress during pregnancy and whether women with scoliosis have normal reproductive experiences. Blount and Mellencamp[7] and Berman et al[5] suggested that adolescent idiopathic scoliosis progressed in adulthood as a result of pregnancy, but Bunnell[12] was not able to detect this effect. Betz et al[6] compared the effects of pregnancy in 355 patients with scoliosis, comparing the group of patients who had never been pregnant with those patients who had at least one pregnancy. They found that the risk of progression was not affected by the number of pregnancies, age at first pregnancy, or curve stability.

The reproductive experiences of women with idiopathic scoliosis has been shown to be no different from those of women without scoliosis.[6,79,85] The incidence of delivery by caesarean section and the health problems during pregnancy was no greater in women with scoliosis than in women without scoliosis.

The psychosocial effects of the cosmetic deformity of adolescent idiopathic scoliosis are difficult to evaluate. They do not manifest in adolescence unless the curve magnitude is severe, but a large rib prominence often is of concern to young patients. Authors of the earliest long-term series involving patients with mixed diagnoses including a substantial number of patients with early onset scoliosis suggested profound problems including poor self image, a greater percentage of unemployment, and a lower marriage rate.[29,54,58] Authors of studies on only patients with adolescent idiopathic scoliosis found few of these problems.[15,65,84,85] In one series a high percentage of patients were self-conscious about their appearances and even embarrassed by their looks.[29]

Adult patients who present with untreated adolescent idiopathic scoliosis often have cosmetic concerns, and this may be the major reason they seek surgical consultation. Their attitude is expressed by buying clothing to hide the deformity[70] and does not seem to be related to the location or the degree of the deformity. The adults' perception of their "deformity" is impacted by cultural and geographic backgrounds, societal and social expectations, and each person's self perception and self confidence. This is seen most in patients with minimal asymmetry who are severely affected and in adults who have marked asymmetry but who have no problems. The cosmetic aspect of scoliosis must be borne in mind and should not be minimized.

Adults Treated in Adolescence for Scoliosis

Treatment decisions of patient with adolescent idiopathic scoliosis also should be based on what happens in an adult patient who was treated in adolescence for scoliosis. It is well known that bracing and surgery can control and correct the curves of adolescent idiopathic scoliosis with followup of 5 to 10 years.[13,22,26,28,39,46,50,51,56,88] The important question is what happens in the long term and how do these patients function in adulthood. Two large long-term followup studies provide this information.[16–20,32,48,64]

The first cohort of patients studied is from the Ste-Justine Hospital in Montreal, Canada consisting of 2092 patients with adolescent idiopathic scoliosis treated between 1960 and 1979 whose progress was reviewed at an average followup of 14 years.[31,32,48,64,90] There were 1476 respondents who were compared with 1766 control patients selected using a telephone survey. All participants were sent a questionnaire concerning health perception and physical activity.[11,12] The baseline information of the treated patients was taken from hospital records with no followup examination or radiographs. The cohort of patients with adolescent idiopathic scoliosis, particularly those who were treated surgically, had a considerably higher prevalence of self-reported arthritis. The patients with scoliosis perceived themselves to be less healthy than the people in the control group, and women with scoliosis had a poorer perception of self image. In addition, the patients with scoliosis reported limitations with certain physical activities (lifting, walking long distances, sitting or standing for long periods of time, traveling, or socializing) and reported more current back pain, more physician visits, and more days ill than did the people in the control group. This negative perception of health in patients with scoliosis can be the result of actual problems or a greater concern about their health or illness as it relates to scoliosis. It is interesting to note that in spite of these replies, the patients with scoliosis had a more positive perception of self compared with the people in the control group. It must be noted that the people in the control group were selected from the telephone directory and were not evaluated for the presence of scoliosis or other spinal problems.

The authors of the second series of articles from Gothenburg, Sweden followed up on a series of patients with adolescent idiopathic scoliosis who were treated between 1968 and 1977.[16–20] There were 283 patients, 156 of whom were treated with a spinal fusion using Harrington instrumentation, and 127 of whom were treated nonoperatively with a brace. The followup consisted of reexamination, radiographs, pulmonary function tests, and a series of outcome questionnaires (Short Form-36, Psychological Well Being Index, Oswestry, Modems, World Health Organization [WHO] health status questionnaire, and study-specific questionnaires) with results compared with a group of 100 age-matched and sex-matched patients who were selected randomly for a control group and who had the same examinations and completed the same questionnaires as the patients with scoliosis. The followup of the patients with scoliosis consisted of 283 patients—156 patients treated surgically (91%) and 127 patients treated with a brace (87%)—with a mean followup of 22 to 23 years. The findings were published in a series of articles and covered a number of areas. It must be emphasized that these studies use a group of age-matched and sex-matched people without scoliosis as the control group.

The curves in the Gothenburg series were controlled by the treatment used. The average pretreatment surgical curve of the patients was 62 ± 9°, reducing to 33 ± 9° postoperatively and becoming 37 ± 10° at followup whereas the average prebracing curve of the patients was 33 ± 10°, reducing to 30 ± 11° after treatment with the brace and becoming 38 ± 15° at followup. The loss of correction was 4° for the patients who were treated surgically and 8° for the patients treated with braces. Degenerative disc changes were noted in the patients treated surgically and with braces but not in the patients in the control group.[19] Whether this is related to scoliosis or to the treatment is unknown because in this time period the patients who were treated surgically were immobilized in a cast postoperatively, and patients treated with braces were not encouraged to be as active as they usually would be. In the surgical group the rate of degenerative changes in the unfused lumbar spinal levels was not related to the level of the lower extent of the fusion.

Back pain was more frequent in the Gothenburg patients in the treatment groups (75% brace group, 65% surgical group) than in the patients in the control group (47%) and was rated as mild on the visual analog scale (scores: 2.4 brace group, 2.7 surgical group, 1.2 control group). Daily pain was infrequent and analgesics were used sparsely. No correlation was found between the back pain and curve location, curve magnitude, degenerative lumbar changes, body mass index, or smoking.[16–20]

Using the outcome questionnaires mentioned previously, the patients in the scoliosis treatment groups showed slight but considerable reduced physical function using the Short Form-36 and Oswestry forms, and participated in limited social activities because of their backs. The ratings on the mental subscales of the questionnaires provided no differences in the groups. In general the psychological wellbeing of the patients with scoliosis was equal to the general population with expected lower cosmetic wellbeing, which was not correlated to curve magnitude or thoracic deformity.[20]

The women in the long-term studies done in Sweden were compared with the women of the control group. There was no difference between the two treatment groups and control group in the percent of patients who were married, the number of children the patients had, whether the women had low back pain during pregnancy, and the rate of cesarean section. The patients in the brace treatment group were considerably older (28 years) at first pregnancy than those in the control group (25.9 years). There was a limitation of sexual function in the patients with scoliosis compared with that in the patients in the control group. This was largely because of difficulties participating physically or self consciousness about appearance and not because of pain. There was no correlation between curve progression and the number of pregnancies or the age at first pregnancy.[18]

Adult Scoliosis

In adults scoliosis either is idiopathic scoliosis, degenerative changes superimposed on idiopathic scoliosis, or pure degenerative scoliosis. The prevalence of scoliosis in younger adults is the same as it is in adolescents, but in adults older than 45 years the rate has been shown to be higher.[41,62,68,78] This has been termed "de novo" scoliosis by Vanderpool et al.[78] In the longitudinal studies of Robin et al[68] and Perennou et al[62] the scoliosis prevalence increased with age and there was the appearance of curves in a previously straight spine. This accompanied the degenerative changes of aging in the lumbar spine, with the majority of curves being small and only 15% being greater than 30°.[62] Additionally, some small patients with curves from adolescent idiopathic scoliosis in adulthood have a curve increase or symptoms with the addition of degenerative disc changes. All authors who studied the latter looked at series of patients presenting for treatment, so the incidence of curve progression caused by degenerative changes is unknown as is what percentage of these patients have symptoms requiring evaluation and treatment.[41,62,68,78]

The natural history of adolescent idiopathic scoliosis in adulthood forms the basis of ideas about treatment of the adult with adolescent idiopathic scoliosis. There are no studies of a population of adults with scoliosis followed up for natural history without treatment. This is because of the big difference in the presentation of scoliosis in adolescents and adults. In adolescents, patients with scoliosis present with a curve or resultant deformity and treatment is to control the curve and prevent progression. In the adult, however, patients with scoliosis present with a problem—scoliosis progression, pain, neurologic complications, cosmesis or psychosocial concerns, or sometimes for advice on and followup treatment for a known adolescent scoliosis. In adults, in many cases it is the back pain and neurologic complications (central stenosis, root compression) that accompany the disc degeneration that are the reasons for presentation and not the scoliosis itself. The natural history as to what happens to these problems without treatment is unknown as is the incidence of these problems in patients with scoliosis. The presence of scoliosis does effect treatment decision making, because at times the presenting problem cannot be addressed without treating the scoliosis. In general, treatment results are for the short term and cover how well the treatment addressed the presenting problem. No control groups of a similar untreated population are available for comparison.

Decision Making in Adolescents

After a child with adolescent idiopathic scoliosis is evaluated, the decision has to be made whether the child needs treatment and whether is should be surgical or nonsurgical. The factors that help in the decision are the factors previously discussed: the Cobb measurement of the scoliosis as well as the curve pattern, the level of skeletal maturity of the child (Tanner Grade, Risser sign, menarchal status), the cosmetic deformity (rotational prominence, decompensation), and the sagittal profile. In addition, it has been shown that the treatment is effective in changing the natural history, and treated patients function well as adults with no deleterious effects of the treatment to date.

The most important question is: where is the child in his or her growth spurt? Because curve progression occurs in the growth spurt[25] identification of the onset of this stage is important. This is seen with the appearance of secondary sexual characteristics: Tanner Grade 2, with pubic hair appearance in both sexes, breast budding in girls, and testicular enlargement in boys.[77] Tanner Grade 2 in boys occurs before the onset of the growth spurt whereas in girls it occurs after the onset of the growth spurt. This means that a boy with Tanner Grade 2 changes soon will enter his growth spurt, whereas a girl with Tanner Grade 2 changes already is in her growth spurt. The other maturity factor to consider is the onset of menarche, because at this stage, girls are in the slowing part of growth and have about 18 months of growth remaining. This stage corresponds to the appearance of axillary hair in boys, which indicates that growth is slowing down, but this stage is longer in boys and can be 2 years or more. It is also known that the sign that all spinal growth is over is a Risser sign of 5: iliac apophysis ossification.[66]

When one considers the natural history data it must be remembered that they reflect the findings in a large population and what percentage of the population will progress or have problems. They do not tell us what will happen to an individual child. We know that a growing child who has a Risser sign of 0 with a curve of 29° has a 68% chance of progressing[44] to a 35° curve. We do not know at what rate this may occur or whether the curve will progress to 38° degrees and stop, or whether it will increase to greater than 60°. This is the problem of applying statistics to a single patient. We deal with "estimates," "likelihoods," and "projections" and must use all the information possible to make these as accurate as possible, realizing that the decision can be fairly clear cut but that often it is more complicated. In the cases in which the decision is difficult, the child is followed up for progression to allow the child to declare his or her own natural history.

In treating a case of adolescent idiopathic scoliosis, the objectives of brace and surgical treatment differ slightly. With bracing, the objective is to prevent a smaller curve from progressing and to correct accompanying cosmetic changes (eg, waistline asymmetry and coronal decompensation). With surgery, the treatment goals are stabilization of a curve and partial correction with reduction of clinical deformity and maintenance or restoration of a balanced spine in the coronal and sagittal planes. In a growing child the question is what curve magnitude separates the bracing decision from a surgical recommendation. It is well known that response to bracing works better with smaller curves (generally less than 40° to 45°); in general, curves smaller than 40° are braced, and curves greater than 50° are treated surgically. Patients with curves between 40° and 50° fall in a gray area and must be evaluated carefully so that the best treatment method is chosen.[13,27,39,45,46]

The indications for bracing also depend on the natural history finding that the chance of progression is less in patients with smaller curves, especially in a patient with a curve less than 20°. The information for decision making therefore is the curve magnitude and the growth potential of the child. A 30° curve in an 11-year-old premenarchal girl with a Risser sign of 0 will be treated whereas the same curve in 14-year-old postmenarchal girl with a Risser sign of 3 may just be observed. Additional factors are used to assess the child's growth potential because the factors used (Risser sign, menarche, height change) may not always be "in phase" with each other. These additional "soft" factors include the parent and sibling heights, their growth spurts, and their ages at menarche. These factors are used in the gray area decisions to try to gauge the child's growth potential in a familial context.

In an actively growing child in the adolescent growth spurt, a curve of 25° or less is assessed for progression. This can be done by comparing the radiograph on presentation with a previous radiograph. A large proportion of these smaller curves is flexible and can vary with the position of the child when the radiograph was taken. This means that the previous xray is valuable only if it was taken with good technique. If no previous xray is available the child is followed up on for progression, with a new radiograph taken in 3 to 6 months. The time to the next visit will depend on the initial curve magnitude and the maturity of the child. With curves less than 20° degrees or for curves in a more mature child in the slowing phase of growth a re-evaluation in 6 months is appropriate; in a curve of 20° to 25° or in an actively growing child (Tanner Grade 1 to 3, Risser sign of 0) the re-evaluation should be in 3 to 4 months.

What curve change is regarded as progression? It is well known that the error in measuring adolescent idiopathic scoliosis is 3° to 4°,[56] so a difference of more than 5° or 6° is regarded as progression and not measurement error. Generally with curves less than 20° a change of 10° is considered progression whereas a change of 5° or 6° in curves greater than 20° is considered progression. In addition to the amount of change, the rate of change is important. An 11-year-old girl who presents with a 25° curve and has Tanner Grade 2-3 changes, a Risser sign of 0, and whose curve progresses under observation to 32° would be said to have had progression. The treatment would be bracing if the progression occurred in 4 to 6 months whereas treatment likely would be continued observation if it occurred in 18 to 24 months. In the latter case the progression is slower because the girl then would be in the slowing phase of growth. In addition the curve pattern and cosmetic appearance is important. Double curves tend to be better balanced whereas single curves (thoracic, thoracolumbar, and lumbar) can affect the cosmesis with shoulder imbalance, coronal decompensation, or waistline asymmetry. If these changes are not marked and are a factor in the decision to brace, the feelings of the child in this matter is important, not the feelings of the family or physician. The child will have to wear the orthosis and should be concerned about the cosmesis if this is a part of the decision making; otherwise the child will not be a cooperative brace wearer.

An actively growing child with an initial presenting curve of 30° to 39° is an ideal candidate for bracing because the chance of progression is very high—more than 68%[11,44]—and the bracing results in the short term and long term are better than natural history.[45,56] In some children who are still growing but are more mature, a curve in this range may be treated with followup for progression, generally if the child is well balanced cosmetically and is nearing the end of growth. A child with a curve of 25° to 29° falls into the gray area. An 11-year-old girl with a curve in this range who is very immature (Tanner Grade 1 or 2, Risser sign of 0, premenarchal) will be a good candidate for a brace whereas if the girl is more mature at a Tanner Grade of 3, but still has a Risser sign of 0, is premenarchal, and is well balanced cosmetically, she may just be followed up for progression with a repeat radiograph done in 3 to 4 months. More mature patients are assessed to get a feeling for exactly where they are in their growth spurts. Additional factors are used in the assessment of these patients: time of onset of the growth spurt, appearance of physical maturity, family history as relates to the growth spurt, menarche, and mother and sister's heights compared with the patient's height.

In assessing a patient as a candidate for bracing, an additional factor is assessed: the thoracic sagittal profile. It is well known that thoracic adolescent idiopathic scoliosis has an element of lordosis in the area of the curve,[21] which on the sagittal radiograph is seen as hypokyphosis or true thoracic lordosis. In treating thoracic adolescent idiopathic scoliosis with a brace one must be aware of the sagittal profile. With thoracic hypokyphosis or minor lordosis (fewer than -5°), the thoracic pad needs to be placed more laterally and any anterior vector needs to be minimized. If this is not done the brace will increase the thoracic lordosis and be ineffective in treating the scoliosis. With true thoracic lordosis of more than −5° to −10° bracing may not be possible and the patient may need to be observed for progression. If the scoliosis progresses surgery is recommended. In addition, if there is true thoracic lordosis, pulmonary functions are useful in assessing the effects of the lordosis. If they are substantially reduced surgery may be appropriate regardless of the Cobb angle of the scoliosis.

A curve of 40° to 45° or 50° also falls into the gray area, this time between treatment with bracing and treatment with surgery. Surgery is recommended for these larger curves in an actively growing child because orthotic treatment is less effective with larger curves.[45,56] In the younger, less mature child (Tanner Grade 1 or 2, Risser sign of 0, premenarchal) bracing also may be chosen to see its effect because surgery at this stage done posteriorly has a high chance of the crankshaft phenomenon.[23,67] Other factors with curves in this range are the curve pattern, because bracing is less effective for high left thoracic curves, and with double thoracic and lumbar King 1 curves,[40] bracing may be chosen with flexible curves so that a long fusion may be avoided. Additional factors considered include the history of the curve, ie, whether it is progressive and the cosmetic changes—especially coronal decompensation and waistline asymmetry—because these may tilt the decision toward surgical treatment.

The decision for surgery is based on the natural history of curves in adolescence, on the progression of adolescent idiopathic scoliosis in adulthood, and on the long-term outcome studies of surgery and bracing. The clear indications for surgery are an actively growing adolescent with a curve of greater than 45° to 50°, because the chance of continued progression is extremely high in adolescence and adulthood. The other clear indication is a brace-treated curve that progresses to greater than 40° to 45° during the bracing. If the curve progresses to this range during the weaning phase of the brace treatment and does not stabilize, this is another indication for surgical treatment. Another clear indication is a patient with thoracic lordosis. In a patient with a curve greater than 40° and thoracic lordosis, pulmonary function testing may help with the decision making. If the functions already are reduced then surgery is indicated, and with no reduction the curve and the pulmonary functions are monitored for any deterioration. In a braced patient an increase in the thoracic lordosis is an indication to stop bracing, and with curve increase surgery is considered.

The surgical decision is not as clear in the more mature child (Risser sign of 3 or more) with a curve of greater than 45°. The first factors to consider are the magnitude of the curve and how close the child is to the end of growth. The larger the curve and the more growth there is remaining, the decision tends to be for surgical treatment rather than observation for the child to declare their own natural history. Additional factors to consider in the decision are the curve pattern and cosmetic changes because of the curve (shoulder imbalance, coronal decompensation, and waistline asymmetry). In general, double curves tend to be better balanced than single curves so that balanced curves with acceptable cosmetic changes can be observed for progression whereas with more marked cosmetic changes surgery is considered.

Decision Making in Adults

The decision for surgery differs a little in an adult patient depending on the patient's age at presentation; the reasons for presentation are different in adults younger than 30 years. The younger adult patient usually presents with the main concern being curvature with additional concerns about progression and possible long-terms effects of the scoliosis. The definite indications for surgery in this case are curve magnitude or curve progression, with cosmesis playing a role. Generally in the younger adult, patients with curves greater than 70° are surgical candidates because of their poor prognosis for progression. In many cases, it is not the curve magnitude alone that is important but also whether the curve is progressive, and the cosmetic effects of the curve. Whether the curve is progressive or not speaks to the natural history of the scoliosis in that specific patient.

The natural history of the curve in such a patient only can be assessed with serial radiographs. If previous treatment—either bracing or observation—had occurred, a comparison of the current xrays and the xrays taken at the cessation of the previous treatment is necessary. If there is no considerable in the curves shown on both xrays, the scoliosis is stable. If there is a considerable difference in the two sets of xrays, progression has occurred. It is impossible to know whether the progression occurred at the stage of maturity and perhaps has been slow during the intervening years or whether the scoliosis currently is progressing. In this case observation for current curve change is necessary to document the patient's own natural history. Re-evaluation with a repeat radiograph yearly or every other year for 5 to 8 years is done to see if the curve is increasing. Only with documentation that the scoliosis is currently progressing, is surgery indicated.

The cosmetic effects of the scoliosis can be more difficult to assess. In some cases the patient presents with concerns of pain and/or the scoliosis, but their main unvoiced concern is the cosmesis. Occasionally this is obvious, but generally the spine surgeon realizes this on repeat visits as he becomes better acquainted with the patient. If the cosmetic changes accompanying the scoliosis are great (marked decompensation, large rotational prominence) this may tilt the decision toward surgical intervention even without documented progression as long as the patient is aware of the expected outcome and cosmetic improvement. If the surgery is done for pure cosmetic reasons, can it be justified in view of the surgical risks, and will the insurance company pay for a cosmetic procedure?

It is essential in discussing surgical treatment of scoliosis with an adult that the patient be realistic as to the expected cosmetic result. At times, even with this discussion the patient may be very unhappy with minor residual waistline asymmetry, thoracic cage asymmetry, or the residual rotational prominence, and will regard the outcome of surgery as poor.

In the older adult the presentation is different because of the superimposition of disc aging on the scoliosis. With the disc degeneration there can be curve increase with increased deformity, severe back pain, and radicular compression centrally or foraminally. The latter is caused by disc degeneration with loss of structural integrity of the spinal motion segment with disc space collapse and rotatory subluxation. The collapse reduces the foraminal height or spinal canal area with resultant nerve root compression and radicular symptoms. These effects of the disc degeneration can occur without scoliosis, and their incidence in idiopathic scoliosis in the adult is unknown. In addition degenerative scoliosis can occur because of the disc degeneration in a previously straight spine.[68,78]

The older adult presenting with back or radicular pain, curve progression, or increasing deformity is evaluated, addressing the specific presenting complaint. Progression of the scoliosis and the accompanying cosmetic changes rarely are the only symptoms, but if they are, documentation of the progression is necessary unless it is very clear. In general, complaints of pain are evaluated and treated as any other back pain: mild to moderate pain is treated with appropriate weight loss, anti-inflammatory medications, general conditioning, spine stabilization exercises, and epidural or foraminal steroid injection when necessary. With severe symptoms and failure of all nonoperative treatment methods, surgery is considered. The surgical plan must address the patients' complaints and maintain or restore spinal balance, especially sagittal balance. In addition the presence of the scoliosis affects treatment when pain is the main complaint. In these cases the back and/or radicular pain is treated appropriately with fusion of all the curves.

The radicular pain is evaluated with magnetic resonance imaging (MRI) and/or a computed tomography (CT) myelogram, the latter generally giving a better evaluation of the stenosis in the curved spine. Once the stenosis is identified, appropriate decompression (central and/or foraminal) is done. If this is the major complaint and the decompression can be limited without affecting the spinal stability, a decompression alone or decompression combined with a local fusion may resolve the patient's complaint in many instances. When a more extensive decompression is necessary or when there is severe back pain, fusion of the scoliosis is indicated. Fusion and instrumentation to the sacrum often is necessary to achieve spinal balance or is indicated with degeneration of the lumbosacral discs. In patients with these problems, an anterior fusion often is part of the surgical plan to improve curve correction, achieve spinal balance and improve the fusion rate. With severe sagittal imbalance, additional techniques are used to restore balance—generally radical anterior and posterior releases combined with the fusion and instrumentation.

DISCUSSION

The treatment of adolescent idiopathic scoliosis in the adolescent and adult patient depends on knowledge of the natural history of the scoliosis in those patient populations and knowledge of the long-term outcomes of the treatment, whether operative or nonoperative. It must be mentioned that there are very few studies on the outcome of untreated adolescent idiopathic scoliosis in adulthood; in the few studies that have been done, the number of patients reported on is small, which makes data analysis difficult. Authors of followup studies[83,85] have reported on the cohort of 353 patients originally reported by Ponseti and Friedman[65]; however, these authors[83,85] only reported on 1/3 of the original cohort, which makes interpretation of the data difficult.[83]

The natural history data of progression in the adolescent has small series and concentrates on smaller curves, generally under 40° to 45°. The data is absent as to what happens to 40° to 60° curves at maturity; this affects surgical decision making in the mature adolescent and adult. The factors that are important in curve progression are well documented in many studies and emphasize the role of growth and the important growth factors to evaluate (Tanner grading, menarchal status, Risser sign).[11,12,14,44]

Progression in adulthood occurs but there are very few studies in the literature. It is difficult to know the true incidence of back pain in idiopathic scoliosis in the adult due to the high prevalence of back pain in the general population. There is no study that shows that the occurrence in the patient with scoliosis differs from the general population.[83–85] Scoliosis can reduce pulmonary function; however, this only occurs with large curves (more than 100°), which is rare in adolescent idiopathic scoliosis and more common in the untreated infantile and juvenile varieties of scoliosis.

Data on adolescents treated with a brace or surgery when he or she reaches adulthood are well covered in the short term (average 14 year followup)[31,32,48,64] and medium term of 22 to 23 years of followup.[16–20] All of the studies of this nature had a control group without scoliosis; however, there is no series with a control group of patients with scoliosis who were not treated. Both series showed that the treated patients with scoliosis had more degenerative changes in the lumbar spine. It is unclear whether this is from the scoliosis or is a result of the immobilization of treatment; all of the patients treated surgically were in a cast postoperatively, and activity was not recommended for the patients who wore a brace. In addition, the patients with scoliosis regarded themselves as being less healthy compared with the controls. It is not known whether these patients really are less healthy in general or whether it stems from the fact that patients with scoliosis tend to have greater concern regarding their health in general.

Adults with idiopathic scoliosis present with pain, cosmetic concerns, or progression. The natural history literature on this group of patients is poor; consequently, each patient has to be evaluated individually and allowed to demonstrate their own natural history.

In the decision making process in adolescent idiopathic scoliosis, the progression data for smaller curves and the factors related to progression drive the decision making. The most important factor is growth; at times this is difficult to assess because the growth factors (Tanner grading, menarchal status, Risser sign) may be "out of phase." In many of these cases, additional factors regarding the growth spurt of older siblings and the same-sex parent are helpful in assessing where the child is in the growth spurt. It cannot be overemphasized that the literature is a review of a cohort with resultant "averages" and only serves as a guideline to apply to an individual child, and cannot serve as a "cookbook" approach. Surgical guidelines for 40° to 60° are given, but it must be appreciated that the natural history of these curves in the mature adolescent is unclear. Decision making for an unbalanced cosmetically unacceptable 50° single right thoracic curve is easy but is unclear for stable balanced 55° double thoracic and lumbar nonprogressive curves.

Decision making in the young adult presenting with untreated adolescent idiopathic scoliosis generally involves progression and cosmesis, the latter either stated or alluded to. The literature generally is not helpful in this group because each case must be assessed individually and patients need to be allowed to demonstrate their own "natural history." In the older adult the picture is complicated by the addition of aging of the disc, and there are no studies on the occurrence and natural history of these changes in untreated adolescent idiopathic scoliosis in the adult. In addition, the treatment decision making is difficult as the treatment of the scoliosis is affected by the degenerative discs and the treatment of the disc ageing is complicated by the scoliosis. There is no literature available on the outcome of treatment of these patients.

There are distinct differences in adolescents and adults with scoliosis. More information is available on adolescent patients; and much less information is available for initial presentation of adults with scoliosis. In general, decision making in an adolescent is based on treatment or prevention of progression with an eye on the future. In an adult, the treatment is focused on the treatment of an existing complaint—back pain, radicular symptoms, or documented curve progression. The treatment in the adult therefore addresses one or more specific complaints and is tailored to solve these complaints. A thorough knowledge of the current literature on natural history and the effects of treatment are essential in evaluating the patient, advising the patient and family, and choosing the best treatment for that specific patient to address the scoliosis and its future ramifications.

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