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REVIEW

Low bone mineral status in adolescent idiopathic scoliosis

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Abstract Adolescent idiopathic scoliosis (AIS) is a pathological entity of unknown etiology. The causes of osteoporosis or osteopenia in AIS remain undetermined. Whether poor bone quality is an etiologic factor remains controversial. To determine the correlation between low bone mineral status and AIS, a review of literature was performed. After a literature search from 1966 to June 2007 (using Medline, EMBASE, Cochrane DSR, ACP Journal Club, DARE, CCTR, CINAHL and hand searches of references) for studies regarding low bone mineral status and AIS, 20 studies meeting the inclusion criteria were reviewed in terms of the appropriateness of valuation technique, the validity of descriptive system, the number and type of respondents, and overall quality of the studies. Nearly all investigations demonstrated that low bone mineral density (BMD) was a generalized phenomenon and a systematic disorder in AIS. The prevalence of AIS with osteoporosis is approximately 20–38%. The follow-up studies indicated that osteopenia in patients with AIS may be a persistent phenomenon. BMD could be affected by the mechanical loading and lower bone mineral mass is always associated with lower bone strength. The spinal architecture associated with the osteopenia may aggravate the spinal deformity. However, with regard to the concave and convex femoral neck BMD values, and the correlation of BMD to scoliosis parameters, the results remain inconsistent. Bracing may not result in permanent loss of bone mineral mass. The effect of the eccentric tension–compression environments on BMD, the correlation of BMD with scoliosis parameters and the effect of bracing on BMD should be investigated further in prospective, randomized and longitudinal follow-up studies.

Keywords Adolescent idiopathic scoliosis · Bone mineral density · Osteoporosis · Osteopenia

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Introduction

Idiopathic scoliosis is a pathological entity of unknown etiology. Adolescent idiopathic scoliosis (AIS), a complex three-dimensional deformity of the spine, is the most common form of idiopathic scoliosis affecting girls aged 10–16 years [45]. Many studies have attempted to uncover the etiology and pathophysiologic process underlying AIS. The consensus is that the etiology is multifactorial.

Since Burner et al. [3] first reported the association of osteopenia with AIS using the Singh index in 1982, some investigators have performed a series of studies on the low bone mineral status and related factors in AIS patients. Osteoporosis is the commonest metabolic bone disorder of adults [27], but is very rare in the young. The prevalence of osteoporosis in AIS patients is much higher than in the general pediatric and adolescent population [5–11].

Bone mass increases progressively during childhood, but mainly during adolescence. Recent studies have shown that at least 90% of peak bone mass is accumulated within the second decade of life [25]. Physicians have become aware of the role of adequate bone mass accrual in

childhood in preventing osteoporotic fractures in late adulthood. Using dual-photon absorptiometry, Velis et al. [43] found that idiopathic scoliosis patients with osteoporosis were more likely to have lateral spondylolisthesis and segmental instability development than those with normal bone density. Based on their study on the gross and microarchitectural changes in the bone of patients with scoliosis, Enneking and Harrington [13] indicated that scoliosis was probably not an abnormality of endochondral growth or a result of an underlying pathological bone condition, and suggested that further research should focus on extraosseous tissues. The causes of osteoporosis or osteopenia in AIS remain undetermined. Unless the changes of bone quality found at skeletal sites remote from the spine are caused by the abnormal mechanical loading in scoliosis, bone quality may need to be investigated as a possible etiologic factor.

The objective of this paper was to provide a review on all aspects of the low bone mineral status of idiopathic scoliosis, to present an inventory of current research, and to suggest directions for future research.

Materials and methods

Search criteria

Relevant literature search was performed using the most common database of medical literature as shown below:

- Medline (Through Pubmed; 1966 to June 2007)
- EMBASE (1980–2007 Week 21)
- All EBM Reviews—Cochrane DSR, ACP Journal Club, DARE, and CCTR
- CINAHL (1982 to May Week 3 2007)

The search strings and the number of hits were given in Table 1. The search was performed with limiting factors of "human" and "English language". Some papers and the reference lists of articles selected for review were found by manual methods. Additional articles identified from these references that contained relevant supporting information were then included. The search was performed by one reviewer.

Inclusion/exclusion criteria

After excluding identical papers, we carried out a selection of peer-reviewed articles to include. The selected articles should meet the following criteria:

- The papers that focused on the low bone mass in idiopathic scoliosis and the results reported the patients diagnosed as osteoporosis or osteopenia were selected.
- All subjects in the selected articles were adolescent.
- The articles focused on concomitant diseases or disorders, such as osteogenesis imperfecta, hyperthyroidism, type 1 diabetes mellitus, or iatrogenic causes were excluded.
- The letters to the editor, the papers contained no primary data, or the single case reports or abstracts were excluded.

Methodological quality assessment

There is not a widely accepted quality rating system for case series or non-randomised comparative studies. The methodological quality of the included studies was low and the number of the selected studies was relatively small. As a result of the wide variations in study design, BMD measurement methods, curve patterns, Cobb angle, measured skeletal site and statistical analyses in the selected studies, a formal assessment of the methodological quality to weigh the results of the studies was not conducted.

The studies were heterogeneous with respect to age, anthropometric parameters, spinal deformity severity, intervention modality, and follow-up duration. Therefore, data were not statistically pooled but the most important results were described in detail. All abstracts were printed and close-reading was performed by two doctors with rich experience in the diagnosis and treatment of idiopathic scoliosis. Some of the articles we reviewed were from the same institute and written by different authors or the same

Table 1 Search strings and number of hits

Search strings	Medline	EMBASE	All EBM Reviews—Cochrane DSR, ACP Journal Club, DARE, and CCTR	CINAHL
"Scoliosis"[mh] and "Bone Diseases, Metabolic"[mh]	137	1	1	1
"Scoliosis"[mh] and "Osteoporosis"[mh]	91	1	1	9
"Scoliosis"[tiab] and "Low bone mineral density"[tiab]	7	0	1	1
"Scoliosis"[tiab] and "Low bone mineral status"[tiab]	1	0	0	0
"Scoliosis" [tiab] and "Bone quality" [tiab]	12	0	0	2

mh mesh heading, *tiab* title/abstract

authors, and there were some disagreement among them about the data they collected. Therefore, all papers were carefully reviewed respectively. The different information extracted from the same article were compared and reread till the information could be agreed upon. If it was difficult for them to obtain a consensus, a third reviewer was consulted. Full text of each selected paper was found, then, careful reading and data extraction was done independently by the two doctors mentioned above. At last, all extracted information were imported into an electronic spread sheet—Microsoft Excel.

Results

After a screening of abstracts, 17 articles underwent further analysis. There were two reports published before 1990, five papers published between 1990 and 2000, and ten papers in the 2000s. There were seven papers mainly focused on BMD and AIS, four follow-up studies on the low bone mineral status in AIS, six articles on the concave and convex femoral neck BMD values, nine articles on the correlation of BMD to scoliosis parameters, and five studies on the association of brace treatment with BMD in AIS.

BMD and AIS

There were seven cross-sectional studies focused on BMD and AIS, and one case report of Bartal et al. [1] on the topic of the low bone mineral status in AIS patients was excluded. Cheng et al. [4, 7], Lee et al. [23, 24], Yeung et al. [48], and Cheung et al. [10] were in the same institute, and most of their data were similar, the most detailed data and the different data were listed in Table 2.

Persistent or transient problem

A transient osteoporotic condition in the general adolescent population at the age of peak growth velocity has been reported [16]. To investigate whether the osteopenia is a transient phenomenon, several follow-up studies on the bone mineral dynamics of the patients with AIS associated osteopenia has been performed. The results of the follow-up studies were presented in Table 3.

The concave and convex femoral neck BMD values

According to the Wolff's law [46], the abnormal mechanical loading applied on the femur might be different according to the convexity side, and BMD of the two sides of the proximal femur would be different accordingly. To determine the existence of this phenomenon in clinical patients with AIS, six investigations were performed [3, 4, 7, 11, 21, 24]. The results with "no significant difference" [3, 4, 7, 11] and "significant difference" [21, 24] between the BMD values of the concave and convex femoral neck were reported in the literature.

Correlation of BMD with scoliosis parameters

To determine whether the scoliosis parameters such as curve pattern, the degree of Cobb angle and curve progression affect the bone density in AIS, we analyzed the data from all articles reviewed. No significant effect of curve pattern, the degree of Cobb angle and curve progression on BMD were reported in four [4, 11, 38, 41], six [4, 7, 9, 11, 38, 41], and three [3, 11, 41] published articles, respectively. However, significant effects of the degree of Cobb angle and curve progression on the BMD values in AIS patients were shown in two recent studies [21, 24].

Brace treatment and BMD

Bracing is the most common form of non-invasive treatment for scoliotic patients at risk of progression [33]. The effect of cast immobilization and non-weight bearing on bone loss has been studied [32, 42]. There were several investigations concerning this issue which draw some conflicting conclusions. The papers and conclusions were listed in Table 4.

Discussion

A complex and probably multifactorial process is presumed to be involved in AIS. The studies included in this review evaluated low bone mineral status and related factors in AIS patients using data from identical or different sources and patient populations. Overall, the data consistently demonstrated that evidences linking low bone mineral status with AIS does exist, but as to whether poor bone quality is an etiologic factor, further high-quality research is needed.

Generalized low bone mineral status in AIS

Osteoporosis in young people has become a clinical and research priority. There is insufficient data to formally define osteopenia in children and adolescents, and much discussion on the meaning of "low bone density" without fractures. According to the recent position statement of the International Society for Clinical Densitometry (ISCD), the terminology "low bone density for chronologic age" may be used if the Z-score is less than -2 in males or females aged <20 years [26, 47].

Table 2 Data of publication about the low bone mineral status in AIS patients

Authors (year of publication)	No. of AIS patients	No. of controls	Age	Sex	Cobb angle (°)	Methods of BMD measurement	Skeletal site measured	Results	Bone mineral density (mean ± SD)
Burner et al. [3] (1982)	50	51	No mentioned	No mentioned	Range from 10 to 20	Singh index	Thoracolumbar spine and both proximal femurs	There is a degree of osteoporosis in idiopathic scoliosis	The mean Singh index: 4.46 for the group with AIS; 5.53 for the normal children
Cook et al. [11] (1987)	44	44	Average age of 15.1 years (range from 9 to 20)	Girl	Thoracic curvature of 25.3 (range 6–50)	Dual-photon absorptiometry	Lumbar spine and femoral neck	The scoliotic subjects exhibited significantly lower lumbar and femoral neck bone mineral densities than the control subjects.	Site: CBMD g/cm^2 (calibrated bone mineral density) Lumbar spine: 1.01 ± 0.17; Femoral neck: 0.93 ± 0.14; Ward's triangle: 0.91 ± 0.16; Great trochanter: 0.74 ± 0.12
Cheng et al. [7] (2000)	75	94	12–14 years	Girl	Not mentioned	DEXA and PQCT	DEXA: Lumbar spine (L2-L4) and bilateral proximal femur; pQCT: Non-dominant distal radius and bilateral distal tibias	Of all the AIS girls, 38% of the aBMD and 36% of the vBMD were below −1 SD of the normal	DEXA g/cm^2 Lumbar (L2-L4) 0.755 ± 0.117 Proximal femur Neck dominant 0.740 ± 0.109 non-dominant 0.732 ± 0.104 Great trochanter dominant 0.615 ± 0.089 non-dominant 0.596 ± 0.083 Ward's triangle dominant 0.619 ± 0.107 non-dominant 0.600 ± 0.106 pQCT measurement (iBMD: integral vBMD tBMD: central 50% of the total bone area) Distal radius tBMD: 224.7 ± 58.2 iBMD: 467.5 ± 93.2 Distal tibia tBMD: dominant 247.8 ± 52.4 non-dominant 246.7 ± 50.9 iBMD: dominant 440.1 ± 77.1 non-dominant 457.4 ± 70.5

Table 2 continued

Authors (year of publication)	No. of AIS patients	No. of controls	Age	Sex	Cobb angle (°)	Methods of BMD measurement	Skeletal site measured	Results	Bone mineral density (mean ± SD)
Lee et al. [24] (2005)	619	300	11–16 years	Girl	Moderate (Cobb: 10–39) severe (Cobb: >40)	DEXA and PQCT	DEXA: lumbar spine and the nondominant proximal femur; pQCT: Non-dominant distal tibiae	Starting from age 13 years, most axial and peripheral BMD and BMC of the moderate or severe AIS group was significantly lower than for the controls	DEXA (g/cm^2) Moderate (≤12 years; 13 years; 14 years; ≥15 years) lumbar spine: 0.67 ± 0.11; 0.76 ± 0.11; 0.78 ± 0.10; 0.81 ± 0.10 femoral neck: 0.68 ± 0.10; 0.74 ± 0.11; 0.75 ± 0.10; 0.77 ± 0.11 Severe (≤12 years; 13 years; 14 years; ≥15 years) lumbar spine: 0.65 ± 0.11; 0.70 ± 0.08; 0.77 ± 0.11; 0.82 ± 0.12 femoral neck: 0.67 ± 0.11; 0.69 ± 0.07; 0.75 ± 0.11; 0.76 ± 0.12 pQCT (mg/cm^3) Moderate (≤12 years; 13 years; 14 years; ≥15 years) Distal tibial trabecular: 238.8 ± 43.9; 245.7 ± 45.6; 242.0 ± 42.1; 254.2 ± 44.4 Distal tibial trabecular and cortical BMD: 410.9 ± 61.3; 432.5 ± 72.8; 447.5 ± 67.8; 463.9 ± 65.8 Severe (≤12 years; 13 years; 14 years; ≥15 years) Distal tibial trabecular: 239.9 ± 49.6; 225.1 ± 47.0; 231.0 ± 48.5; 242.1 ± 64.1 Distal tibial trabecular and cortical BMD: 404.6 ± 85.8; 397.6 ± 52.9; 422.0 ± 66.7; 440.3 ± 87.9
Yeung et al.[48] (2006)	78	44	15–18 years	Girl	Moderate (Cobb: 20–40) severe (Cobb: >40)	PQCT	The distal region and the midshaft of non-dominant radius	A systemic low BMD including the cortical bone was demonstrated in AIS patients and AIS girls may have disturbance in mineralization and ossfication during peripubertal growth.	pQCT (mg/cm^3) Site BMD midshaft (mg/cm^3) 1433.0 ± 101.2 (moderate); 1415.4 ± 118.6 (severe) Cortical bone BMD (mg/cm^3) 1633.5 ± 39.71433.0 ± 101.2 (moderate); 1608.8 ± 48.6 (severe) Moderate 1433.0 ± 101.2 1415.4 ± 118.6 Severe 1633.5 ± 39.7 1608.8 ± 48.6

Table 3 Data of the follow-up studies of low bone mineral status in AIS patients

Authors (year of publication)	No. of AIS patients	No. of controls	Age	Sex	Follow-up period	Cobb angle degrees (°) (mean ± SD)	Methods and skeletal site of BMD measurement	Treatment	Results	Bone mineral density (mean ± SD)
Thomas et al. [41](1992)	22	0	Initial: mean 11.5 years(5–14 years) Follow-up: averaged 17.7 years(11–20 years)	Girl	Mean of 30.8 months (range 28.5–41 months)	Thoracic Initial 29.8 ± 12.2 Follow-up 30.6 ± 8.8 Lumbar Initial 27.7 ± 11.7 Follow-up 29.1 ± 9.5	Dual-photon absorptiometry Lumbar spine and femoral neck	Initial: follow-up only 14; bracing 6; electrical stimulation 2 Follow -up: follow-up only 15; bracing 3; surgery 2; electrical stimulation 2	Approximately half of the scoliotic subjects were markedly osteoporotic, having BMD measurements at least two standard deviations below the expected values	Site initial (g/cm^2) follow-up (g/cm^2) Lumbar spine 1.015 ± 0.202 1.112 ± 0.163 Femoral neck 0.917 ± 0.153 0.931 ± 0.133 Ward' triangle 0.900 ± 0.162 0.881 ± 0.145 Greater trochanter 0.736 ± 0.125 0.721 ± 0.117
Cheng et al. [5] (1999)	14	70	Initial: 12–14 years Follow-up: 14–17 years	Girl	Mean of 29 months (range 18–36 months)	Main curvature (right thoracic 8; double thoracic 4; thoracolumbar 2) Initial: range 20–51	DEXA Bilateral proximal femur	During follow-up: observation 1; bracing 10; surgery 3	The patients showed persistent and significantly lower BMD. The rate of increase of BMD in patients with AIS who have low BMD was lower	Age-based Z-score of BMD in the proximal femurs of AIS patients (g/cm^2) Initial mean 0.468 Follow-up mean 0.494
Snyder et al. [37] (2005)	52	0	Entry: 13.6 ± 1.5 years Follow-up: 14.8 ± 1.6 years	Girl	12 months	Major cobb angle: Initial: 29 ± 7 (range 20–40) Follow-up: 31 ± 9 (range 10–50)	DEXA Hip (femoral neck and total hip) and spine	Bracing only and observation only	The annual rate of bone density accumulation was similar to reported normal values. Bracing treatment does not affect bone density accumulation in girls with AIS	Site entry follow-up AP L1-L4 (g/cm^2) 0.848 ± 0.112 0.917 ± 0.110 AP L3 (g/cm^2) 0.872 ± 0.120 0.943 ± 0.116 Width-adjusted mid L3 (g/cm^3) 0.202 ± 0.021 0.208 ± 0.031 Femoral neck (g/cm^2) 0.776 ± 0.107 0.826 ± 0.110 Total hip (g/cm^2) 0.840 ± 0.121 0.894 ± 0.125
Cheng et al. [6] (2006)	196	120	Entry: mean 13.5 (range 12–16 years) Follow-up: 16.8 years	Girl	Average of 43.2 months	Initial: 26 (range 19–33) Follow-up: 28 (range 20–35)	DEXA and pQCT Bilateral proximal femur and non-dominant distal tibia	No mentioned	AIS girls had a persisitently lower BMD till they reach skeletal maturity	Initial: Z-score ≤ -1 SD: 35.9% (71 patients) Follow-up: constantly lower BMD at skeletal maturity: 86.0%

Table 4 The association of brace treatment with BMD in AIS

Authors	Conclusion
Cook et al. (1987) [11]	Although the BMD values of the 11 patients treated with bracing were lower than the 30 subjects not treated with bracing, these differences were not statistically significant
Thomas et al. (1992) [41]	The type of treatment including bracing, electrical stimulation and surgery had no effect with respect to the lower lumbar and femoral neck bone mineral densities
Synder et al. (1995) [38]	After adjusting for the magnitude and type of the curve, body mass index (BMI), activity, and diet, they demonstrated that no significant difference of the BMD values of the spine and hip between the brace treatment and observation group in AIS patients
Synder et al. (2005) [37]	Over 1 year period of brace treatment of scoliosis during adolescence did not adversely affect bone density accumulation at the spine or hip. The bone density accumulation was not significantly correlated with reported daily duration of brace use, annual change in BMI, severity of scoliosis
Sun et al.(2006) [40]	Both BMC and BMD levels increased during brace treatment in AIS at a rate similar to reported normal values, and bracing dose not appear to adversely affect the accumulation of bone mass in AIS

In the literature, only several studies described the association of osteopenia with spinal deformities in idiopathic scoliosis as listed in Table 2. When the osteoporosis is defined as a condition of BMDs more than 2 SDs below the mean value in age-matched healthy control subjects, the prevalence of patients with osteoporosis who have AIS is approximately 20–38% [5–11]. However, in one study of 15 healthy female volunteers with untreated adolescent structural lumbar idiopathic scoliosis, age range 23–58 years, Hans et al. [17] did not find a significant reduction of BMD in the reference population based on the whole body and femoral neck dual X-ray absorptiometry (DXA) measurements. Their results may be limited for no measurements of the spine and the small sample size in their work. And lumbar spine bone mineral was measured significantly lower by whole-body DXA than by regional DXA [31]. Therefore, they may not have sufficient data to obtain results similar to those in previous publications.

In the papers we reviewed, the skeletal site measured in the literature involved thoracolumbar spine, bilateral proximal femurs, lumbar spine (L2-L4), bilateral distal tibias, the distal region of radius and the mid-shaft of radius. It was interesting to find that AIS patients had a low BMD at different sites compared with the controls. The most prominent reduction of BMD was located at Ward's triangle in all three age groups [4]. Therefore, it seemed that low BMD was a generalized phenomenon and a systematic disorder in AIS patients. The histomorphometric findings also demonstrated significant less osteocyte count in the trabecular bone characterized with smooth and continuous borders in AIS patients [9].

Methods of the BMD measurements

A number of non-invasive techniques, including single and dual photon absorptiometry (SPA and DPA), single and DXA and quantitative computed tomography (QCT), have been developed to quantitate bone mass more sensitively. The radiographs or bone densitometers such as SPA or DXA were utilized for measuring bone mineral density in AIS patients. The deformity and the rotation of the spine may affect the BMD measured with DXA from an anteroposterior scan in idiopathic scoliosis subjects. The vertebral axial rotations accompanying the sagittal and frontal plane changes in spine contour might influence the truth of BMD assessed by DXA and so on. The degree of spinal rotation influences apparent bone mineral density by increasing the apparent vertebral segment area [15]. Larnach et al. [22] found that vertebral rotation of more than 8° would lead to errors in BMD assessment. Their study design might not represent the effect of vertebral rotation in vivo for a constant density phantom made of $Ca_{10}(PO_4)_6(OH)_2$. However, after scanned in the sagittal plane using cadaveric L4 vertebral bodies, Snyder et al. [38] showed that axial rotations up to 25° had little effect (10%) on the vertebral body BMD. Based on their observational study, Cheng et al. [8] acclaimed that DXA BMC of the lumbar spine is a reliable parameter in the assessment of bone mineral status for patients with scoliosis, although the lumbar spinal BMD may be underestimated due to the projected spinal bone area varies with the degree of rotational deformity of the scoliotic spine [14]. To minimize this error, an angulated analysis tool specially designed for BMD measurements of the lumbar spine was applied in their scoliosis researches [21]. To avoid adverse effect of the rotational component of the scoliosis, the interactive use of an operator-selected sub region of interest was performed [38].

Low BMD as a primary and persistent disorder

It is interesting whether the lower BMD value in scoliotic patients is secondary to the back deformity and the associated disorders in mechanical loading of the spine and hips, or whether it is happened as a primary problem.

Several studies revealed that the presence of low BMD in the pre- and early menarche girls with idiopathic scoliosis was a systematic and generalized phenomenon groups with mild scoliosis [7, 11, 41]. The histologic findings, namely the reduction in osteoclast number and dynamic activity in the trabecular bone, revealed the presence of abnormal bone metabolic activity and growth disturbance in AIS and supported the hypothesis that osteopenia could be a primary phenomenon rather than secondary to the deformity [9]. The osteopenia might generate before the presence of spinal deformity, and the low bone mineral content in patients with AIS might be related to the primary etiology of the spinal deformity. Based on the DXA and pQCT study, low aBMD of the lumbar spine and the bilateral proximal femur and the correspondingly low vBMD in the distal extremities was found, and the results also indicated the presence of generalized osteopenia in the pre- and early menarche groups with mild scoliosis.

During childhood and adolescence, bone mass acquisition occurs primarily through skeletal growth. Maximizing peak bone mass is advocated as a way to prevent osteoporosis. If the osteopenia is a persistent phenomenon in AIS, the patients would be at risk of failure to achieve an optimal peak bone mass which is an important determinant for preventing osteoporosis in late adulthood. Velis et al. [44] assessed the peak skeletal mass at locations unaffected by deformity in young adults with idiopathic scoliosis and their results showed significant decrease in average BMC measurements in scoliotic subjects. They presumed that an inherited connective tissue variation determines the initial bone density. A study included 33 young women treated for scoliosis in adolescence demonstrated that AIS patients with osteopenia wore a brace for significantly longer duration and had more severe scoliosis in adulthood than those without osteopenia [12].

The results of the follow-up studies shown in Table 3 indicated that osteopenia in patients with AIS may be a persistent phenomenon. A lower rate of increase of BMD was observed in the patients with scoliosis-associated osteoporosis compared with the control subjects [5], and at the time of skeletal maturity, the patients with AIS associated osteopenia were still over 86% at both distal tibia and femoral neck regions [6].

BMD of the bilateral proximal femur

The evidence linking idiopathic scoliosis with the concave and convex femoral neck BMD values has been somewhat contradictory based on the published data. Although the data of Cheng et al. [4, 7], Hung et al. [21], and Lee et al. [24] were collected from the same institute in different periods, their results were inconsistent. In adult subjects with untreated adolescent structural lumbar idiopathic scoliosis, age range 23–58 years, lower femoral bone density on the convexity side than the opposite one was found [17].

Bone mineral density could be affected by the mechanical loading, and many studies have been done involving exercise, impact loading, and the effect on BMD [18]. A limited numbers of studies have evaluated the microarchitectural changes in the bone associated with the spinal deformity and bone remodeling under eccentric tension–compression environments [9, 13, 34, 39]. On the basis of their study using scanning electron microscopy, Shea et al. [34] demonstrated that the concave side was significantly less porous than the convex side, and that the cortex of the facets on the concave side was significantly thicker than that on the convex side. The eccentric tension and compression stresses applied to the convex and concave portions of the curve in scoliotic patients might produce bone microarchitectural changes in the spinal facets similar to those seen in animal researches of eccentrically loaded bone [35, 36].

Basset [2] proclaimed that impact loading could produce an effect on bone formation. Impact can be attenuated by the attitude of the extremity at the moment of heel contact. If the abnormal mechanical loading according to the convexity side in scoliosis could cause a localized area of increased or decreased bone mineral content, BMD of the two sides of the proximal femur would be expected to be different. Additional force on the opposite hip might be produced for the shift of trunk gravity line to the convexity side. The long-term influences of impact-loading exercise on bone quantity and quality in young females have been reported [30]. The dynamic mechanism might result in the asymmetrical repartition of bone on the femoral neck. However, using a weight-bearing pattern analyzer, Hoppenfeld et al. [19] found that spinal deformity has no effect on the amount of weight borne on the right versus left foot. Their findings seemed to be concordant with the clinical investigation that spinal deformity did significantly alter BMD of the bilateral proximal femur.

Association of BMD with scoliosis parameters

Lower bone mineral mass is always associated with lower bone strength. The spinal architecture weakened by the osteopenia might aggravate the spinal deformity. The investigators had studied the correlation between BMD and scoliosis parameters, but the conclusions they drew were inconsistent. Almost no significant effect of scoliosis parameters associated with BMD was found in the articles published before 2000. Based on the histomorphometric study, no correlation was found between the severity of the lateral curve and the bone density. Their study did not show any clear association between the histologic features

and the age or severity of the scoliosis [9]. The histologic study by Enneking and Harrington [13] also found no significant correlation between asymmetrical growth of the posterior structures and the degree of histologic changes or the severity of the lateral curvature. However, it has been reported that low bone mineral density was strongly associated with the presence of vertebral wedge and loss of standing height in old patients [29]. A study on the associations between scoliosis and bone mineral density in a population of young women treated for scoliosis in adolescent was performed and the results indicated that the patients with osteopenia wore a brace for significantly longer duration and had more severe scoliosis in adulthood than those patients without osteopenia [12]. Although some authors advocated that poor bone quality was regarded as a new and unique prognostic factor in curve progression [21, 24], the correlation of BMD with scoliosis parameters should be studied further.

Bracing and BMD

Brace treatment for scoliosis is used to prevent spinal curve progression and to maintain the appearance of the back [28]. It is known that low bone density and fractures may be consequence of immobilization and muscle weakness. Immobilization of the forearm after hand or wrist surgery significantly decreases bone mass in the distal radius and ulna [20]. Bracing for adolescent scoliosis has been postulated to result in permanent loss of bone mineral mass and to predispose to adult osteoporosis. However, the studies concerning this issue do not support this presumption (Table 4). Since there was not an objective measure of actual brace wear, it was impossible to verify the patient compliance with bracing in any long term follow-up study in the articles we reviewed. The lack of standardized techniques used for clinical assessment of brace treatment remains a concern as the results and their implication would be limited.

Whether bone quality is an etiologic factor needs to be investigated further in prospective, randomized and longitudinal follow-up studies with more subjects enrolled. The findings from future studies would facilitate the understanding of potential pathomechanisms of low bone mineral status in AIS in a more rational way.

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