Article

Scoliosis: Causes and Treatments

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Abstract: Scoliosis is an abnormal curvature of the spine, which generally develops during childhood or adolescence. It affects 2–4 percent of the global population and is more prevalent among girls. Scoliosis is classified by its etiology: idiopathic, congenital, or neuromuscular. Among these, the former is the most common. Treatment options for scoliosis vary depending on the severity of the curve. Most scoliosis diagnoses tend to be mild and only require monitoring. However, curves between 20 and 40 degrees require bracing, while 40 degrees and above require surgery. There are various bracings available, such as Boston, Charleston, and Milwaukee. In severe cases of scoliosis, either fusion or fusionless surgery may be required. This review aims to discuss etiologies and different treatment interventions for scoliosis.

Keywords: scoliosis; etiology; bracing; surgery

1. Introduction

Scoliosis is diagnosed when a spinal deformity exceeds a curve of 10 degrees [1]. This disease is most often identified at an early age, typically at 10 to 16 years [2]. Although scoliosis mostly affects children and carries on through adulthood, cases of adults developing this disease do occur. Fortunately, most cases of scoliosis tend to be mild. However, some experience worsening of the curve during puberty [3].

Although the exact cause is often unknown, scoliosis is generally classified depending on its etiology: idiopathic, congenital, or neuromuscular [3]. Idiopathic scoliosis can further be subdivided according to the age of onset as infantile (age 0–3), juvenile (age 4–9), or adolescent (age 10 up to skeletal maturity) [1,2]. Congenital scoliosis is due to embryological malformation; thus children are typically diagnosed at a very early age [1]. Neuromuscular scoliosis is associated with secondary factors such as spinal cord trauma, cerebral palsy, spina bifida, or muscular dystrophy and can occur later in life [4]. Among these three groups, idiopathic scoliosis tends to be the most prevalent worldwide [5] with approximately 2–4% of children between 10 and 16 years of age being diagnosed [2].

The curve itself was initially classified into five types under the King and Moe criteria [6]; however, in 2001 a new six-type classification system was developed by Lawrence Lenke (Figure 1) [6]. In Type 1, there is a main thoracic (MT) curve as the only structural curve while proximal and thoracolumbar are nonstructural. Type 2 is a double thoracic MT major curvature, while proximal thoracic (PT) is minor and structural, and thoracolumbar (TL) is minor and nonstructural. Type 3 has a double major curve pattern in the MT with lumbar as minor and structural, while PT is nonstructural. Type 4 has a triple major curve pattern in the MT with all three curves being structural. Type 5 has either a thoracolumbar or lumbar major curve, while PT and MT are minor and nonstructural. Finally, Type 6 has thoracolumbar or lumbar as the major curve measuring at least 5 degrees more than the MT curve, which is minor but structural. Lenke's Types 1 and 5 are typically treated via either anterior or posterior methods, while Types 2, 3, 4, and 6 can be treated completely via the posterior method [6].

	Lumbar deviation (A-C)			
	A	**B**	**C**	**Sagittal Plane**
Type 1 Single Thoracic				Normal
Type 2 Double Thoracic				Cerv.-thor. kyphosis
Type 3 Double Major				Thor.-lumb. kyphosis
Type 4 Triple Curve				Cerv.-thor.+ Thor.-lumb kyphosis
Type 5 Thor.-lumbar or lumbar				
Type 6 Thor.-lumbar or lumbar				

Figure 1. Lenke classification for spinal curvature. Modified from [6]. Generally, Type A has the CSVL between the pedicles to the lumbar apex. Type B has the CSVL touching the apical bodies to the lumbar apex. Type C has the CSVL completely medial to the apical lumbar vertebrae.

Initially, scoliosis is screened for via physical examination but only fully diagnosed by either CT scan, MRI, or X-ray [2]. Based on the degree angle, the severity of scoliosis is determined. Curves of 10 degrees or less are considered mild, between 10 and 50, moderate, while above 50 degrees is severe [5]. Curves under 20 degrees usually only require monitoring and thus no therapeutic intervention. Curves between 20 and 40° tend to require some form of bracing [2,7]. Severe scoliosis often requires surgery, typically spinal fusion [1]. Some risk factors for developing scoliosis include gender, age, ethnicity, and family history [5]. The ethnic disparity in scoliosis suggests that adolescents of African descent are more likely to be diagnosed than either European or Latin American individuals, in addition to also being more likely to suffer from complications [8].

Psychosocial factors are additional concerns for children since treatment often involves wearing a bulky brace on a daily basis. This can cause stress while in school or when trying to perform physical activities [9]. Young adolescents, as well as their peers and parents, often visualize scoliosis as a body disfigurement, which can lead to negative body image perceptions. This dissatisfaction with appearance can often lead to decreased self-esteem, anxiety, and even depression [10]. Herein is an overview of factors that can contribute to developing scoliosis, in addition to a brief overview of various treatment options.

2. Causes

There is controversy regarding the causes of scoliosis, whether it is solely genetic or has specific contributing factors, such as exercising and the environment. According to a study done by Zhuang et al., it was concluded that patients with adolescent idiopathic scoliosis (AIS) had an alteration in five bone growth-related proteins, specifically pyruvate kinase M2, annexin A2, heat shock 27 k protein, γ-actin, and β-actin [11]. In addition, from linkage analysis, mutations in the gene loci of MAPK7 and allele marker DS 1034 on chromosome 19p13.3 were shown to contribute to AIS [12].

A genome-wide association study (GWAS) which analyzed single nucleotide polymorphisms (SNPs) and phenotypes, as well as copy number variants (CNV), specifically looked at AIS. Ogura et al., found that ladybird homeobox 1 (LBX1) and CNV of chromosomes 1q21.1, 2q13, 15q11.2, and 16p11.2harbor were associated with AIS [13]. Additionally, Mao et al., evaluated DNA methylation levels and observed an inverse relationship between cartilage oligomeric matrix protein (COMP) promotor and expression of the COMP gene. Over-methylation led to a lower expression of this gene, which itself is responsible for bone formation. The positive methylation of the pituitary homeobox 1 gene of its promotor region led to larger curve angles of the spine [14]. Raggio suggested that the autosomal recessive chromosome, 12p.13.3 heavily influences AIS [15]. Likewise, Chan reported that chromosome p13.3, among Asian children, is a key factor for AIS development [15]. A few other chromosomal influencers have also been identified (Table 1) [12].

Table 1. Summary of current genetic linkage studies for AIS. Modified from [13].

Region(s)	No. of Families/Individuals	Model	Results/Comments	Ref.
19p13.3	7/52	Autosomal dominant	Recruited Asians who developed scoliosis during adolescence	[16]
6q distal 10q 18q	1/14	Autosomal dominant	Genome-wide search in one family of French Acadian and English descent (7 affected members), with validation of "hot spots" in a second large family	[17]
17p.11	1/17	Autosomal dominant	Three generations of an Italian family	[18]
Xq23 Xq26.1	202/1198	X-linked dominant	Max. LOD score of 1.69 was identified at marker GATA172D05 and found a LOD score of 2.23 in one family with 6 affected individuals	[19]
4q35	47/176	N/A	No linkage to MTNR1A (Melatonin receptor 1A) and no mutations in MTNR1A	[20]
8p23.2-8q11.21	7 individuals	Autosomal dominant	Pericentric inversion in chromosome 8 disrupts SNTG1 (syntrophin); 5 of 7 in a family had SNTG1 deletion	[21]
6, 9, 16 and 17	202/1198	Autosomal dominant	Model independent linkage analysis	[22]
19p11.3	202/1198	Autosomal dominant	Threshold of curvature at 30 degrees. Fibrillin 3 and thromboxane A2 receptor: possible candidate	[23]
Chromosome 3 Chromosome 7	1500 individuals	Autosomal dominant	Familial relationships confirmed via database	[18]
8q	52	N/A	CHD7 Gene polymorphisms are associated with susceptibility to AIS	[24]
9q31.2-q34.2; 17q25.3-qter	25/208	Autosomal dominant	Confirmation of 9q	[25]
12p13.3	7/48	Autosomal dominant; autosomal recessive	All families contribute to recessive model 5 of 7 families to dominant model	[15]

Table 1. *Cont.*

Region(s)	No. of Families/Individuals	Model	Results/Comments	Ref.
18q	1/22	Autosomal dominant	LOD score at 3.86 Scoliosis and pectus excavatum	[26]
3p26.3 ($P < 8 \times 10^{-8}$)	419	N/A	GWAS study CHL1, DSCAM, CNTNAP2 genes related to axon guidance	[27]
LBX1 ($P = 1.24 \times 10^{-19}$)	1050	N/A	GWAS study LBX1 determines dorsal spinal neurons and alters somatosensory function	[28]

In addition, there have been multiple findings linking scoliosis with genetic inheritance. A study conducted in 1968 by Wynne-Davies evaluated the familial incidence rate of AIS. The first, second, and third generational inheritance was 6.9, 3.7, and 1.6%, respectively [29].

Although debatable, research has explored the effect of hormones on the development of AIS. Pinchuk suggested that disturbance in biorhythm secretion plays a role in the development of scoliosis [30]. Additionally, melatonin receptor 1B (MT2) expression in osteoblast cells in patients with AIS was observed at a lower level compared to those without scoliosis [31]. Similarly, a lack of estrogen has been linked to deficits in bone maturation which can further lead to the potential development of AIS [32].

Gender is strongly linked with scoliosis prevalence, with much higher rates among females. Remarkably, the ratio of spinal curves of 30 degrees or higher between females to males is 10:1 [32,33]. A region on the X-chromosome, which plays a role in scoliosis, has recently been identified. In 2003, Justice et al., analyzed 15 markers for X chromosomes in 202 families. It was concluded that regions Xq23 and Xq26.1 significantly contribute to the higher prevalence of AIS among females [19].

Although the exact causative relationship between exercising and scoliosis remains unclear, specific research was conducted to assess this [34]. Male and female athletes between the ages of 12 and 15 were evaluated. Accordingly, the prevalence of AIS was 2–3 fold higher among athletic versus non-athletic adolescents. It was found that among various exercises, early introduction of swimming had the greatest association with developing AIS, while dancing, skating, horseback riding, gymnastics, and karate were less so. The study concluded that there were no additional statistically significant data related to age, height, weight, or BMI influencing the prevalence of AIS among adolescent athletes [34].

In addition to exercising, other secondary factors have been investigated as possibly contributing to scoliosis. These are grouped into three categories: inherited disorders of connective tissue, neurologic disorders, and musculoskeletal disorders [2]. Neuromuscular etiologies, such as cerebral palsy, spinal amyotrophy, or myelodysplasia are all neurologic disorders that in themselves can lead to scoliosis [4]. Other examples of specific disease states related to secondary causes of scoliosis are listed in Table 2 [2].

There has also been some linkage of vertebral malformations with the consumption of alcohol, maternal insulin-dependent diabetes mellitus, and anticonvulsant medications, such as valproic acid and dilantin during fetal development [35]. Although there have been no direct studies assessing the causative relationship of environmental teratogens with vertebral malformations, similar studies performed on animals suggest that there may indeed be some influence [35]. Yang et al., observed that a high-selenium concentration can induce S-curve deformity in guppy fish [36]. Likewise, McMaster et al., suggested that chloroform generated in heated swimming pools can contribute to scoliosis via a neurotoxic effect [37]. There is approximately a three times higher rate of developing infant and normal adolescents' scoliosis among children who regularly use heated indoor swimming pools [34,37]. These findings may explain the aforementioned disparity among adolescent

swimmer athletes [37]. Further testing still needs to be done to confirm any additional association between environmental factors and scoliosis.

Table 2. Secondary factors leading to scoliosis. Modified from [2].

Inherited Disorders of Connective Tissues	Neurologic Disorders	Musculoskeletal Disorders
Ehlers-Danlos syndrome	Tethered cord syndrome	Leg length discrepancy
Homocystinuria	Syringomyelia	Developmental dysplasia of the hip
	Spinal tumor	Osteogenesis imperfecta
	Neurofibromatosis	Klippel–Feil syndrome
	Muscular dystrophy	
	Cerebral palsy	
	Poliomyelitis	
	Friedreich's ataxia	
	Familial dysautonomia (Riley–Day syndrome)	
	Werdnig–Hoffmann disease	

3. Kinesitherapy

The first treatment for scoliosis dates back to the 5th century BC when it was described by Hippocrates as longitudinal traction. This was a painful and crude treatment utilizing a scamnum (similar to a torture rack) and continued until the 2nd century AD [38]. The first torso brace was developed by Ambrose Pare, a French army surgeon in the 16th century. He hypothesized that spinal deformity was due to the dislocation of the spine. Pare designed a padded iron corset for patients to reduce the progression of the curve [38,39]. Subsequently, additional treatment methods were developed, and in 1946 the Milwaukee brace was introduced, becoming a leading option for treating scoliosis [38].

Presently, there are various braces, and other additional treatment options, such as acupuncture. Besides bracing and surgery, which will be discussed below, other approaches have also been evaluated, such as acupuncture [40–42]. From a case report, where acupuncture was performed 3 times a week for 6 weeks, a correction in the curvature was reported at 10 degrees [41]. In another study, 24 AIS patients, between the age of 14 and 16 received acupuncture treatment lasting approximately 25 min. It was concluded that AIS patients with curvature below 35 degrees benefited [42]. However, more research and follow-up investigation are necessary to validate this treatment option.

Bracing is the most widely studied and utilized approach for scoliosis treatment. Although there is very limited research to directly compare the effectiveness of these braces to each other, certain ones are preferred for a variety of reasons. For bracing to be successful, the spinal curve should remain under 45 degrees until the patient reaches full maturity [1]. Walter Blount's specific advancement was to introduce removable cervicothoracolumbosacral orthosis (CTLSO) pads. This Milwaukee brace uses both passive and active forces to assist in spinal straightening. Passive correction is accomplished from pressure by the CTLSO pads. The original chin rest of the Milwaukee brace was ultimately changed to a throat pad because its pressure led to orthognathic deformities. In addition, the custom-molded leather from the patient's cast was modified to prefabricated thermoplastics as it was easier to use and less expensive. However, compliance with wearing was and is one of the major issues associated with this brace. Many patients complain about its appearance as well as general discomfort. Despite these limitations, the Milwaukee brace has been used for 75 years and has been shown to assist in halting the progression of AIS [38].

The Milwaukee brace is often used to treat thoracic curves with an apex at or above T8 [43]. Misterska et al., performed a study to evaluate the efficacy of the Milwaukee

brace [44]. A total of 30 female patients who completed treatment with Milwaukee brace before they reached 19 years old were evaluated. The success rate was defined as an increase in the spinal curve of fewer than 6 degrees since the start of bracing [44]. The Milwaukee brace led to curves between 20 and 29 degrees progressing 28% less compared to when left untreated, and curves between 30 and 39 degrees progressed 14% less [43].

In 1969, G. Dean MacEwen created a low-profile thoracic lumbar spinal orthosis (TLSO) brace which was lighter, more comfortable, and less obtrusive for patients. The first TLSO brace was coined the Wilmington brace. It was constructed as semi-rigid from moldable plastic. Due to the challenges of custom-molding these braces, John Hall and William Miller created another TLSO referred to as the Boston brace in 1972. Instead of custom-fitting each patient, prefabricated braces were custom-modified. Similar to the Milwaukee brace, Boston braces also used passive and active corrective forces [38].

The Boston brace has shown to be most effective in scoliosis at an apex between T6 and L4, with curves from 20 to 49 degrees [43]. It is not generally as useful when curves are located above T6 [43]. Steen et al., examined patients treated with the Boston brace to evaluate its efficacy [45]. A total of 365 patients with AIS participated in the study, of which 339 were female and 26 were male. The effectiveness of bracing decreased when worn less than 17 h daily. After brace weaning, follow-up was performed at 6, 12, and 25 months as well as long-term. Most participants attended one or more sessions. A success rate was seen in 300 of 365 patients (82%), while treatment failure was observed in 65 patients, with 27 (7%) requiring surgery. Treatment failure was defined as curve progression to greater than 50 degrees. Patients with poor compliance had an average of 6.9 degrees larger progression [45].

Both Milwaukee and TLSO braces require patients to wear them for 18 to 23 h per day to be most effective. To increase patient compliance, nighttime bracing was introduced in 1979 by Frederick Reed [38]. This Charleston brace was intended to be worn only during sleeping hours. However, due to its rigid plastic mold and discomfort, compliance was often compromised. In 1992, Charles d'Amato and Barry McCoy developed an alternate brace to correct spinal curves with minimal discomfort. Unlike the Charleston brace which utilizes side-bending, this Providence brace directly applies forces in both a lateral and derotational manner. Both the Charleston and Providence braces are only used at nighttime [46].

The Charleston brace is employed in patients with a single major curve of 25–35 degrees at an apex below T8 and is only worn for 8–10 h during sleep [47]. Nighttime bracing has been suggested to be more effective in those who have a single, correctable thoracolumbar, or lumbar curve [43]. A study performed by Wiemann evaluated the efficacy of the Charleston brace by enrolling 21 patients and 16 control group females [7]. All participants were followed up for a minimum of 2 years. In the control group, eight patients had between 5 and 10 degrees of curve progression, while the remaining eight had greater than 10 degrees. Among the treatment group, 6 patients (29%) maintained without progression of the curve, 4 patients (19%) progressed between 5 and 10 degrees, while 11 patients (52%) had greater than 10 degrees change. Additionally, two in the control and four in the bracing groups ended up requiring surgical intervention [7].

A study was performed to compare the effectiveness of the Milwaukee, TLSO, and the Charleston braces when treating AIS [46]. A total of 170 patients aged 10–13 years, without a history of spinal surgery were eligible for the study. Of those patients, 30 used the Milwaukee brace (18%), 45 used a TLSO (26%), and 95 used the Charleston brace (56%). For scoliosis at the thoracic or double curve, as is often found in Type 2 and 3 cases, the Milwaukee brace is mainly utilized [6,46]. A TLSO, such as the Boston brace, is typically used for single lumbar and thoracolumbar curves with apexes at T8 or below [38,48]. Thus, a direct comparison of these braces may not be applicable as the curves are at different sites. Additionally, since the Milwaukee brace is mostly used for double curves, a comparision with a TLSO or Charleston brace may not be valid [46]. However, initial spinal correction showed better outcomes when treated with a TLSO than the Milwaukee brace. Long-term

use of a TLSO brace minimized the progression of the curve. Additionally, patients who were treated with TLSOs had the lowest rate of surgery. Surgical rates after treatment with a brace were highest for those using Charleston. Ultimately, 8 of 45 patients with TLSO, 7 of 35 with Milwaukee, and 29 of 95 with the Charleston required surgical correction. However, the study had a limitation as it did not provide a follow-up and only examined patients who were at the end of brace treatment [46].

Another study performed by Katz et al., compared Boston and Charleston braces [49]. The eligible AIS patients included those 10–17 years old with curves between 25 and 45 degrees. Of the 268 patients, 127 used a Boston brace and 141 used the Charleston. Among these, 243 were females (117 Boston and 126 Charleston) and 25 were males (10 Boston and 15 Charleston). Ultimately, the Boston brace was deemed more effective in preventing progression when starting curves were between 25 and 35 degrees. Only 29 of 99 patients (29%) treated with the Boston brace showed curve progression greater than 5 degrees, while 56 of 120 (47%) were seen with the Charleston brace. In addition, the Boston brace was more effective in preventing progression in curves with starting points between 36 and 45 degrees. A total of 23 of the 54 patients (43%) with curves between 36 and 45 degrees who were treated with the Boston brace had progression of more than 5 degrees while 38 of 46 (83%) were seen in the Charleston brace group [49]. However, a comparison is again difficult due to each brace being used for different spinal curve locations. Howard et al., analyzed a recently published retrospective meta-analysis, which compared improvements in patients who wore a brace for approximately 23 h a day [46]. Data was collected during the bracing period and followed up to evaluate which brace had better overall success rates between the TLSOs, Charleston, and Milwaukee. It was concluded that TLSOs significantly lowered the progression of the curve and thus had the highest overall brace success rate compared to other braces [46]. However, due to several limitations, such as the small sample size for follow-up and being used at different sites, no brace could be concluded as being superior to another [46]. Other braces have been developed such as the aforementioned Providence, Flexpine, Lyon, Chêneau, Spine-Cor, and ScolioSMART, but fewer clinical studies have been conducted on these, making it difficult to compare bracing treatments.

The Scoliosis Research Society (SRS) identifies the Cobb angle as a primary outcome that is most used to determine the success and effectiveness of orthosis treatment. A Cobb angle of 5° or less at the end of treatment or at the time of brace discontinuation is considered a successful and effective orthosis. Although comparisons have been done with different braces, the studies themselves are performed by different groups. Therefore each study has its own set of inclusion and exclusion criteria, which may differ significantly. Thus it is difficult to exactly compare and contrast the different braces. Additionally, individual researchers define success and failure in terms of brace effectiveness differently. Some studies include compliance and include maturity as a variable in their studies. Thus, a uniformity across studies is difficult to compare. Although there have been specific comparison studies on orthosis treatment for scoliosis, to fully compare and assess the efficacy of each orthosis, specific criteria need to also be included. Factors such as the initiation of the bracing period, curve magnitude at the initiation of therapy, and years of skeletal maturity differ across these studies. Ideally, there should be more stringent patient characteristics or inclusion criteria among studies to make a true comparison. Additionally, patients who were categorized as being "successful" should be followed up for a minimum of 2 years after skeletal maturity. Likewise, studies should include patient compliance to decrease bias, even if the report may be subjective (Tables 3 and 4).

Table 3. Outcomes and conclusion from different bracing. Modified from [50].

Type of Brace	Number of Patients	Risser	Average Initial Curvature	Definition of Brace Effectiveness	Results	Ref.
Milwaukee	1020	0–>2	30–35°	Success: <5° progression Failure: ≥5° progression or surgery	Immediate bracing on Risser 0 and curves greater than 25° prevents curve progression	[51]
Charleston	139	0–2	25–49°	Success: 5° progression at end of treatment Failure: good: >5° but ≤10°; fair: >10° but no surgery or Δ brace; poor: surgery or Δ brace	66% improved or progressed less than 5°	[52]
Boston	51	0–2	36–45°	Success: ≤5° progression Failure: ≥6° progression or surgery	61% did not progress greater than 5° until bracing discontinued	[53]
Providence	102	0–2	27°	Success: ≤5° progression Failure: ≥6° progression at follow-up, addition of TLSO brace or surgery	61–79% success rate; effective when curves are less than 35°	[54]
Spine-Cor	249	0–3	24–40°	Success: correction of >5 degrees or stabilization ± 5 degrees Failure: not defined	60% success rate; prevented progression of the curve	[55]

Table 4. Limitations, length follow-up, and biases of brace studies.

Type of Brace	Definition of Maturity	Average Follow-Up after Maturity	Limitation/Bias	Ref.
Milwaukee	No change in height on consecutive visits; Risser 4 or 5; 18 months after menarche for females	6 years	229 (22%) had operative intervention (curve >30° at the time of bracing and Risser sign of 0 or 1) and the 791 remaining were managed with the brace only A large number of participants were included in the study even if their curve progression of scoliosis were not minor and needed operative intervention	[51]
Charleston	Not defined	1.1 years	Average follow-up period is very short No specific definition of maturity is given 90 females and only 8 males; uneven gender distribution Lost during follow-up; from 139 to 98 patients (30% loss to follow up) Could not verify the true compliance rate of patients	[52]
Boston	Skeletal maturity	2.7 years	Limited sample size (only 51 patients) to evaluate its efficacy 47 females and only 4 males; uneven gender distribution 31 success treated patients had a mean value Cobb angle 3 of 9.9°and 20 failed patients had 39.2°; p-value = 0.35 Inability to identify threshold value for success rate with single curves	[53]

Type of Brace	Definition of Maturity	Average Follow-Up after Maturity	Limitation/Bias	Ref.
Providence	No growth at 2 consecutive visits 6 months apart; Risser 4; 18 months after menarche for females	2.6 years	Only consist of female participants Result also included those who were noncompliant with brace treatment; this could have impacted the interpretation of the data Has a greater percentage of participants with less progressive lumbar curves and Risser 3, 4 Compliance data is subjective and limited; worse responses from patients recorded	[54]
Spine-Cor	Skeletal maturity	2 years	Although the study was performed for a long period of time (from 1993 to 2006), many were lost during the follow-up; initially began with 493 to 249 fitted into inclusion criteria but ultimately 170 were followed up among which only 79 were being actively treated In addition, the inclusion criteria of the study are vague and not specific	[55]

4. Surgical Treatments

After diagnosis, curve progression of scoliosis approximately occurs at 1 degree annually [5]. The general goal of bracing is to maintain the curve below 50 degrees upon patient maturation. Although effective, bracing tends to prevent curves from worsening rather than permanently correcting or improving [5]. The rate of surgery after bracing is between 11 and 42.5%, depending on the previous treatment methods employed [56]. If treatment was rather conservative, there is a greater chance of surgery [56]. Surgical options are considered when a curve exceeds 45 degrees in immature patients and 50 degrees in mature. The goal of surgery is to halt the progression and improve spinal curvature and balance [5]. Surgical management of scoliosis is generally divided into fusion and fusionless [56]. In order to allow chest and lung development, spinal fusion is usually reserved until the patient is 10–12 years old or older. The fusion can be conducted either anteriorly or posteriorly, depending on the patient's characteristics [57]. However, the posterior approach is more commonly used [56,57].

Posterior fusion surgery had been the mainstay of surgical treatment since it was first introduced by Paul Harrington in the 1950s. This involves the implantation of a Harrington rod along the spine to straighten the curve. Less implant failure, as well as better corrections, have been accomplished with more recent technology advancements. The modern posterior instrumentation has stronger anchorage support between the rod and spine. Presently, segmental pedicle screws or a hybrid construct using pedicle screws are commonly utilized in posterior surgery. In 1994, Suk was the first to introduce the segmental pedicle screw [58]. The safety of the segmental pedicle screw was evaluated with 203 thoracic AIS patients [59]. Among those, 170 patients had single thoracic and 33 had double thoracic curves. The patients were categorized under the older King 5-type classification. In total 122 patients were Type 2, 29 were Type 3, 19 were Type 4, and 33 were Type 5. Approximately 14 thoracic screws are inserted per patient. The two main goals of the study were to correct the spinal deformity and maintain stability [59]. According to the 5-year follow-up, the average correction was from 16 degrees to 51 degrees [58]. When evaluated in its totality, 2867 thoracic pedicle screws were used. However, 43 screws were found to be misplaced in 24 patients, which was confirmed by either CT or plain radiography. Of these, 12 screws were misplaced in lateral, 3 in medial, 8 in superior, and 20 in inferior regions. Regardless of malpositioning, follow-up showed no neurological or vascular adverse effects [59].

Another fusion surgical method is anterior instrumentation. This method is preferred for thoracolumbar and lumbar scoliosis due to its superior correction at shorter fusion levels [58]. A combination of anterior and posterior fusion was generally preferred in severe and rigid curvatures [60]. However, utilization of anterior instrumentation has recently been decreasing due to the possibility of screw penetration, which can lead to a risk of thoracic aorta as well as having longer surgery and anesthesia times [58,60]. In 2005, Potter compared anterior and posterior spinal fusion [61]. The result showed that posterior instrumentation had better outcomes compared to anterior. The main thoracic posterior method showed 62% correction, while the anterior showed 52%. Additionally, thoracolumbar and lumbar had 56% correction with posterior, while only 41% with the anterior method [61].

Fusionless surgery is generally performed due to several reasons, such as to control growth, delay the timing of fusion surgery, or increase the volume of the thorax. Because mobility and flexibility of the spine are removed with fusion surgery, use on immature children is often avoided (Table 5). This is even more so if the child has a spinal cord injury or myelodysplasia. In addition, performing fusion surgery when too young can also result in a shorter trunk compared to extremities, which can also influence the development of the lungs. Fusionless surgery is often preferred in AIS patients with a right thoracic curve. When 20 patients with right thoracic curves were treated with fusionless surgery and followed for an average of 8.9 years, no neurological complications were found [58]. Ultimately, 4 patients had a 9.8% correction rate after fusionless surgery (74.8 degrees to 67.5 degrees), while 16 patients had a 29.4% correction (61.3 degrees to 43.3 degrees) [58].

Table 5. Outcomes and comparison of different spinal fusion in scoliosis. Modified from [47].

Approach	No. of Patients	Follow-Up Period	Level of Evidence	Results	Comments	Ref.
Anterior Posterior	132 44	Min. 2 years	III	No statistical difference between anterior (48%) and posterior (49%) approaches of SLCC.	Both approaches can lead to equal SLCC.	[62]
Anterior Posterior	30 30	Min. 10 years	III	In PSF, AO occurred in 47%, progression of scoliosis in 7%, and degenerative disc in 43%. In ASF, AO occurred in 53%, progression of scoliosis in 37%, and degenerative disc in 53%.	Better scoliosis correction with ASF post-op; however, greater loss of correction upon 10 years follow-up post-op.	[63]
Anterior Posterior	135 218	Post-op, 1 and 2 years	III	After surgery, T5-12 kyphosis was significantly greater with ASF and remained greater at 1 and 2 years post-op.	ASF was superior when restoring thoracic kyphosis to PSF.	[64]
Anterior Posterior	21 26	Post-op, 1 and 2 years	III	Avg. of 0.61 fewer segments fused in ASF compared with 0.81 in PSF. SRS-22 was significantly higher in the ASF group.	ASF results in shorter fusion segments, better sagittal alignment, and QOL in Lenke Type 5 AIS.	[65]
Anterior Posterior	40 40	2 years	III	PSF had a significantly more fused level. ASF had a greater percent of lumbar Cobb correction with dLOF standardized to L3.	When dLOF was controlled, ASH led to superior thoracolumbar correction.	[66]

Table 5. *Cont.*

Approach	No. of Patients	Follow-Up Period	Level of Evidence	Results	Comments	Ref.
Anterior Posterior	22 24	Min. 2 years	III	Lumbar curve % correction and un-fused thoracic curve spontaneous correction was similar in PSF and ASF.	No statistically significant difference in lumbar or thoracic correction. However, fusion levels are shorter in the ASF group.	[67]
Anterior Posterior	69 92	Min. 2 years	II	No significant difference in % correction of the main curve, C7 decompensation, length of hospital stay, and SRS scores at 2-year follow-up.	ASF resulted in less fusion level. PSF resulted in less disc angulation below the lowest instrumented vertebrae; greater lumbar lordosis and % correction of lumbar prominence.	[68]
Anterior Posterior	18 24	2 years	II	No significant differences in the degree of improvement were seen in both. PSF corrected rib hump by 53% and thoracic Cobb angle by 62%, while ASF corrected by 61% and 64%.	The complications were varied and largely intrathoracic with ASF, and wound-related with PSF.	[69]
Anterior	25	Avg. 15.2 years	III	Overall radiographical findings and patient outcome measures were satisfactory.	Average preoperative instrumented level was significantly improved at a follow-up. However, avg. percent predicted FVC and FEV1 were significantly reduced.	[70]
Posterior	42	Avg. 5.6 years	IV	Post-op vertebral tilt below the site of fusion increased from 6.21 ($\pm$5.73) to 11.12 ($\pm$7.92) degrees.	PSF might result in irreversible complications (i.e., DDD) despite its safety and efficacy. New DDD was observed in 16%.	[71]
Anterior Posterior	308	N/A	III	No significant differences in correction rate of thoracolumbar/lumbar curve.	ASF had significantly shorter fusion segments. PSF had a larger increasing Cobb angle of lumbar lordosis.	[72]
Combined and Posterior	872	N/A	III	No significant difference in Cobb angle and percent predicted FEV1.	PSF group had a better percent predicted FVC, significantly fewer complications, blood loss, operative time, and length of hospital stay.	[73]
Combined Posterior	25 25	N/A	III	Hospital stays in the posterior-only group was 11.84 $\pm$ 5.18 and the combined group was 26.5 $\pm$ 5.2 days.	PSF is advisable and advantageous in patients with severe scoliosis over 70 degrees.	[74]
Combined Posterior	20 34	Min. 2 years	III	No statistical significance between the number of levels fused, preoperative coronal/sagittal Cobb angle, and coronal curve flexibility.	PSF provides superior correction without needing to enter the thorax and has a less negative effect on pulmonary function.	[75]

Table 5. *Cont.*

Approach	No. of Patients	Follow-Up Period	Level of Evidence	Results	Comments	Ref.
Combined Posterior	25 38	3, 6, 12, 24, and 36 months	II	No significant difference in operation time, blood loss, length of hospital stay, SRS-22 score, coronal curve flexibility, and post-op coronal Cobb correction.	12 screws misplaced in PSF group. Implant density was significantly lower in the combined group. However, a combined approach is recommended in high-risk implant complication patients.	[76]

SLCC spontaneous lumbar curve correction; PSF: posterior spinal fusion; ASF: anterior spinal fusion; AO: adding on; QOL: quality of life; dLOF: distal level of fixation; FVC: forced vital capacity; FEV1: forced expiratory volume in 1; DDD: degenerative disc disease; SRS-22: scores for pain, self-appearance, function/activity, mental, and satisfaction of management.

5. Conclusions

The goal of bracing therapy for scoliosis is to halt the progression of the curve to under 50 degrees until maturity. There are a number of braces available, such as Charleston, Boston, and Milwaukee, which are used depending on the patient's curve characteristics. However, because bracing often does not stop the progression completely, surgical methods are a consideration in certain instances. Either fusion or fusionless approaches are utilized for surgical intervention. There are numerous studies done to evaluate the safety and efficacy of surgical treatment for scoliosis. Additionally, not enough clinical studies are available, making it impossible to compare different braces. Even with current studies analyzing and comparing various braces, there are limitations, such as limited follow-up and different treatment locations of the curve. Thus, a true comparison of one brace to another is not possible. Regardless, treatment for those diagnosed has come a long way from the days of the scamnum rack. As the technology continues to advance, spinal fusion may be more tolerable for patients. Conversely, with improvements in bracing in conjunction with physical therapy, there may be less need for surgery at all or perhaps less invasive surgeries. Finally, with advancements in pharmacogenomic testing, there is a possibility to understand AIS variants to allow for even earlier detection. Although neither bracing nor surgery cure scoliosis, genetic testing to determine those children at higher risk of AIS may open the possibility of preventing its development early with nutritional and physical therapies.

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