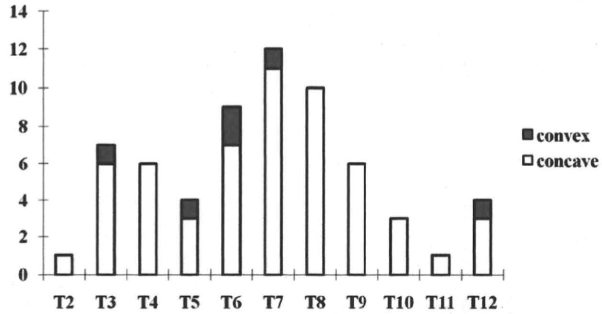

Figure 4. Distribution of type C pedicles.

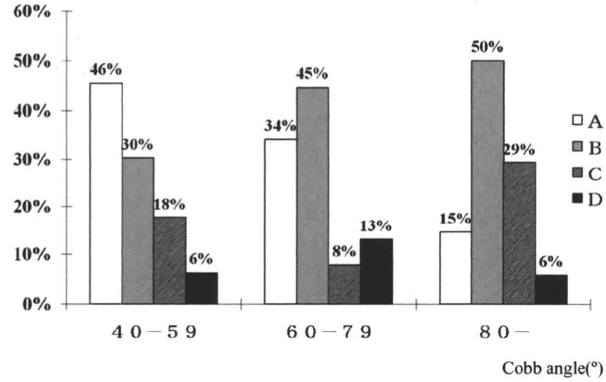

Figure 6. Cobb angle to pedicle type comparison.

except between types A and B (A *vs.* B; $P = 0.6947$, A and C; $P < 0.0001$, A and D; $P < 0.0001$, B *vs.* C; $P < 0.0001$, B *vs.* D; $P < 0.0001$, C *vs.* D; $P = 0.0436$).

Discussion

In the present study, we propose a novel classification describing the osseous anatomy encountered during probe insertion into the pedicle channel. The classification was defined from a feasibility standpoint of pedicle probe insertion, which is the most critical step in the placement of thoracic pedicle screws. During pedicle probe navigation using the free hand technique, we often encountered pedicles in which the probe was easily inserted. This type of pedicle was presumed to have an abundance of cancellous bone and so we designated this pedicle as type A or as having a large cancellous channel pedicle. We also often encountered pedicles in which increased force needed to be applied to the probe for insertion. Because the pedicle was presumed to have less cancellous bone than type A, we designated this pedicle as type B or as having a small cancellous channel pedicle. We occasionally encountered pedicles in which the probe could not be inserted even with increased manual force applied after reconfirmation of an optimal starting point. In that case, we used a mallet to tap the probe carefully down the pedicle into the vertebral body. This type of pedicle was assumed to have no or at least a very small amount of cancellous bone so we designated this type of pedicle as type C or a cortical channel pedicle. We rarely encountered pedicles that did not accept complete intraosseous probe insertion. Medial and/or lateral pedicle perforation was recognized during probe insertion even after reconfirmation of the pedicle probe starting point. Thus, we classified this pedicle as type D or a slit/absent channel pedicle. For type D pedicles, screws were required to be placed in a juxtapedicular position. Thus, type A and B pedicles do not require special techniques for manual probe insertion, whereas type C and especially type D pedicles require a more highly specialized probe insertion technique for safe pedicle screw placement. Surgeons will be required to utilize special methods such as tapping the probe with a mallet using a small high-speed drill or burr, or they will need to perform juxtapedicular placement.

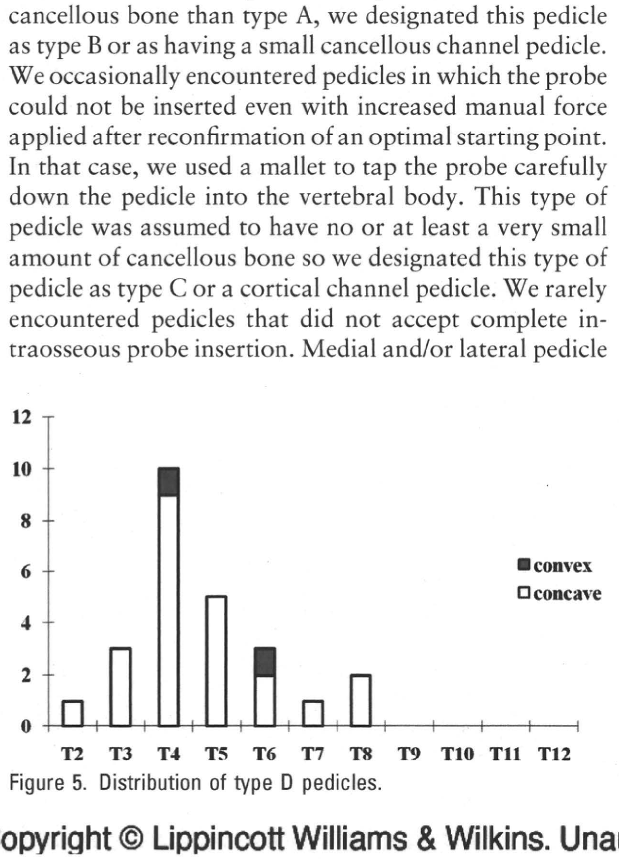

Figure 5. Distribution of type D pedicles.

On the basis of our prospective evaluation of 1021 thoracic pedicles, the most significant and surprising finding was that 90.2% of thoracic pedicles were either type A or B (A: 61.0%, B: 29.2%), and types C and D pedicles only accounted for 9.8%. Therefore, 90.2% of thoracic pedicle screws in this group of scoliotic patients had cancellous channels. Regarding the distribution of pedicle types, almost all pedicles (98.2%) were type A or B pedicles on the convex side. Although on the concave side, regardless of the reported fact that thoracic pedicles on the concave side have significantly smaller pedicles than that of the convex side, we still found that 82% had cancellous channels (A: 46.3%; B: 35.2%).[11,13–17]

Regarding the proportion of pedicle types to the diagnoses, the adult idiopathic scoliosis group had more type A and B pedicles and fewer type C and D pedicles compared with the AIS or syndromic scoliosis groups. The reason the adult idiopathic scoliosis group had fewer type D pedicles might be related to aging. The average age of the AIS group and the syndromic group was 14 to 16 years of age, whereas the average age in the adult idiopathic group was 57 years. As patients mature, the width of the pedicle increases and osteoporosis also increases. The average Cobb angles were identical at the time of evaluation. However, as Cobb angles increase 0.5° to 1° per year after skeletal maturity,[18,19] the average Cobb angle of the adult group might be smaller in magnitude at the time of adolescence.

Type C and D pedicles were localized around the concave apex of the main thoracic and proximal thoracic

Table 4. Width of Pedicle and Channels/Proportion of Cancellous Bone and Cortical Pedicles

	N	%	Pedicle Widths (mm)	Cancellous Bone Width (mm)	Proportion of Cancellous Bone (%)	No. Cortical Pedicles	%
A	186	59.6	5.8 ± 1.7	3.4 ± 1.7	56 ± 16	2	1.1
B	75	24.0	5.0 ± 1.7	2.6 ± 1.6	49 ± 18	2	2.7
C	30	9.6	3.7 ± 1.3	1.5 ± 1.3	34 ± 27	10	33.3
D	21	6.7	3.6 ± 1.3	1.6 ± 1.1	38 ± 26	13	61.9

Total N = 312.

curves. Our results are consistent with previous reports, which demonstrate that pedicles located on the concavity of thoracic curves were found to be significantly smaller than that on the convexity with a maximal difference at T8 where most apexes were located.[14] The width of the pedicles on the concave side of the proximal thoracic curve was also found to be significantly narrower with a maximal difference at T4.[14]

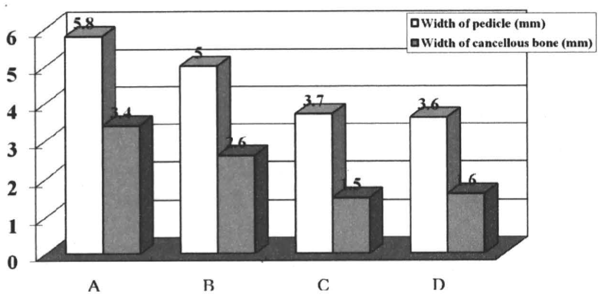

Figure 7. Pedicle width *vs.* cancellous bone width.

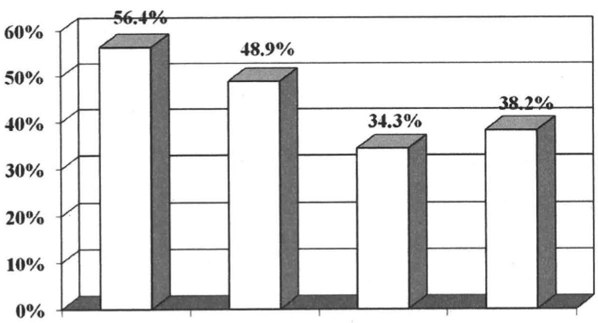

Figure 8. Proportion of cancellous bone width *vs.* pedicle width.

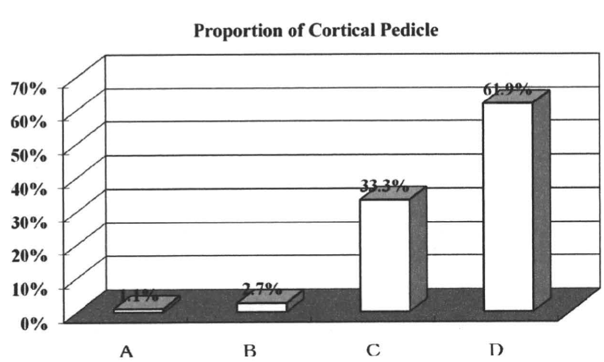

Figure 9. Proportion of pedicles with cortical channels.

Regarding the proportion of the pedicle types and the magnitude of the Cobb angle, our results indicated that as the magnitude of the Cobb angle increased, the proportion of type A pedicles decreased, and the proportion of type B pedicles increased. In addition, the proportion of type C pedicles increased as the Cobb angle exceeded 80°. Because the relation between pedicle width and Cobb magnitude is still not well known, our results provide insight into this relationship.

CT imaging appears to validate our morphologic evaluation of and subsequent description of the 4 pedicle types. The results that type A pedicles were wider with abundant cancellous bone validated that the morphology of type A was a large cancellous channel. Meanwhile, type B pedicles were significantly narrower and had significantly less cancellous bone compared with type A pedicles, but had wider widths and more cancellous bone than type C and D pedicles.

In conclusion, we propose a novel description of the osseous pedicle morphology encountered during pedicle probe insertion. Based on the classification, surprisingly, we found that 90% of the thoracic scoliotic pedicles had cancellous channels (types A and B), which were relatively safe for pedicle probe insertion and screw placement, whereas 7% had a cortical channel (type C) and only 3% an absent channel (type D). Surgeons should be aware of the breakdown of these pedicle types when considering pedicle screw placement for patients with thoracic scoliosis. This osseous pedicle morphologic description will aid surgeons during manual probing of pedicle tracts demonstrating specific methods required for safe screw insertion of each of the 4 types.

■ Key Points

- We propose 4 types of thoracic scoliotic pedicles: type A, large cancellous channel; type B, small cancellous channel; type C, cortical channel; and type D, slit/absent channel.
- The breakdown of a prospective evaluation of the 4 pedicle types was: type A, 61%; type B, 29%; type C, 7%; and type D, 3%.
- 98% of convex pedicles had a cancellous channel (types A and B) *versus* 81.5% of concave pedicles.
- As the magnitude of the Cobb angle increased over 80°, the proportion of the type C pedicle increased.

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Ball tip technique for thoracic pedicle screw placement in patients with adolescent idiopathic scoliosis

Technical note

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Object. The aim in this study was to evaluate the efficacy of the ball tip technique in placing thoracic pedicle screws (TPSs), as compared with the conventional freehand technique, in both a cadaveric study and a clinical study of patients with adolescent idiopathic scoliosis. Although posterior spinal surgery using TPSs has been widely applied, these screws are associated with the potential risk of vascular, pulmonary, or neurological complications. To further enhance the accuracy and safety of TPS placement, the authors developed the ball tip technique.

Methods. After creating an appropriate starting point for probe insertion, a specially designed ball tip probe consisting of a ball-shaped tip with a flexible metal shaft is used to make a guide hole into the pedicle. Holding the probe with the fingertips while using an appropriate amount of pressure or by tapping it gently and continuously with a hammer, one can safely insert the ball tip probe into the cancellous channel in the pedicle.

In a cadaveric study, 5 spine fellows with similar levels of experience in placing TPSs applied the ball tip or the conventional technique to place screws in 5 cadavers with no spinal deformities. The incidence of misplaced screws was evaluated by dissecting the spines. In a clinical study, 40 patients with adolescent idiopathic scoliosis underwent posterior surgery with TPS placement via the ball tip or conventional technique (20 patients in each treatment group). The accuracy of the TPS placements was evaluated on postoperative axial CT scanning.

Results. In the cadaveric study, 100 TPSs were evaluated, and the incidence of misplaced screws was 14% in the ball tip group and 34% in the conventional group ($p = 0.0192$). In the clinical study, 574 TPSs were evaluated. One hundred seventy-one intrapedicular screws (67%) were recognized in the conventional group and 288 (90%) in the ball tip group ($p < 0.01$). In the conventional and ball tip groups, the respective numbers of TPSs with a pedicle breach of ≤ 2 mm were 20 (8%) and 15 (5%), those with a pedicle breach of > 2 mm were 32 (13%) and 9 (3%; $p < 0.01$), and those located in the costovertebral joints were 32 (13%) and 7 (2%).

Conclusions. In both cadaveric and clinical studies the ball tip technique enhanced the accuracy of TPS placement as compared with the conventional freehand technique. Thus, the ball tip technique is useful for the accurate and safe placement of TPSs in deformed spines. *(DOI: 10.3171/2010.3.SPINE09497)*

Key Words • adolescent idiopathic scoliosis • ball tip technique • thoracic pedicle screw • posterior correction surgery

Posterior spinal correction surgery using TPSs has gained popularity among spine surgeons for the treatment of spinal deformity, replacing hook and wire constructs because mechanically strong TPS constructs provide 3D correction of the deformity and eliminate the need for postoperative bracing.[5,6,8,12] However, TPSs are associated with the potential risks of vascular, pulmonary, or neurological injuries, which can result in catastrophic sequelae.[2,10] A variety of techniques have been developed for the safe and accurate placement of these screws, including "anatomical" techniques such as the freehand technique,[7] open-lamina technique,[13] minilaminotomy technique,[4] and the insertion of guide pins at pedicle entry points.[11] Computer-generated imaging techniques have also been proposed as a means of fur-

Abbreviations used in this paper: AIS = adolescent idiopathic scoliosis; TPS = thoracic pedicle screw.

ther minimizing the misplacement of TPSs.[1–3,9] Although computer-generated imaging techniques have decreased the incidence of screw misplacement, their use requires a longer operative time, which can increase intraoperative blood loss and the chance of wound infection.

Since October 2006, we have been utilizing the ball tip technique rather than the freehand technique for TPS placement during posterior spinal correction surgery to enhance the accuracy and safety of screw insertion without requiring a prolonged surgical time and costly special equipment. In the ball tip technique, a specially designed flexible "ball tip probe" (Fig. 1) is used for the placement of TPSs. The purpose of our study was to confirm whether the ball tip technique enhances the accuracy of TPS placement compared with the conventional freehand technique in both cadaveric studies and clinical studies in patients with AIS.

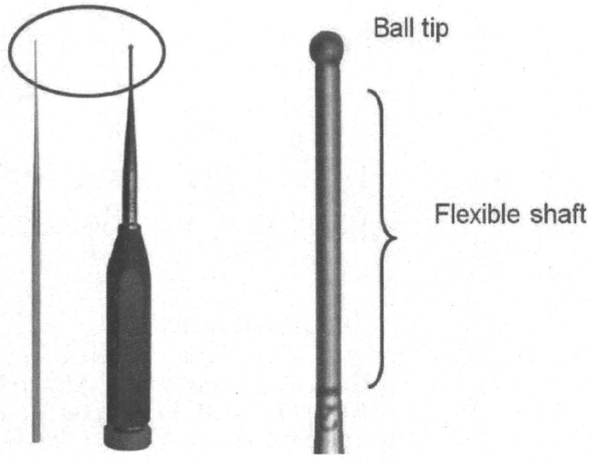

Fig. 1. Illustration of the ball tip probe, which consists of a ball-shaped metal tip with a metal flexible shaft. It is used to create a guide hole in the ball tip technique.

Methods

Thoracic Pedicle Screw Placement Technique

Ball Tip Technique. First, the posterior elements including the spinous processes, laminae, facets, and transverse processes are meticulously exposed. The starting points for TPS placement at each thoracic vertebra are identical to those proposed by Kim et al.[7] A 5-mm high-speed bur is used to remove the cortical bone of the dorsal lamina at the appropriate starting points approximately 3 mm in depth and then to expose the cancellous bone suggesting entrance at the base of the pedicle. Next, a specially designed ball tip probe is used to make a guide hole through the pedicle into the vertebral body. The ball tip probe consists of a ball-shaped metal tip with a flexible metal shaft (Medtronic Sofamor Danek; Fig. 1). It is held with the fingertips and gently pushed into the cancellous channel of the pedicle (Fig. 2). The ventral pressure of the ball tip probe is slightly less than is needed when inserting a rigid thoracic pedicle probe. If the cancellous channel is wide enough, the tip of the probe is smoothly advanced into the pedicle. If the cancellous channel is narrowed or if the tip of the probe makes contact with the cortical bone of the pedicle, a slight resistance against the probe will be encountered. In that case, the probe can be very gently tapped with a hammer (Fig. 3). Gentle tapping enables the ball tip to slip along the cortical wall into the cancellous channel of the pedicle (Fig. 4). Once the tip of the probe passes beyond the isthmus of the pedicle, which is recognized by a loss of resistance, the probe easily passes into the vertebral body. The probe is advanced until its tip hits the anterior cortex of the vertebral body. One should feel the probe penetrating the cancellous bone for the entire length of the pedicle and the vertebral body. Any sudden advancement of the ball tip probe suggests penetration of the pedicle or vertebral body. A gearshift probe (Medtronic Sofamor Danek; Fig. 5) is used to widen the guide hole. Next, a pedicle sounding device is used to check whether the pedicle walls have been breached. The TPS length is typically 5 mm less than the maximal probed depth, as determined by directly measuring the pedicle length using a pedicle sounder. The TPS diameter is predetermined based on preoperative CT studies. For patients with AIS, the typical screw diameter is 5.5 mm in the upper and midthoracic regions and 5.5–6.5 mm in the lower thoracic regions (T10–12). The pedicle is tapped using a tap device that is 1 mm smaller than the actual TPS diameter. After a recheck for pedicle perforation using the pedicle sounder, the TPS is placed through the pedicle into the vertebral body (Fig. 6).

Conventional Freehand Technique. Basically, the conventional freehand technique in this study corresponds to the freehand technique described by Kim et al.[7] In the conventional technique, the gearshift probe (Fig. 5) is used to create the guide hole after identification of the starting point. The conventional technique is essentially the same as the ball tip technique except for the use of the ball tip probe (Fig. 1) in creating the guide hole.

Cadaveric Study

Five cadavers (2 male and 3 female) were used in the cadaveric study. The average age at the time of death was 88.2 years (range 78–95 years), and the average height was 155 cm (range 145–160 cm). No evidence of congenital or developmental spinal malformations was found in any of the cadavers. All the cadavers had various degrees of age-related osteoporosis and degenerative changes.

Five spine fellows who had completed a similar training program in spine surgery conducted the cadaveric study; none of them had any experience in TPS placement. The cadavers were placed prone, and a standard midline posterior approach was used to expose the posterior elements. Each of the 5 cadavers was randomly assigned to a fellow. In each cadaver, the conventional technique and the ball tip technique were used for placement of the TPSs. Before starting screw placement, the fellows attended a senior surgeon's lecture regarding anatomy of the thoracic vertebra and the procedure for screw placement, especially how to find an appropriate starting point for TPS insertion at different thoracic levels. Exercises

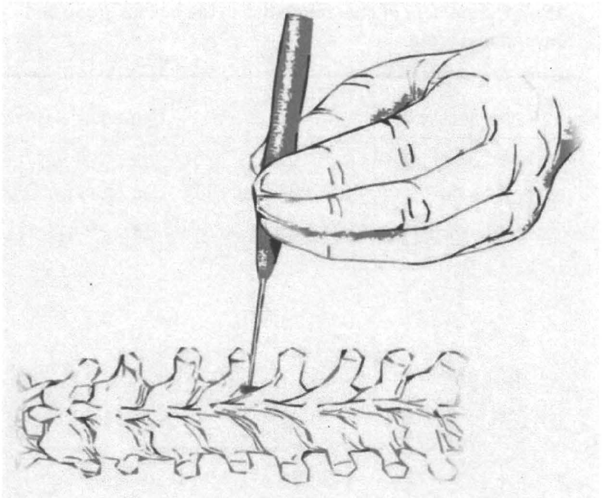

FIG. 2. Illustration demonstrating the ball tip technique (probe insertion). The ball tip probe is used to make a guide hole in the pedicle after the creation of a cortical breach at an appropriate starting point. Holding it with the fingertips, the probe is inserted into the pedicle with an appropriate amount of ventral pressure.

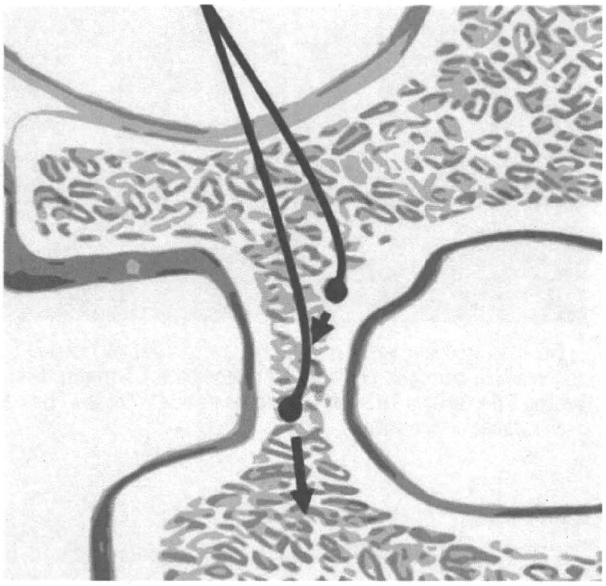

FIG. 4. Drawing showing the behavior of a ball tip in a pedicle. When the ball tip reaches the cortical wall of the pedicle, the shaft of the probe bends slightly against the inner cortical wall and the ball tip slips along the surface of the cortical bone without penetrating it; the tip then proceeds into the cancellous vertebral bone, where the resistance is much smaller.

for handling the screw-placing devices, such as the ball tip and the gearshift probes, were performed utilizing lumbar pedicle screw placement.

During the actual TPS placements, starting points were identified by the senior surgeon if the fellow was unable to locate the correct position. The TPSs were placed from T-3 to T-12 in all the cadavers (Fig. 7). The ball tip technique was performed before the conventional technique using 1 side of the spine; then the conventional technique was applied on the opposite side. The ball tip technique was performed on the left side in 3 cadavers and on the right side in 2. Once all TPS placements had been completed, the cadaveric specimens were dissected to evaluate the accuracy of screw placements. The presence or absence of a pedicle perforation and its direction—medial or lateral—were judged by 2 independent observers. Medial perforation was determined after a laminectomy and lateral perforation after rib disarticulations at every level. Pedicle screws without any cortical perforations were considered to be successfully placed. The accuracies of TPS placements using the conventional technique versus the ball tip technique were then compared.

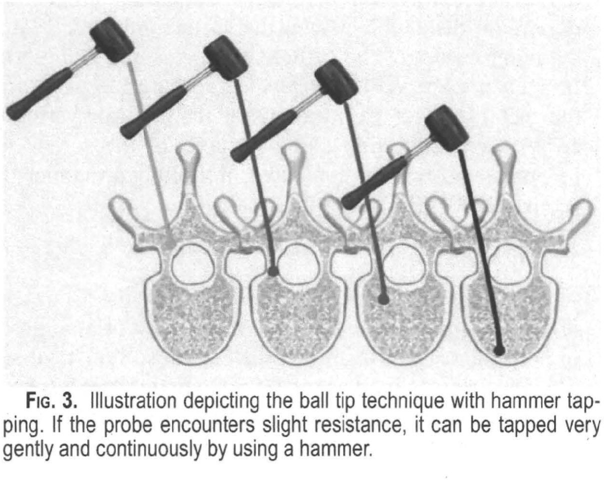

FIG. 3. Illustration depicting the ball tip technique with hammer tapping. If the probe encounters slight resistance, it can be tapped very gently and continuously by using a hammer.

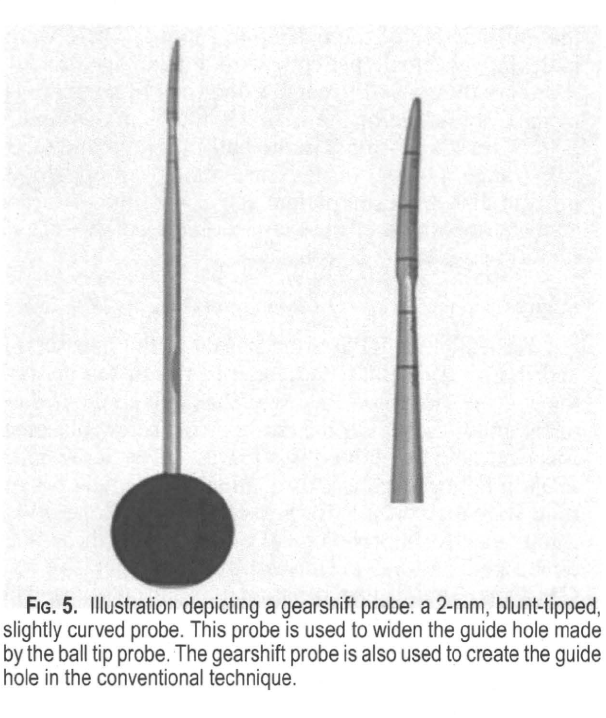

FIG. 5. Illustration depicting a gearshift probe: a 2-mm, blunt-tipped, slightly curved probe. This probe is used to widen the guide hole made by the ball tip probe. The gearshift probe is also used to create the guide hole in the conventional technique.

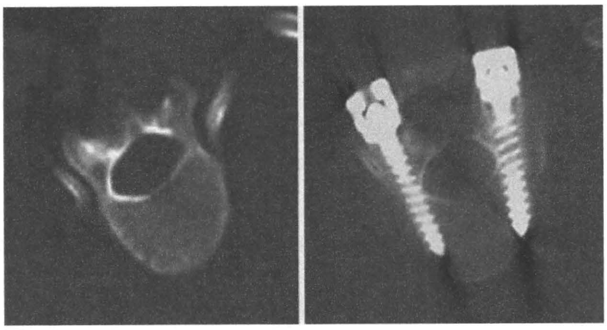

Fig. 6. A preoperative CT scan **(left)** showing a severely rotated T-10 vertebra with narrowed pedicles. A postoperative CT **(right)** demonstrating 5.5 × 35–mm TPSs placed into the pedicles. These TPSs were in an intrapedicular position.

Clinical Study in Patients With AIS

Forty patients with AIS who had been treated using only TPSs and lumbar pedicle screws were included in this study (Table 1). All patients had a main thoracic curve (Lenke Type 1, 21 cases; Type 2, 14 cases; and Type 4, 5 cases). Patients were divided into 2 treatment groups: a ball tip group and a conventional group. The ball tip group consisted of 20 consecutive patients who underwent posterior correction surgery using the ball tip technique between November 2006 and December 2007. There were 2 male and 18 female patients, with a mean age of 14.5 ± 3.1 years (range 9–22 years) at the time of surgery. The conventional group consisted of 20 consecutive patients who underwent posterior correction surgery using the conventional freehand technique[7] for TPS placement between December 2004 and October 2006. These 20 patients were the most recent cases treated using the conventional technique before the introduction of the ball tip technique. There were 3 male and 17 female patients, with a mean age of 13.4 ± 3.3 years (range 9–22 years) at the time of surgery. The mean Cobb angle of the main thoracic curve was 63.9 ± 14.6° (range 34–105°) in the ball tip group and 60.3 ± 5.3° (range 47–90°) in the conventional group. No significant differences in patient age at the time of surgery or the Cobb angle of the main thoracic curve were observed between the 2 groups.

Pedicle Screw Placement Planning in Patients With AIS

Basically, the TPSs were placed at the most cranial and the most caudal 2 vertebrae in the fusion area. On the concave side, the TPSs were placed in all the pedicles of the main curve. On the convex side, screw placement was occasionally omitted in a few pedicles. Screw placement in both groups was discontinued if pedicle perforations were recognized after several trials. Postoperatively, a retrospective morphological evaluation of these abandoned pedicles was performed using preoperative axial CT scans. The evaluated parameters included the width at the isthmus and the percentage of the cancellous bone width at the isthmus.

Pedicle screw placements on the left side were performed by a single senior spine surgeon, whereas those on the right side were performed by spine fellows under the direct supervision of the senior surgeon. Two spine fellows were involved in the conventional TPS placement and another spine fellow used the ball tip technique during this study.

TABLE 1: Summary of characteristics in the ball tip group and conventional group

Characteristic	Ball Tip Group	Conventional Group
no. of cases	20	20
treatment period	Nov 2006–Dec 2007	Dec 2004–Oct 2006
mean age in yrs (range)	14.5 ± 3.1 (9–22)	13.4 ± 3.3 (9–22)
sex		
M	2	3
F	18	17
Lenke type		
1	11	10
2	6	8
4	3	2
Cobb angle of main thoracic curve in degrees (range)	63.9 ± 14.6 (34–105)	60.3 ± 5 (47–90)

Computed Tomography Analysis

The accuracy of TPS placements was evaluated based on postoperative fine-cut (width of 1.25 mm) CTs in all patients in the clinical study. All thoracic levels were scanned using CT, and the gantry was set parallel to the TPSs. The positions of the screws were classified as follows: intrapedicular, pedicle breach ≤ 2 mm, pedicle breach > 2 mm, and intracostovertebral joints.[2] The direction of the pedicle breach (medial, anterior, or lateral) was also recorded. For screws with a pedicle breach, the maximum distance between the surface of the TPS and the outer cortex of the pedicle was measured using NIH Image software. All CT scans were filtered to minimize the metal artifact. Perforations of the anterior vertebral cortex were measured along the axis of the screw. An independent observer evaluated in a blinded manner the accuracy of TPS placements.

Statistical Analysis

A chi-square test was used to compare the accuracies of the ball tip group with those of the conventional group in both the cadaveric and clinical studies. Statistical significance was defined as $p < 0.05$. Statistical analysis was performed using SPSS, version 10.0 (SPSS, Inc.). Mean values are presented ± SDs.

TABLE 2: Summary of results of cadaveric study

Treatment	No. of Cases				
	Lateral Breach	Medial Breach	Total Breach	Intrapedicle (%)*	Total
ball tip method	4	3	7	43 (86)	50
conventional free-hand method	6	11	17	33 (66)	50

* p = 0.0138 with chi-square test, ball tip method compared with conventional method.

Results

Cadaveric Study

One hundred TPSs placed between T-3 and T-12 bilaterally in 5 cadavers were evaluated (Table 2 and Fig. 7). The incidence of TPS misplacement was 14% in the ball tip group (7 pedicles, 4 lateral, and 3 medial) and 34% in the conventional group (17 pedicles, 6 lateral, and 11 medial). The accuracy of TPS placement was significantly different between the 2 groups (p = 0.0192).

Clinical Study

Pedicle screws were placed in 607 pedicles. In 17 (5.1%) of 336 pedicles in the ball tip group and 16 (5.9%) of 271 pedicles in the conventional group, TPS placement was discontinued because pedicle perforations were recognized after several trials; all these pedicles were located on the concave side of the main curves. A retrospective evaluation of preoperative CT images of these abandoned pedicles in the ball tip group showed that the mean width at the isthmus was 2.8 ± 1.1 mm and the mean percentage of cancellous bone width at the isthmus was 21 ± 28%.

Five hundred seventy-four TPSs were evaluated. The numbers of screws classified as intrapedicular were 171 (67.1%) of the 255 screws placed in the conventional group and 288 (90.3%) of the 319 placed in the ball tip group (Table 3 and Fig. 4). A significant difference in the accuracy of TPS placement was observed between the 2 groups (p < 0.01). Twenty TPSs (7.8%; 7 medial, 9 lateral, and 4 anterior) in the conventional group and 15 (4.7%; 5 medial, 7 lateral, and 3 anterior) in the ball tip group were classified as pedicle breaches of ≤ 2 mm. Thirty-two TPSs (12.5%; 12 medial, 14 lateral, and 6 anterior) in the conventional group and 9 (2.8%; 6 lateral and 3 anterior) in the ball tip group were classified as pedicle breaches of > 2 mm. Thirty-two TPSs (12.5%) in the conventional group and 7 (2.2%) in the ball tip group were located in the costovertebral joints. A significant difference in the percentage of TPSs located in the costovertebral joints was observed between the 2 groups (p < 0.01). No vascular, pulmonary, or neurological injuries caused by TPS placement occurred in either group.

TABLE 3: Positions of TPSs

Parameter	No. of TPSs (%)	
	Conventional Group	Ball Tip Group
intrapedicular*	171 (67.1)	288 (90.3)
pedicle breach of ≤2 mm	20 (7.8)	15 (4.7)
pedicle breach of >2 mm*	32 (12.5)	9 (2.8)
intracostovertebral joint*	32 (12.5)	7 (2.2)
total	255 (100)	319 (100)

* p < 0.01, chi-square test, ball tip group compared with conventional group.

Discussion

Efficacy of Ball Tip Technique

In the clinical study performed in patients with AIS, the accuracy of TPS placement (including intrapedicular plus pedicle breaches of ≤ 2 mm) was 74.9% in the conventional group and 95.0% in the ball tip group. These results indicate that the ball tip technique enhanced the accuracy of TPS placement. In the cadaveric study, the incidences of TPS misplacement were 14% in the ball tip group and 34% in the conventional group. Thus, the ball tip technique was also effective in the cadaveric study, despite the fact that the elderly specimens had very poor bone quality and that the TPS placements were conducted by spine fellows with no previous experience in TPS placement.

In the ball tip technique, the probe is inserted into the cancellous channel of the pedicle either manually or sometimes with gentle tapping using a hammer (Fig. 3). When the ball tip reaches the cortical wall of the pedicle, the shaft of the probe bends slightly against the inner cortical wall and the ball tip slips along the surface of the cortical bone without penetrating it; the tip then proceeds into the cancellous vertebral bone, where the resistance is much smaller (Fig. 4). One of the advantages of the ball tip probe is its flexible shaft, which allows the probe tip to deflect from the cortical bone, especially from the thicker medial cortical bone of the pedicle. Misunderstanding the probe insertion angle, which will increase the risk of pedicle perforation, is more likely to happen in a scoliotic spine since vertebral bodies are always rotated around an apex of the curve. Since the ball tip probe will curve or bend before perforating the cortical bone, the chance of penetrating the pedicles will decrease. In the present study, medial perforations > 2 mm were not found in the ball tip group.

To eliminate a bias in patient selection and surgical techniques, we included the most recent consecutive 20 patients in the conventional group and the earliest consecutive 20 patients in the ball tip group. The TPSs located on the left side of the spine were inserted by the same senior spine surgeon in both groups. Although the

FIG. 7. Photographs demonstrating TPS placement in cadavers. Thoracic pedicle screws were placed from T-3 to T-12 using the ball tip technique and the conventional freehand technique **(left)**. After TPS placement, the presence of medial perforations was evaluated after a laminectomy **(right)**. *Arrows* indicate medial perforations from T-6 to T-8.

TPSs located on the right side of the spine were inserted by different fellows in the 2 groups, all TPS placements were performed under the direct supervision of the senior surgeon.

Limitations of the Ball Tip Technique

The ball tip probe may not work for a well-corticated pedicle or for an extremely small cancellous channel pedicle since the flexible shaft will bend before creating a guide hole in the pedicle. Even using the ball tip technique, TPS placement was discontinued in 17 (5.1%) of 336 pedicles because of repeated perforations by the ball tip probe. The majority of perforations occurred to the lateral side of the pedicles, which might be due to the thicker medial cortex as compared with the lateral cortex. This failure rate is similar to the rate (5.9%) when using the conventional technique. This result indicates that although the ball tip probe enhances the accuracy of TPS placement, there are still some pedicles that cannot accommodate the ball tip probe. An evaluation of preoperative CT axial scans revealed that in such pedicles, the width of the pedicle was relatively narrow (2.7 mm) and the proportion of cancellous bone was relatively low (20%); in other words, these pedicles were slit pedicle channels.

Although we demonstrated the usefulness of the ball tip technique in this study, we must emphasize that it may not be helpful to a surgeon who does not have any experience in placing TPSs. The technique will be more helpful to a surgeon who has had experience in placing TPSs and will help to identify approximate starting points for screw insertions, since a mistake in the identification of a screw starting point can lead to a high rate of missed screw placements even if the ball tip technique is used.

Limitations of This Study

A limitation of this study was that the patients were not randomized for both techniques in the clinical study. Because after several surgeries we felt safe and comfortable with the ball tip technique, we determined that randomization of the patients was not allowed ethically. Instead, we performed the cadaveric study to compare the conventional technique with the ball tip technique at the same time.

Another limitation of the study was that the senior surgeon identified the starting points of the probe insertions if the fellows were unable to determine the correct points. Because the misidentification of starting points would greatly affect the study results, we tried to eliminate the error caused by misidentification of the starting points. Although a lecture about the starting points of probe insertions was given before starting the study, the reliability of inexperienced surgeons in identifying the correct starting points was deemed to be low and varied among them.

Conclusions

In summary, the ball tip technique enhanced the accuracy of TPS placement, compared with the conventional freehand technique, in patients with AIS, in whom TPS placement is regarded to be relatively difficult. An adult cadaveric study also confirmed the efficacy of the ball tip technique. It is expected to be useful for the safe and accurate placement of TPSs in deformed spines.

Disclosure

Dr. Chiba is a consultant for Medtronic Sofamor Danek Japan and Stryker Japan. Drs. Watanabe and Matsumoto are consultants for Medtronic Sofamor Danek Japan.

Author contributions to the study and manuscript preparation include the following. Conception and design: Watanabe, Matsumoto. Acquisition of data: Watanabe. Analysis and interpretation of data: Watanabe. Drafting the article: Watanabe, Matsumoto. Critically revising the article: Watanabe, Tsuji, Ishii, Takaishi, Nakamura. Reviewed final version of the manuscript and approved it for submission: all authors. Statistical analysis: Watanabe. Administrative/technical/material support: Watanabe, Toyama, Chiba. Study supervision: Watanabe, Toyama, Chiba.

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Prospective Ten-Year Follow-up Study Comparing Patients With Whiplash-Associated Disorders and Asymptomatic Subjects Using Magnetic Resonance Imaging

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Study Design. A prospective 10-year follow-up study of patients with whiplash-associated disorders (WAD) and asymptomatic volunteers.

Objective. To clarify long-term impact of whiplash injury on patient's symptoms and on magnetic resonance imaging (MRI) findings of the cervical spine.

Summary of Background Data. Long-term prognosis of WAD has not been fully elucidated.

Methods. Between 1993 and 1996, we conducted cross-sectional comparative study of 508 acute WAD patients and 497 asymptomatic volunteers, all of whom underwent MRI of the cervical spine. For this follow-up study, 133 WAD patients and 223 control subjects were recruited again. All participants underwent follow-up MRI and physical examination, and answered to questionnaires regarding neck symptoms. Evaluation of MRI included decrease in signal intensity of discs, posterior disc protrusion, disc space narrowing, and foraminal stenosis using 2 to 4 numerical grades. Increase in the numerical grades by one or more was considered to be progression of degenerative changes.

Results. Progression of decrease in signal intensity was observed in 109 WAD patients (82.0%), and 132 control subjects (59.2%), (age, sex adjusted odds ratio [OR]: 3.06), posterior disc protrusion in 101 (75.9%) and in 155 (69.5%) (OR = 1.46), disc space narrowing in 33 (24.8%) and in 59 (26.5%) (OR = 0.98), and foraminal stenosis in 6 (4.5%), and in 20 (9.0%) (OR = 0.52), respectively. Neck pain was observed in 34 WAD patients (25.6%) and 22 control subjects (9.9%) ($P < 0.0001$). There was no statistically significant correlation between neck pain and progression in each MR finding in either group.

Conclusion. The results of this study suggest that, although some WAD patients are more likely to suffer from long-lasting neck pain, MRI findings cannot explain the symptoms.

Key words: whiplash, magnetic resonance imaging, cervical spine, asymptomatic volunteer. **Spine 2010;35: 1684–1690**

"Whiplash injury" was first reported by Crowe in 1928,[1] followed by Gay and Abbott,[2] who subsequently reported cases of whiplash injuries caused by vehicular rear-end collisions. Ever since, the motorization of the society has elevated the incidence of whiplash injury throughout the world. The various symptoms seen in patients suffering from whiplash injury were termed "whiplash-associated disorders" (WAD) by the Quebec Task Force.[3] WAD, although self-limiting in most cases, sometimes becomes chronic and refractory. In patients with whiplash injury, disc injury sometimes results from the forced flexion and extension of the neck caused by acceleration and deceleration at the moment of collision,[4] possibly leading to the subsequent degeneration of the intervertebral discs. Jonsson *et al*[5] conducted an magnetic resonance imaging (MRI) study of 50 WAD patients with chronic symptoms and performed anterior decompression and fusion surgery in 8 patients with severe pain and disc abnormalities, as revealed by MRI; during the surgeries, they found extruded disc materials in all 8 patients. Pettersson *et al*[6] conducted a 2-year follow-up evaluation of 39 WAD patients and found that 13 patients (33%) had disc herniations with impingement on the spinal cord or dura; all patients with spinal cord impingement had persistent or increased symptoms. However, all disc abnormalities seen in WAD patients cannot necessarily be attributed to neck injury because degenerative changes of the intervertebral discs are often seen in asymptomatic healthy populations as sequelae of the normal aging process (Figures 1, 2). Between 1993 and 1996, we conducted a cross-sectional comparative study between acute WAD patients and asymptomatic healthy volunteers, approximately 500 in each arm, all

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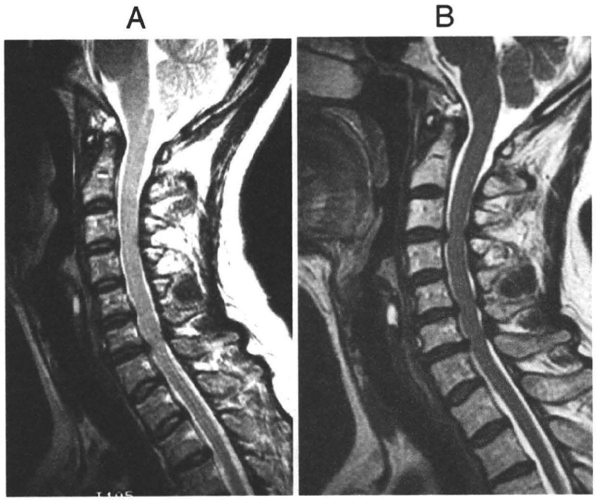

Figure 1. A 37-year-old woman suffering whiplash injury has progression of degeneration of the cervical spine 10 years after injury (**A, B**). **A**, T2-weighted sagittal image taken at the time of injury. **B**, Ten years later.

of whom underwent MRI of the cervical spine.[7–9] We found that degenerative changes, such as decreases in the signal intensity of the intervertebral discs and posterior disc protrusion, were equally seen in both groups. Kongsted *et al*[10] also reported that degenerative discs observed on MRI were not associated with the short-term prognosis of WAD patients. Thus, inconsistent results regarding the relation between disc abnormalities visible on MRI and the symptoms or prognosis of patients with WAD have been reported.

We conducted a 10-year follow-up study of our previously recruited cohorts (both asymptomatic volunteers and WAD patients) to investigate time-interval changes in the intervertebral discs of the cervical spine over a 10-year period and to clarify the long-term impact of whiplash injury on patient's symptoms.[11,12] The objectives of the present study were to compare the prevalence of symptoms related to the cervical spine and the incidence of the progression of degenerative changes in the cervical intervertebral discs by MRI, between the volunteers and the WAD patients, to determine whether whiplash injury can accelerate the degeneration of cervical intervertebral discs.

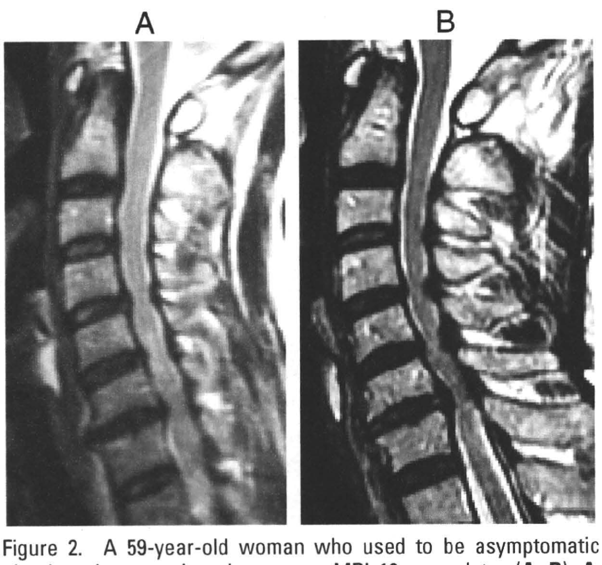

Figure 2. A 59-year-old woman who used to be asymptomatic also has degenerative changes on MRI 10 years later (**A, B**). **A**, T2-weighted sagittal image taken at the previous investigation. **B**, Ten years later.

■ Materials and Methods

Study Participants

For this follow-up study, conducted between 2005 and 2007, 133 WAD patients (63 males and 70 females; mean age, 49.6 ± 15.3 years at the time of the present investigation) and 223 control subjects (originally asymptomatic subjects; 123 men, 100 women; mean age, 50.5 ± 15.0 years) were recruited again by mail and telephone. Before this study, the approval of the institutional review boards of each participating institution was obtained, and a written informed consent from the participants was obtained after an oral explanation about the present study. The background characteristics of the participants were described in the previous reports.[7–9,11,12] Briefly, in the previous study, 506 patients who suffered from whiplash injuries underwent MRI and a physical examination within 2 weeks after the injury. A total of 281 of the 506 patients whose addresses were available were contacted and, 133 patients agreed to participate in the present study (26.3% of the original cohort, 47.3% of the located patients). In the control group, 497 subjects underwent MRI between 1993 and 1996. A total of 327 of the 497 original subjects were located and asked to participate in the follow-up study. Two hundred thirty-three volunteers finally agreed to participate in the present study (46.9% of the original cohort, 71.3% of the located patients). The control subjects included medical workers at the participating institutions as reported previously,[9,11,12] thereby, making the follow-up rate of the control group higher than that of the WAD group. Between the 2 groups, no significant differences in the male to female ratio, the mean age, the interval between the previous and present study, smoking habits, or the body mass index at follow-up were observed; in the WAD group, however, the follow-up rate was significantly lower and the percentage of patients engaged in heavy labor (drivers, farmers, constructors) and in sports activities, was significantly higher than the control subjects (Table 1).

MRI Examination

All participants underwent follow-up MRI examination using a 1.5-Tesla (T) superconducting MR imager. At the time of the previous investigation, a 0.5-T or a 1.5-T superconducting MR imager (a Resona-0.5-T [Yokogawa Medical System, Tokyo], a Toshiba MRT-0.5-T [Toshiba, Tokyo], or a Signa-1.5-T [General Electric, WI]) was used. A total of 103 (77.4%) patients in the WAD group and 155 (69.5%) subjects in the control group were examined using a 0.5-T MR machine in the previous study. Thus, 0.5-T machines were used more frequently in the WAD group than in the control group in the previous study, although the difference was not statistically significant ($P = 0.11$).

In the previous investigation, T1-weighted sagittal images (TR: repetition time/TE: echo time, 520/12; echo train length, 4; slice thickness, 5 mm; field of view [FOV], 24 cm; matrix size, 256 × 192; number of excitations [NEX], 4 times), T2-

Table 1. Demographics of Participants

	WAD Patients	Control	P*
No. participants	133	223	
Gender			
Male	63	123	0.19
Female	70	100	
Age at follow-up	49.6 ± 15.3	50.5 ± 15.0	0.62
Duration of follow-up	11.4 ± 0.6	11.6 ± 1.4	0.14
Follow-up rate			
% of all patients	26.3%	46.9%	<0.001†
% of located patients	47.3%	71.3%	<0.001†
Smoking	45 (33.8%)	65 (29.1%)	0.41
Sports activity	35 (26.3%)	32 (14.3%)	0.007†
BMI	23.0 ± 3.5	23.3 ± 3.1	0.40
Engagement in heavy labor	15 (11.9%)	10 (4.5%)	0.016†

*χ^2 test was used for categorical data, and unpaired t test was used for numerical data.
†Difference was statistically significant.
WAD indicates whiplash-associated disorder; BMI, body mass index.

Table 2. Grading System of MRI

Decrease in signal intensity of intervertebral disc	
0	As bright as or slightly less bright than cerebrospinal fluid
1	Markedly darker than cerebrospinal fluid
2	No signal
Posterior disc protrusion	
0	No protrusion
1	Disc material protruding beyond the posterior margin of the vertebral body without cord compression
2	Beyond vertebral body with cord compression
Disc space narrowing	
0	100%–75% of height of upper healthy disc
1	75%–50% of height of upper healthy disc
2	Less 50% of height of upper healthy disc
Foraminal stenosis	
0	No stenosis
1	Foraminal stenosis

weighted sagittal images (TR/TE, 5000/102; echo train length, 16; remaining parameters are the same as for the T1-weighted sagittal images), and T1- and T2-weighted cross-sectional images (FOV, 16 cm; remaining parameters are the same as for the T1- and T2-weighted sagittal images) were taken using a fast spin-echo technique and a phased array coil for the 1.5-T superconducting MR machines. For the 0.5-T superconducting MR machines, a T1-weighted sagittal image (TR/TE, 450–500/25; slice thickness, 5–7 mm; FOV, 25 cm; matrix size, 256 × 256 or 256 × 192; NEX, 4 times), a T2-weighted sagittal image (TR/TE, 2000/100; slice thickness, 5–7 mm; FOV, 25 cm; matrix size, 256 × 224 or 256 × 160; NEX, twice), and T1- and T2-weighted cross-sectional images (TR/TE, 550/25; slice thickness, 7 mm; FOV, 22 cm; matrix size, 256 × 256; NEX, twice) were taken using the spin-echo technique and a quadrature spine coil. In the present study, 1.5-T superconducting MR machines (EXCELART-1.5-T [Toshiba] and Signa-1.5-T [General Electric]) were used. T1-weighted sagittal images (TR/TE, 600/10; echo train length, 4; slice thickness, 4 mm; FOV, 23 cm; matrix size, 256 × 304; NEX, twice), T2-weighted sagittal images (TR/TE, 3000/108; echo train length, 17; slice thickness, 4 mm; FOV, 23 cm; matrix size, 320 × 320; NEX, twice), and T1- and T2-weighted cross-sectional images (TR/TE, 4000/108; echo train length, 17; slice thickness, 4 mm; FOV, 16 cm; matrix size, 192 × 192; NEX, twice) were mainly taken using the fast spin-echo technique and a phased array coil.

Physical Examination and Questionnaire

The participants also underwent physical examination and answered a questionnaire on cervical spine-related symptoms including neck pain, shoulder stiffness, headaches, and arm pain and/or numbness. In the questionnaires, the participants in both groups were asked whether they had such symptoms, and the WAD patients were asked if their symptoms had improved, remained unchanged, or become exacerbated at the time of the follow-up examination, compared with immediately after injury.

MRI Evaluation

The MRI findings were evaluated by 2 experienced neuroradiologists, who were unaware of the patient group assignment, with regard to the decrease in the signal intensity of the intervertebral discs on the T2WSI images, posterior disc protrusion, disc space narrowing, and foraminal stenosis on the T1WSI and T2WAI images. The evaluated intervertebral levels ranged from C2–C3 to C7–T1. Each degenerative MR finding was graded using 2 to 4 numerical grades (Table 2) according to previously reported criteria, with some modifications.[9,11,12] An increase in the numerical grade by one or more in at least one intervertebral level was considered to indicate the progression of degenerative changes. The interobserver reliability between the 2 readers has already been proven to be good in the previous study (Kappa scores, 0.62–0.88 for each reading item).[11]

Analyses

The prevalences of the clinical symptoms and the incidences of progression for each degenerative MR finding were compared between the 2 groups. The correlations between the MR findings and the cervical spine-related symptoms were evaluated in WAD patients. For the statistical analyses, the χ^2 test and an unpaired t test, logistic regression analysis were performed using SPSS 15J for Windows (SPSS Japan Inc., Tokyo). A P value less than 0.05 was considered statistically significant.

■ Results

Clinical Symptoms

At the time of injury, neck pain was present in 125 (94.1%) of the 133 WAD patients, shoulder stiffness in 81 (61.0%), headache in 51 (38.3%), and arm pain/numbness in 17 (12.8%). At the follow-up, more than half of the symptomatic WAD patients felt that their symptoms had improved (Table 3). The WAD patients complained of neck pain, shoulder stiffness, headaches,

Table 3. Changes of Symptoms in WAD Patients

	Immediately After Injury Prevalence of Symptoms	Improved	At Follow-up Unchanged	Exacerbated
Neck pain	125 (94.0)	96 (76.8)	14 (11.2)	15 (12.0)
Stiff shoulder	81 (60.9)	46 (56.8)	25 (30.9)	10 (12.8)
Headache	51 (38.3)	37 (72.5)	7 (13.5)	7 (13.7)
Arm pain/ numbness	17 (12.8)	12 (70.6)	2 (11.8)	3 (17.6)

WAD indicates whiplash-associated disorder.

Table 4. Comparison of Prevalence of Symptoms at Follow-up

	WAD*	Control
Neck pain	34 (25.6)	22 (9.9)
Stiff shoulder	73 (54.9)	34 (25.6)
Headache	37 (27.8)	16 (7.2)
Arm pain/numbness	23 (17.3)	10 (4.5)

The parentheses indicate percentage of patients with each symptom.
*WAD patients have significantly higher prevalence of each symptom at follow-up ($P < 0.001$, χ^2 test).
WAD indicates whiplash-associated disorder.

Table 6. Gender and Clinical Symptoms

	WAD Patients		Control	
	Male	Female	Male	Female
Neck pain	13/63 (20.6%)	21/70 (30.0)	9/123 (7.3%)	13/100 (13.0)
Stiff shoulder	25/63 (39.7)	48/70 (68.6)*	18/123 (14.6)	45/100 (45)*
Headache	14/63 (22.2)	23/70 (32.9)	2/123 (1.6)	16/223 (7.2)*
Arm pain/numbness	7/63 (11.1)	16/70 (22.9)	8/123 (6.5)	2/100 (2.2)

Parentheses indicate percentage of patients with each clinical symptom ($P < 0.01$).
*Statistically significant difference.
WAD indicates whiplash-associated disorder.

and arm pain/numbness significantly more frequently than the control group at the time of the follow-up examination ($P < 0.001$) (Table 4). None of the subjects in either group developed myelopathy detected by neurologic examination or underwent cervical spinal surgery.

Factors related to the presence of clinical symptoms at the time of follow-up were investigated using a logistic regression analysis with independent variables, including history of whiplash injury, sex, age at follow-up (<40 years or >40 years), body mass index at follow-up (<25 kg/m^2 or >25 kg/m^2), smoking habit, participation in regular sports activity, and engagement in heavy labor (Table 5). History of whiplash injury was a significant risk factor for neck pain (odds ratio [OR], 2.74), shoulder stiffness (3.26), headache (4.30), and arm pain/numbness (3.71). Men had neck pain (0.51), shoulder stiffness (0.19), and headache (0.22) less frequently than women. The preponderance of clinical symptoms in women was observed in both groups, although only shoulder stiffness was significantly more frequent among women in both groups and arm headache was more frequent only among women in the control group (Table 6). Regular sports activity was negatively related to shoulder stiffness (0.40).

MRI Findings

In the initial MRI study, a decrease in the signal intensity of the intervertebral discs at one or more levels, disc space narrowing, and foraminal stenosis were not significantly different between the WAD patients and the control subjects, while posterior disc protrusion was significantly more frequent among the WAD patients than the control subjects (48.9% *vs.* 33.6%, $P = 0.005$) (Table 7).

In the MRI study performed at the time of the follow-up examination, a decrease in the signal intensity of the intervertebral discs was observed more frequently among the WAD patients than the control subjects. Regarding the other 3 MRI findings, no statistically significant differences in the frequencies of positive findings were observed between the 2 groups (Table 8).

Incidence of Progressive Degenerative MRI Findings

Progressive decreases in the signal intensity of the intervertebral discs were observed in 98 of the WAD patients (83.1%) and 132 of the control subjects (59.5%) (age, sex adjusted OR, 3.3; $P < 0.001$), posterior disc protrusion was observed in 89 (75.4%) of the WAD patients and 155 (69.8%) of the control subjects (OR = 1.4, $P = 0.22$), disc space narrowing was observed in 30 (25.4%) of the WAD patients and 60 (27.0%) of the control subjects (OR = 0.9, $P = 0.89$), and foraminal stenosis was observed in 6 (5.1%) of the WAD patients and 20 (9.0%) of the control subjects (OR = 0.5, $P = 0.25$), respectively (Table 9). Thus, progressive decreases in the signal intensity of the intervertebral discs were significantly more frequent in the WAD patient than the control subjects, while the progressive changes in the other MRI findings were equally frequent between the 2 groups. No specific intervertebral level where the difference in progressive decreases in the signal intensity of the intervertebral discs was identified.

Table 5. Factors Related to Presence of Clinical Symptoms at Follow-up

	Neck Pain	Shoulder Stiffness	Headache	Arm Pain/Numbness
History of whiplash	2.74 (1.45–5.15)*	3.26 (1.91–5.55)*	4.30 (2.14–8.64)*	3.71 (1.62–8.52)*
Gender (male/female)	0.51 (0.26–1.00)†	0.19 (0.11–0.33)*	0.22 (0.10–0.49)*	0.53 (0.22–1.25)
Age at follow-up (≥40)	0.94 (0.87–1.13)	1.74 (0.98–3.08)	0.99 (0.47–2.08)	1.84 (0.73–4.64)
Smoking	1.35 (0.69–2.63)	1.60 (0.90–2.81)	1.42 (0.67–3.00)	1.59 (0.68–3.73)
Sports activity	1.25 (0.57–2.73)	0.40 (0.19–0.83)*	1.00 (0.40–2.47)	1.48 (0.58–3.80)
BMI (≥25)	0.74 (0.36–1.53)	1.01 (0.58–1.76)	0.93 (0.43–2.00)	1.48 (0.65–3.37)
Engagement in heavy labor	1.05 (0.32–3.37)	1.66 (0.65–4.26)	3.01 (1.06–8.58)	1.13 (0.30–4.35)

Odds ratio and 95% confidence interval determined by logistic regression analysis.
*$P < 0.01$.
†$P = 0.05$.

Table 7. MRI Findings at Initial Study

	WAD Patients	Control	*P*
Decrease in signal intensity of intervertebral disc	80 (60.2)	122 (54.7)	0.32
Posterior disc protrusion	65 (48.9)	75 (33.6)	0.005*
Disc space narrowing	15 (11.3)	20 (9.0)	0.47
Foraminal stenosis	4 (3.0)	1 (0.4)	0.07

The parentheses indicate percentage of patients with positive MRI finding.
WAD indicates whiplash-associated disorder; MRI, magnetic resonance imaging.
*Statistically significant (chi squared test).

Relation Between Clinical Symptoms and the Progression of Degenerative MRI Findings

Neck pain was observed in 27.5% of the WAD patients with a progressive decrease in the signal intensity of the intervertebral discs on MRI and in 16.7% of those without such a decrease, in 26.7% of the patients with progressive posterior disc protrusion and 21.9% of those without such progression, in 21.2% of the patients with progressive disc space narrowing and 27.0% of those without such progression, and in 5.7% of the patients with foraminal stenosis and 3.3% of those without foraminal stenosis, respectively (Table 10). No significant associations between the progression of each degenerative MRI finding and the clinical symptoms were observed in either group.

■ Discussion

While a number of short- and middle-term follow-up studies on WAD patients have been reported,[13–18] the long-term prognosis of this pathologic condition has not been fully elucidated. Gargan and Bannister[19] reviewed 43 patients who had sustained soft tissue injuries of the neck a mean interval of 10.8 years earlier. Of these patients, only 12% had recovered completely. Pain in the neck and lower back were the most common complaints, and older patients had poorer outcomes. They also followed these patients for 5 more years and reported that the conditions of 18% of the patients improved, whereas those of 28% of the patients deteriorated.[20] When conducting a long-term follow-up of WAD patients, age-related degenerative changes in the cervical spine leading to clinical symptoms must be considered, as such symptoms may be superimposed on symptoms related to whiplash injuries. Therefore, comparisons with healthy persons, who presumably will exhibit the effects of the natural aging process, are important for understanding the true long-term impact of whiplash injuries on the symptoms and radiologic findings of patients.

Table 8. MRI Findings at Follow-up

	WAD Patients	Control	*P*
Decrease in signal intensity of intervertebral disc	128 (96.2)	184 (82.5)	<0.001*
Posterior disc protrusion	115 (86.5)	181 (81.2)	0.24
Disc space narrowing	39 (29.3)	72 (32.3)	0.64
Foraminal stenosis	10 (7.5)	24 (10.8)	0.36

The parentheses indicate percentage of patients with positive MRI finding.
MRI indicates magnetic resonance imaging.
*Statistically significant (χ^2 test).

Table 9. Incidence of Progression of Degenerative MRI Findings

	WAD Patients	Control	Odds Ratio (95% Confidence Interval, *P*)
Decrease in signal intensity of intervertebral disc	109 (82.0)	132 (59.2)	3.06 [1.82–5.14, *P* = 0.001]*
Posterior disc protrusion	101 (75.9)	155 (69.5)	1.46 [0.89–2.40, *P* = 0.13]
Disc space narrowing	33 (24.8)	59 (26.5)	0.98 [0.59–1.61, *P* = 0.93]
Foraminal stenosis	6 (4.5)	20 (9.0)	0.52 [0.20–1.33, *P* = 0.17]

The parentheses indicate percentage of patients with progression of each MRI finding.
*Statistically significant.
WAD indicates whiplash-associated disorder; MRI, magnetic resonance imaging.

In the present study, improvements in the clinical symptoms, including neck pain, shoulder stiffness, headache, and arm pain/numbness, were obtained in the majority of WAD patients. None of the patients developed myelopathy or underwent cervical spinal surgery. Thus, the overall long-term outcome of the patients with WAD was considered to be favorable. However, compared with the control subjects who used to be asymptomatic 10 years before, all investigated clinical symptoms were observed significantly more frequently among the WAD patients at the time of the follow-up examination. This result suggests that WAD patients may have long-lasting clinical symptoms for as long as 10 years after their initial injuries in addition to symptoms related to the natural aging process.

Previous studies on WAD patients have revealed various factors related to the prognoses including age, gender, presence of malalignment and degenerative changes of the cervical spine, litigation, accidents with serious car damages and with double collisions, *etc.*[12–18,21–24] In the present study, a logistic regression analysis revealed that females exhibited clinical symptoms more often than males. This result was true in both WAD patients and control subjects. Women have been reported to have a worse outcome after whiplash injury than men. However, not only the female WAD patients, but also the female control subjects tended to develop cervical spine-related symptoms more frequently.

During the 10-year follow-up period, a progressive decrease in the signal intensity of the intervertebral discs was observed more frequently among WAD patients than the control subjects, while structural changes in the cervical spine, including posterior disc protrusion, disc space narrowing, and foraminal stenosis, progressed almost equally in both groups. The clinical symptoms observed in the WAD patients and the control subjects were not associated with any of the MR findings. These results suggest that, although some WAD patients suffer from

Table 10. Relationships Between Clinical Symptoms and Progression of Degenerative MRI Findings

	Neck Pain		Shoulder Stiffness		Headache		Arm Pain/Numbness	
	WAD	Control	WAD	Control	WAD	Control	WAD	Control
Decrease in signal intensity of intervertebral disc								
Progressed	30/109 (27.5)	14/132 (10.6)	58/109 (53.2)	34/132 (25.8)	30/109 (27.5)	9/132 (6.8)	16/109 (14.7)	7/132 (5.3)
Not progressed	4/24 (16.7)	8/91 (8.8)	15/24 (62.5)	29/91 (31.9)	7/24 (29.2)	7/91 (7.7)	7/24 (29.2)	3/91 (3.3)
Posterior disc protrusion								
Progressed	27/101 (26.7)	17/155 (11.0)	53/101 (52.5)	44/155 (28.4)	29/101 (28.7)	12/155 (7.7)	19/101 (18.8)	8/155 (5.2)
Not progressed	7/32 (21.9)	5/68 (7.4)	20/32 (62.5)	19/68 (27.9)	8/32 (25.0)	4/68 (5.9)	4/32 (12.5)	2/68 (2.9)
Disc space narrowing								
Progressed	7/33 (21.2)	6/59 (10.2)	15/33 (45.5)	19/59 (32.2)	5/33 (15.2)	5/59 (8.5)	8/33 (24.2)	5/59 (8.5)
Not progressed	27/100 (27.0)	16/164 (9.8)	58/100 (58.0)	44/164 (26.8)	32/100 (32.0)	11/164 (6.7)	15/100 (15.0)	5/164 (3.0)
Foraminal stenosis								
Progressed	1/6 (16.7)	1/20 (5.0)	5/6 (83.3)	6/20 (30.0)	1/6 (16.7)	0/20 (0)	2/6 (33.3)	1/20 (5.0)
Not progressed	33/127 (26.0)	21/203 (10.3)	68/127 (53.5)	57/203 (28.1)	36/127 (28.3)	16/203 (7.9)	21/127 (16.5)	9/203 (4.4)

No statistically significant difference was observed between any MRI finding and clinical symptom (χ^2 test).
WAD indicates whiplash-associated disorder; MRI, magnetic resonance imaging.

long-lasting clinical symptoms including neck pain, shoulder stiffness, and headache, whiplash injury may not significantly accelerate the symptomatic structural deterioration of the cervical spine during the 10-year period following injury, and the progression of disc degeneration observed using MRI in the majority of WAD patients might be attributable to the normal aging process, similar to the changes seen in the healthy control volunteers.

The present study has several limitations. First, the MR imagers and pulse sequences differed between the previous and present studies, which might have caused differences in the MRI grading, particularly with regard to the contrast on the T2-weighted MR images. This difference might explain why progressive decreases in the signal intensities were observed significantly more frequently among WAD patients than among the control subjects, while the progressions of the other MR findings were not significantly different between the 2 groups. A 0.5-T machine and the conventional spine echo sequence, rather than a 1.5-T machine and the fast spine echo sequence, was used more often among the WAD patients than among the control subjects in the previous study. Although we used objective criteria to evaluate decreases in the signal intensity of the intervertebral discs taking reference on the cerebrospinal fluid at corresponding levels, the signal intensity shown on the T2-weighted images might have been influenced by the differences in the pulse sequences and the strengths of the magnetic fields. Another limitation was the lower follow-up rate in the WAD group, although about half (47.3%) of the WAD patients whose addresses were detected participated in the study. This low follow-up rate might cause selection bias of the patients. Richter *et al*[14] conducted a follow-up study of 1136 patients with whiplash-type neck distortions. They sent a questionnaire to those patients, but only 138 patients (12%) responded. The authors stressed the difficulty in performing retrospective follow-up studies of WAD patients, especially among those with less severe injuries.

Nonetheless, this is the first long-term follow-up study of WAD patients with an appropriate control group and using the results of MR examinations, which can provide important information regarding long-term sequelae after whiplash injury.

■ Conclusion

The overall long-term clinical prognosis was favorable for the patients with WAD, although the prevalence of clinical symptoms was higher than that among the control subjects. Whiplash injury may not significantly accelerate the symptomatic structural deterioration of the cervical spine during a 10-year period following injury.

■ Key Points

- A prospective 10-year follow-up study of patients with whiplash-associated disorder (WAD) and asymptomatic volunteers was conducted.
- Progression of decrease in signal intensity was observed in 109 WAD patients (82.0%), and 132 control subjects (59.2%), posterior disc protrusion in 101 (75.9%) and in 155 (69.5%), disc space narrowing in 33 (24.8%) and in 59 (26.5%), and foraminal stenosis in 6 (4.5%) and in 20 (9.0%).
- Neck pain was observed in 34 WAD patients (25.6%) and 22 control subjects (9.9%) ($P < 0.0001$).
- There was no statistically significant correlation between neck pain and progression in each MR finding in either group.
- Whiplash injury may not accelerate the structural deterioration of the cervical spine during 10 years after the injury.

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Age-Related Changes of Thoracic and Cervical Intervertebral Discs in Asymptomatic Subjects

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Study Design. Magnetic resonance imaging (MRI) study on degeneration of the thoracic spine in asymptomatic subjects.

Objective. To investigate the incidence of degenerative MRI findings of the thoracic spine in asymptomatic subjects and to identify factors related to the degeneration of the thoracic discs.

Summary of Background Data. Studies on age-related degenerative changes of the thoracic spine are scarce.

Methods. Ninety-four asymptomatic Japanese volunteers (48 men and 46 women, mean age of 48.0 ± 13.4 years) underwent MRI of the thoracic and cervical spine and filled the questionnaire regarding life styles. The items evaluated on MRI using a numerical grading system were (1) decrease in the signal intensity of the intervertebral discs (DSI), (2) posterior disc protrusion (PDP), (3) anterior compression of the dural sac (ACD), and (4) disc space narrowing. Association between each degenerative MRI finding and several factors, including age, sex, smoking, sports, body mass index, and degeneration of cervical spine was investigated.

Results. Forty-four (46.8%) patients demonstrated positive degenerative MRI findings at 1 or more thoracic intervertebral levels. The percentage of the subjects with positive MRI findings was 37.2% in DSI, 30.9% in PDP, 29.8% in ACD, and 4.3% in disc space narrowing. The percentages of all MRI findings increased with aging. In 85 (90.4%) patients, degenerative MRI findings were positive in the cervical spine. DSI was significantly associated with age (odds ratio, 11.21, 95% confidence interval, 2.70–46.5), PDP with age (3.44, 1.02–16.61), smoking (4.94, 1.55–15.71) and presence of PDP in the cervical spine (4.25, 1.01–17.92), and ACD was associated with smoking (3.99, 1.28–12.44).

Conclusion. Degenerative changes in the thoracic spine on MRI was observed in approximately half of the asymptomatic subjects, whereas their incidences were less frequent than those in the cervical spine. Factors significantly associated with degenerative changes in the thoracic spine included age, smoking, and degeneration in the cervical spine.

Key words: thoracic spine, magnetic resonance imaging, posterior disc protrusion, asymptomatic subject, age-related change. **Spine 2010;35:1359–1364**

Aging of the intervertebral discs with or without clinical symptoms occurs in everyone. The aging process of the intervertebral discs in the cervical and lumbar spine has been widely investigated in various cadaveric, genetic, radiographic, magnetic resonance imaging (MRI), and epidemiologic studies.[1–9]

MRI studies in asymptomatic subjects are a popular method for investigating age-related changes in the intervertebral discs because MRI is very sensitive to detect disc degeneration and because abnormalities seen in asymptomatic subjects can serve as norms for evaluating MR images of symptomatic patients. Boden *et al*[3,4] conducted MRI studies on the lumbar and cervical spine in asymptomatic subjects and found that degenerative changes, such as disc degeneration and disc herniation, were frequently recognized in subjects aged 40 years and older. Jensen *et al*[7] reviewed MRI images of the lumbar spine in 98 asymptomatic volunteers and found herniated discs in 27 (28%) subjects. Letho *et al*[5] reported an MRI study of the cervical spine in 89 healthy subjects, among whom abnormal findings were recognized in 62% of the subjects aged 40 years or older, whereas abnormal findings were rare among those younger than 40 years.

We also conducted an MRI study of the cervical spine in 497 asymptomatic volunteers between 1993 and 1996 and found that the incidence of degenerative changes in the cervical spine on MRI increased with age.[6] For example, a decrease in the signal intensity of the intervertebral discs was observed in 17% and 12% of the discs in men and women, respectively, in their 20s, whereas a decrease was observed in 86% and 89% of the discs in men and women, respectively, over the age of 60 years. Recently, we conducted a 10-year follow-up study of this original cohort, in which 81% of the subjects exhibited

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progressive degenerative changes on MR images at the 10-year follow-up examination.[10]

In contrast to the accumulated knowledge of age-related changes in the cervical and lumbar spine, such changes in the thoracic spine are poorly understood because symptomatic degeneration are thought to be far rarer in the thoracic than in the cervical and lumbar spine. The stabilization of the thoracic spine by the thoracic cage, which reduces the mechanical stress that is imposed on the intervertebral discs, is thought to explain this difference in the incidences of degenerative diseases.[11] Aizawa *et al*[12] conducted a surveillance study in 1 prefecture in Japan between 1988 and 2002 and found that an average of 0.9 per 100,000 inhabitants received surgery for thoracic myelopathy arising from intervertebral disc herniation, spondylosis, or ossification of the spinal ligaments; this incidence was less than 1/10 of that for cervical myelopathy. However, the recognition of degenerative disorders in the thoracic spine, despite their paucity, should not be underestimated because thoracic degenerative disorders often cause serious disabilities, including back and intercostal pain as well as gait and urinary disturbances arising from myelopathy.[13]

Wood *et al*[14] conducted an MRI study of the thoracic spine in asymptomatic individuals and found high prevalence of anatomic irregularities, including disc herniation (the incidence of asymptomatic thoracic disc herniations is ~37%) and deformations of the spinal cord (29%). Meanwhile, Arana *et al*[15] studied the relation between degenerative discs of the upper thoracic and cervical spine in 156 patients with cervical pain and found that degenerative changes in thoracic discs were observed in 13.4% of the patients with cervical pain. However, they did not find a significant correlation between the degeneration of the cervical and thoracic intervertebral discs. Thus, very few studies have been reported on age-related degenerative changes of the thoracic spine.[14–17] Furthermore, to the authors' knowledge, the incidences of degenerative changes in the intervertebral discs of the cervical and thoracic spine have not been compared in asymptomatic subjects. A comparison of the incidence of disc degeneration in the thoracic and cervical intervertebral discs may be important, because many patients have tandem neck and back pain that might be attributable to abnormalities of either the cervical or thoracic spine. Such information would provide spine care physicians and surgeons with a diagnostic baseline for determining the intervertebral level responsible for the patients' symptoms.

In this study, the incidence of degenerative MRI findings of the thoracic spine was investigated in asymptomatic subjects, and the relationships between degenerative changes of the cervical and thoracic spine were examined to determine whether subjects with degenerative cervical discs are more prone to degenerative thoracic discs. Furthermore, we attempted to identify factors related to the degeneration of the thoracic discs.

■ Materials and Methods

This study was approved by the institutional review board of each participating facility. This study was conducted as a part of a 10-year follow-up study,[10] in which 497 originally asymptomatic Japanese volunteers who underwent an MRI examination of the cervical spine between 1993 and 1996[6] were asked to participate in a follow-up study by mail and telephone. Two hundred and twenty-three subjects participated in the follow-up study and underwent a second MRI examination of the cervical spine. At the same time, the subjects were asked whether they would also undergo MRI scans of the thoracic spine, and 129 subjects gave consent to this additional examination. However, 35 subjects were excluded from the analysis because they had pain in the neck, back, or both, at the time of the follow-up study; thus, 94 asymptomatic subjects (48 men and 46 women; mean age, 48.0 ± 13.4 years; range, 24–77 years) were included in the final analysis. The age distribution of the participants was as follows: 6 (6.4%) in their 20s, 22 (23.4%) in their 30s, 27 (28.7%) in their 40s, 19 (20.2%) in their 50s, 12 (12.8%) in their 60s, and 8 (8.5%) >70 years. Forty-six of the subjects were medical workers, 29 were office workers, 8 were students, 6 were housewives, 3 were retirees, and 2 were farmers. Written informed consent from all participants was obtained after oral and written explanations of the details of this study. Before the MRI studies, the participants were asked to complete a questionnaire on clinical symptoms related to the cervical spine, such as neck and back pain, and their daily habits, including smoking (daily smoking for >10 years) and sports (regular participation in a sports activity at least once a week).

Table 1. Grading System of MRI

1. Decrease in signal intensity of intervertebral disc	0: As bright as or slightly less bright than cerebrospinal fluid
	1: Markedly darker than cerebrospinal fluid
	2: No signal
2. Posterior disc protrusion	
Sagittal	0: No protrusion
	1: Disc material protruding beyond the posterior margin of the vertebral body without cord compression
	2: Beyond vertebral body with cord compression
Axial	0: No protrusion
	1: Central
	2: Paramedian
	3: Lateral
3. Anterior compression of dura and spinal cord	0: No compression
	1: Compression on dural sac only
	2: Compression on less than one third of spinal cord
	3: Compression on more than one third and less than two third of spinal cord
	4: Compression on more than two third of spinal cord
4. Disc space narrowing	0: 100–75% of height of upper healthy disc
	1: 75–50% of height of upper healthy disc
	2: <50% of height of upper healthy disc

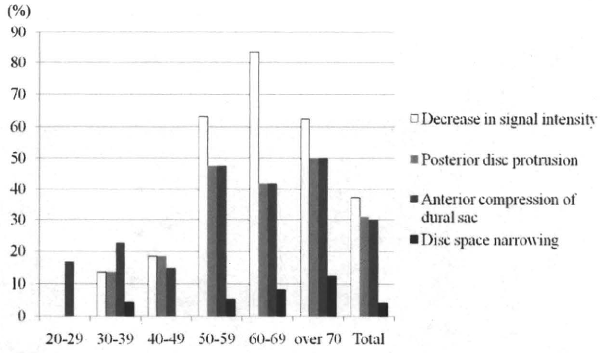

Figure 1. Percentage of subjects with positive MRI findings in each age group.

MRI Protocol

The MR images were taken using a fast spin-echo technique with the following sequences: T1-weighted sagittal images (repetition time [TR]/echo time [TE], 380/8.2; echo train length, 2; thickness of slice, 4 mm; field of view, 24–30 cm; matrix size, 256 × 192; number of excitations, 3 times), T2-weighted sagittal images (TR/TE, 5000/100; echo train length, 16; number of excitations, 3 times; remaining items were the same as those for T1-weighted sagittal images), and T1- and T2-weighted axial images (TR/TE, 5000/102; thickness of slice, 5 mm; field of view, 16 cm; remaining items were the same as those for T1-weighted sagittal images).

Evaluation of MRI

The thoracic spine MR images were evaluated with regard to the following 4 findings related to intervertebral disc degeneration: (1) a decrease in the signal intensity of the intervertebral discs, (2) posterior disc protrusion in the sagittal and axial images, (3) anterior compression of the dural sac, and (4) disc space narrowing. The presence of abnormalities in the endplates, such as Schmorl nodule, was also recorded. All thoracic intervertebral levels from T1–T2–T12–L1 were investigated. The cervical intervertebral levels from C2–C3–C7–T1 were also evaluated.

To assess the MR findings, the classification system used in our previous investigation on the cervical spine was used again, with minor modifications; for each MR finding, 1 of 3 to 5 grades was assigned to all thoracic and cervical levels (Table 1).[10] The MRI films of the thoracic spine were read by 1 experienced neuroradiologists (H.F.) who had no knowledge of the participants, whereas another experienced neuroradiologist (S.M.) read MRI films of 25 patients randomly chosen from the 94 patients by one of the investigators to evaluate the interobserver reliability of the image grading, which was assessed using the kappa score. The kappa score indicates the coefficient of concordance. Coefficients of 0.75 or higher indicate excellent concordance, those between 0.75 and 0.40 indicate good to fair concordance, and those lower than 0.40 indicate poor concordance.[18]

Degenerative MRI Findings and Associated Factors

The association between each degenerative MRI finding and several factors was investigated using logistic regression analysis. The factors investigated were age (<40 years or ≥40 years), sex, smoking habit, participation in sports (1 or more times per week or none), body mass index (<25.0 or ≥25.0), and the presence of degenerative findings in the cervical spine.

Statistical Analyses

The statistical analysis was conducted using a χ^2 test, and a logistic regression analysis for categorical data. A P value <0.05 was considered statistically significant. All statistical analyses were performed using a statistical package, PASW 17J, for Windows (SPSS Japan Inc., Tokyo, Japan).

Results

Degenerative Changes in the Thoracic Spine on MRI

Forty-four (46.8%) subjects exhibited positive MRI findings, indicating the presence of degeneration at 1 or more intervertebral levels in the thoracic spine. The percentages of subjects with a positive finding at 1 or more intervertebral disc levels of the thoracic spine were as follows: 37.2% exhibited a decrease in the signal intensity of the discs, 30.9% exhibited posterior disc protrusion, 29.8% exhibited anterior compression of the dural sac, and 4.3% exhibited disc space narrowing (Figure 1). The percentages increased with age for all MRI findings. For example, a decrease in the signal intensity of the discs was observed in none of the subjects in their 20s but in 83.3% of the subjects in their 60s. Degenerative MRI findings other than disc space narrowing, which was rarely positive, were observed more frequently in the lower thoracic spine than in the upper thoracic spine (Table 2).

Posterior disc protrusion was evaluated in more detail. In the axial plane, the protruded disc was located in the central region in 63.1% of the subjects and in the paramedian region in 36.9%. Posterior disc protrusion was observed at 1 level in 12 subjects (41.4%), at 2 levels in 4 subjects (13.8%), at 3 levels in 4 subjects (13.8%), at 4 levels in 3 subjects (10.3%), at 5 levels in 5 subjects (17.2%), and at 7 levels in 1 subject. Thus, 58.6% of the subjects with posterior disc protrusion had multilevel lesions. However, posterior disc protrusion with spinal cord impingement was observed in 2 subjects only at T5–T6 and at T8–T9, respectively (Figure 2). Other ab-

Table 2. Number of the Discs With Positive MRI Findings at Each Intervertebral Level

	T1–T2	T2–T3	T3–T4	T4–T5	T5–T6	T6–T7	T7–T8	T8–T9	T9–T10	T10–T11	T11–T12	T12–L1
Decrease in signal intensity	16 (17.0)	18 (19.1)	21 (22.3)	22 (23.4)	26 (27.7)	28 (29.8)	29 (30.9)	26 (27.7)	28 (29.8)	18 (19.1)	13 (13.8)	12 (12.8)
Posterior disc protrusion	3 (3.2)	4 (4.3)	4 (4.3)	4 (4.3)	5 (5.3)	3 (3.2)	7 (7.4)	11 (11.7)	11 (11.7)	8 (8.5)	10 (10.6)	6 (6.4)
Anterior compression of dura	2 (2.1)	3 (3.2)	3 (3.2)	4 (4.3)	5 (5.3)	3 (3.2)	6 (6.4)	10 (10.6)	11 (11.7)	9 (9.6)	10 (10.6)	6 (6.4)
Disc space narrowing	1 (1.1)	1 (1.1)	1 (1.1)	1 (1.1)	2 (2.1)	1 (1.1)	1 (1.1)	2 (2.1)	2 (2.1)	0	0	0

Values in parentheses are percentage values.