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Evaluation of Spinal Interbody Fusion Using Magnetic Resonance Imaging

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Summary. **Study design: Prospective study of magnetic resonance imaging (MRI) in human spinal interbody fusion.**
Objectives: To determine whether a consistent pattern of bony fusion could be identified on MR images during spinal interbody fusion.
Summary of background data: Plain radiography has traditionally been used to monitor changes in bone graft incorporation in patients with spinal interbody fusion. We felt that MRI would provide additional significant information in monitoring the course of bony union in spinal interbody fusion.
Methods: Twenty patients underwent spinal interbody fusion via an anterior approach in this study. Beginning immediately after surgery, serial T1-weighted and T2-weighted MR images, as well as post-contrast MRI, were performed. Signal intensity changes were examined in the bone graft, the border between the graft and the adjacent vertebrae, and in the adjacent vertebrae, and were classified into 5 patterns (P1 ~ P5) on each image. Unclassifiable patterns were also defined.
Results: On T1-weighted images, the graft exhibited high intensity immediately after surgery. The intensity subsequently decreased with time. On T2-weighted images, the graft was isointense for a period of time after surgery, and then exhibited high intensity. The grafts eventually became isointense on both T1-weighted and T2-weighted images by the time of bony union as determined from plain radiographs. On post-contrast images, an enhancement effect was noted from the upper and lower edges of the graft. This effect gradually increased until the entire graft became enhanced. In the adjacent vertebrae, transient changes were found in the early postoperative period. Post-contrast images revealed contrast enhancement. In cases with a favorable course, there was a tendency to gradually change from P1 to P5 with time. Unfavorable courses were characterized by a mosaic appearance of the graft on the T1-weighted image, widening of the border in the direction of the graft, and continuous changes in the adjacent vertebrae on each image (pattern PU).
Conclusions: A consistent pattern was observed in serial MRI after spinal interbody fusion. This technique would seem useful in evaluating the course of bony fusion.

Key words—magnetic resonance imaging (MRI), spine, surgery, interbody fusion, bone graft, delayed union, nonunion.

INTRODUCTION

In spinal interbody fusion using autogenous iliac bone, it is vital that the grafted bone fragment is incorporated, and that the interbody fusion be reliably obtained. Prior to this, plain radiography has been the means to monitor changes in the grafted bone fragment over time. In recent years, increasing use has been made of postoperative magnetic resonance imaging (MRI) to assess the extent of graft incorporation in spinal interbody fusion. Attention has been paid to characteristic changes in the intensity of the images of the grafted bone fragment over time. However, these changes have rarely been reported in the literature. We performed serial MRI until bony union was achieved in patients undergoing spinal interbody fusion, to clarify whether a consistent pattern of graft incorporation could be identified, and to determine what differences existed on the MR images between cases of complete and incomplete bony union.

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SUBJECTS AND METHODS

The subjects were 20 patients who underwent spinal interbody fusion via an anterior approach at Tachikawa General Hospital from February 1991 to April 1992. There were 6 males and 14 females ranging in age from 36 to 65 years. The placement of a bone graft at one disc level was considered to be a single procedure. The fusion sites in this study included the cervical spine in 12 cases (12 procedures), and the lumber spine in 8 cases (9 procedures), for a total of 21 procedures. A tricortical bone segment was obtained from the anterior iliac crest, and was used in a single piece for the cervical spine, and in two pieces for the lumbar spine. The underlying disease in the cervical spine cases was either disc herniation (5 procedures), cervical myelopathy (2), discopathy (1), or trauma (4). The underlying disease in the lumbar spine cases was either discopathy (6) or degenerative spondylolisthesis (3). Patients with neoplastic or inflammatory conditions were excluded from this study.

A 1.5 Tesla MR imager (Toshiba MRT200FX II) was used for the cervical spine, and a 0.5 Tesla imager (Toshiba MRT50A) was used for the lumbar spine. The spin echo pulse sequence was employed. T1-weighted images (TR:400-700, TE:15-30), T2-weighted images (TR:1200-2500, TE:80-120), and T1-weighted images after the intravenous injection of gadolinium-diethylene triamine pentaacetic acid (Gd-DTPA; post-contrast MRI) were obtained. All MR imaging was performed with patients' permission just immediately after surgery, and then at 2 and 4 weeks, and later at 2, 3, and 4 months after surgery. Imaging was then performed at 2-month intervals until 1 year after surgery, and thereafter as needed. Post-contrast MRI was performed, together with plain MRI, from two weeks after surgery. Special attention was paid to signal intensity changes on the T1-weighted and T2-weighted images, and to the presence/absence of an enhancement effect on the post-contast MRI. These factors were evaluated in the bone graft, at the border between the graft and adjacent vertebrae, and in the adjacent upper and lower vertebrae. The T1-weighted and T2-weighted image intensities were expressed as either high intensity, isointensity, or low intensity, relative to the neighboring vertebrae of the fused region which were defined as isointensity.

T1-weighted images were classified as either one of five patterns (P1 ~ P5) which characterized the signal intensity as shown in Fig. 1. In Pattern 1 (T1-P1), the image of the graft exhibited a high intensity, while the adjacent vertebrae were isointense. In Pattern 2 (T1-P2), the image of the majority of the graft had a high intensity, while both upper and lower are as bordering the interfaces between the graft and adjacent vertebrae had a low intensity. In Pattern 3 (T1-P3), the image of the upper and lower thirds of the graft demonstrated a low intensity, while the middle third of the graft remained at high intensity. In Pattern 4 (T1-P4), the upper and lower thirds of the graft were isointense, the middle third of the graft had a low intensity, and the center of the graft occasionally exhibited a thin region of high intensity. In Pattern 5 (T1-P5), the majority of the graft was isointense, and the center of the graft occasionally exhibited a thin region of high intensity. There were three unclassifiable patterns (PU) of the T1-weighted images as shown in Fig. 2. In one of these patterns, the upper or lower border between the graft and the adjacent vertebra was widened in the direction of the graft (T1-PU1), while in the second of these patterns, the signal intensity of either the upper or lower adjacent vertebra was low (T1-PU2). In Fig. 2, upper and lower areas of the graft show low intensity, which indicates a normal T1 pattern. In the third unclassifiable pattern, the signal intensity of the graft exhibited a mosaic pattern with a mixture of high intensity, isointensity, and low intensity (T1-PU3).

T2-weighted images were classified as either one of five patterns (P1 ~ P5) which characterized the signal intensity as shown in Fig. 1. In Pattern 1 (T2-P1), the graft and adjacent vertebrae were isointense. In Pattern 2 (T2-P2), the image of the graft and areas bordering the interfaces between the graft and adjacent vertebrae exhibited a high intensity. In Pattern 3 (T2-P3), the image of the graft had a high intensity, and the interfaces between the graft and adjacent vertebrae were clear. In Pattern 4 (T2-P4), the graft demonstrated a high intensity, and the interfaces between the graft and adjacent vertebrae were not clear. In Pattern 5 (T2-P5), the middle third of the graft exhibited a high intensity, and the upper and lower thirds of the graft were isointense. There were two unclassifiable patterns (PU) in the T2-weighted images as shown in Fig. 2. In one of these patterns, either the upper or lower border between the graft and adjacent vertebra was widened (T2-PU1), while in the other pattern, the signal intensity of either the upper or lower vertebrae was high (T2-PU2).

Post-contrast (PC) images were also classified as either one of five patterns (P1 ~ P5) as shown in Fig. 1. In Pattern 1 (PC-P1), the areas bordering the interfaces between the graft and adjacent vertebrae exhibited an enhancement effect, while the middle three-fifths of the graft did not. In Pattern 2 (PC-P2), the upper and lower thirds of the graft, and the areas

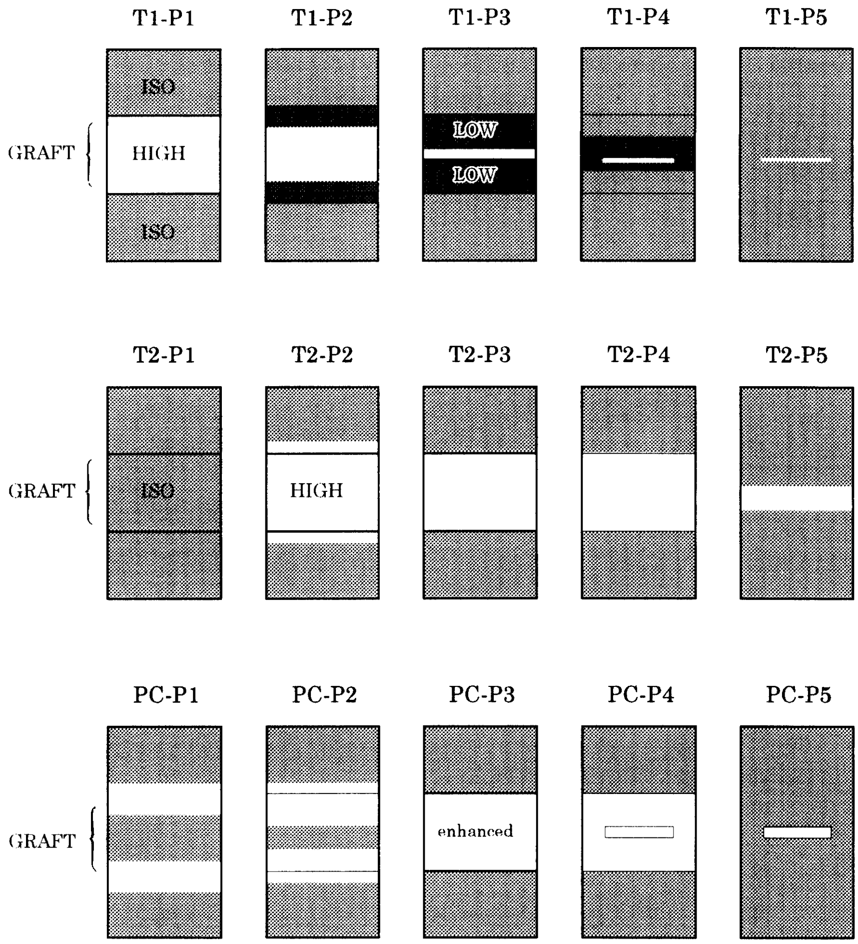

Fig. 1. Patterns of intensity on T1-weighted and T2-weighted images, and patterns of enhancement on post-contrast images (P1 ~ P5).

bordering the interfaces between the graft and adjacent vertebrae demonstrated an enhancement effect, while the middle third of the graft did not. In Pattern 3 (PC-P3), the enhancement effect was evident throughout the entire graft, while the areas bordering the interfaces between the graft and adjacent vertebrae did not show enhancement. In Pattern 4 (PC-P4), the entire graft was enhanced, but the borders between the graft and adjacent vertebrae were not clear. In Pattern 5 (PC-P5), both the graft and adjacent vertebrae did not show the effect of enhancement, and the center of the graft occasionally exhibited a high intensity. There were two unclassifiable post-contrast patterns (PC-PU), as shown in Fig. 2. One of these patterns demonstrated a widening of either the upper or lower border between the graft and adjacent vertebra (PC-PU1), while the other exhibited the presence of the enhancement effect in either the upper or lower adjacent vertebra (PC-PU2).

All five patterns of each T1-weighted, T2-weighted, and post-contrast image demonstrated changes of both the graft and adjacent vertebrae. Each image was designated by only one of these five patterns.

In the unclassifiable patterns, PU1 showed a change from the border to grafted bone, PU2 showed a change in the adjacent vertebra with an end-plate, and PU3 showed a mosaic pattern of the grafted bone as a whole. Any image including findings of both the graft and adjacent vertebra may be shown by either one or a combination of these unclassifiable patterns.

The occurrence of bony union was assessed from plain radiographs, and from the coalescence of the trabeculae of the bone graft and adjacent vertebrae as determined from the movement of the spinous processes on functional radiographs which were

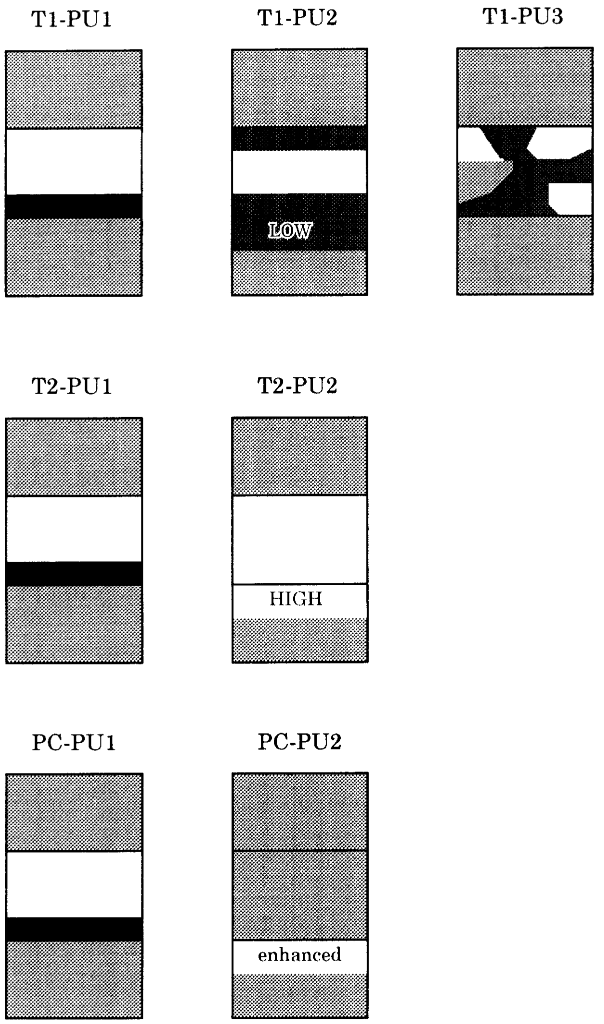

Fig. 2. Unclassifiable patterns (PU) on T1-weighted, T2-weighted, and post-contrast images.

obtained at four months after surgery and thereafter. In cases in which this assessment was difficult, reference was also made to tomograms.

RESULTS

Complete bony union occurred within one year in 9 cervical and 7 lumbar spine procedures, which was defined as a favorable course. One cervical and one lumbar spine procedure required more than one year for bony union to occur, and were classified as delayed unions. In one cervical and one lumbar spine procedures, bony union had not yet occurred at the time of the final evaluation for this study, and these were classified as nonunions. Another cervical spine procedure, which was also diagnosed as nonunion and required an additional posterior fusion surgery at one year and three months after the initial surgery, eventually resulted in bony union. Delayed unions and nonunions were defined as unfavorable courses.

In each procedure, patterns of all images from the different periods after surgery were classified according to the criteria previously mentioned. The numbers of procedures which exhibited the various patterns at the specific follow-up periods are shown in Tables 1, 2, 3 and 4.

Cases with a favorable course

There was a tendency for the patterns to gradually change from P1 to P5 with time on every T1-weighted, T2-weighted, and post-contrast image.

Changes in the bone graft

T1-weighted images: Immediately after surgery, the

Table 1. The numbers of each pattern for all cases on T 1-weighted images at different periods after surgery

Pattern	Period after surgery										
T 1 WI	Op	2 W	4 W	2 M	3 M	4 M	6 M	8 M	10 M	12 M	2 Y
T 1-P 5							3	6	11	14	5
T 1-P 4				1	2	2	10	4	1	1	
T 1-P 3			3	6	11	6	3	1			
T 1-P 2		13	12	7							
T 1-P 1	21	6	1								
T 1-PU			2	6	7	5	5	5	4	4	2
Total	21	19	18	20	20	13	21	16	16	19	7

Table 2. The numbers of each pattern for all cases on T 2-weighted images at different periods after surgery

Pattern	Period after surgery										
T 2 WI	Op	2 W	4 W	2 M	3 M	4 M	6 M	8 M	10 M	12 M	2 Y
T 2-P 5				1	2	1	4	5	9	13	5
T 2-P 4							6	3	4	2	
T 2-P 3		1	2	10	13	10	8	5	1	1	
T 2-P 2		14	16	7	3						
T 2-P 1	21	4									
T 2-PU				2	2	2	3	3	2	3	1
Total	21	19	18	20	20	13	21	16	16	19	6

Table 3. The numbers of each pattern for all cases on post-contrast images at different periods after surgery

Pattern	Period after surgery									
Post-contrast MRI	2 W	4 W	2 M	3 M	4 M	6 M	8 M	10 M	12 M	2 Y
PC-P 5				1	1	1	6	8	14	3
PC-P 4			1		1	9	5	6	1	2
PC-P 3		1	9	12	6	6	1			
PC-P 2	1	8	1							
PC-P 1	11	2	4							
PC-PU	3	4	5	7	5	5	5	3	4	1
Total	16*	17*	20	20	13	21	17	17	19	6

* One of 16 cases at 2 weeks and two of 17 cases at 4 weeks after surgery exhibited the T1-P1 pattern.

Table 4. The numbers of PU on T1-weighted, T2-weighted, and post-contrast images at different periods after surgery

Pattern	Period after surgery										
T 1 WI	Op	2 W	4 W	2 M	3 M	4 M	6 M	8 M	10 M	12 M	2 Y
T 1-PU 1			2	3	3	1	3	3	2	3	2
T 1-PU 2				4	4	4	1	1	1		
T 1-PU 3					1	1	2	2	2	2	
Pattern T 2 WI											
T 2-PU 1					1	1	3	3	2	3	1
T 2-PU 2				2	1	2					
Pattern Post-contrast MRI											
PC-PU 1					1		3	3	2	3	1
PC-PU 2		3	4	5	6	5	2	2	1	1	

(T 1-PU 1+T 1-PU 2: 1 case, T 1-PU 1+T 1-PU 3: 1 case, T 2-PU 1+T 2-PU 2: 1 case)

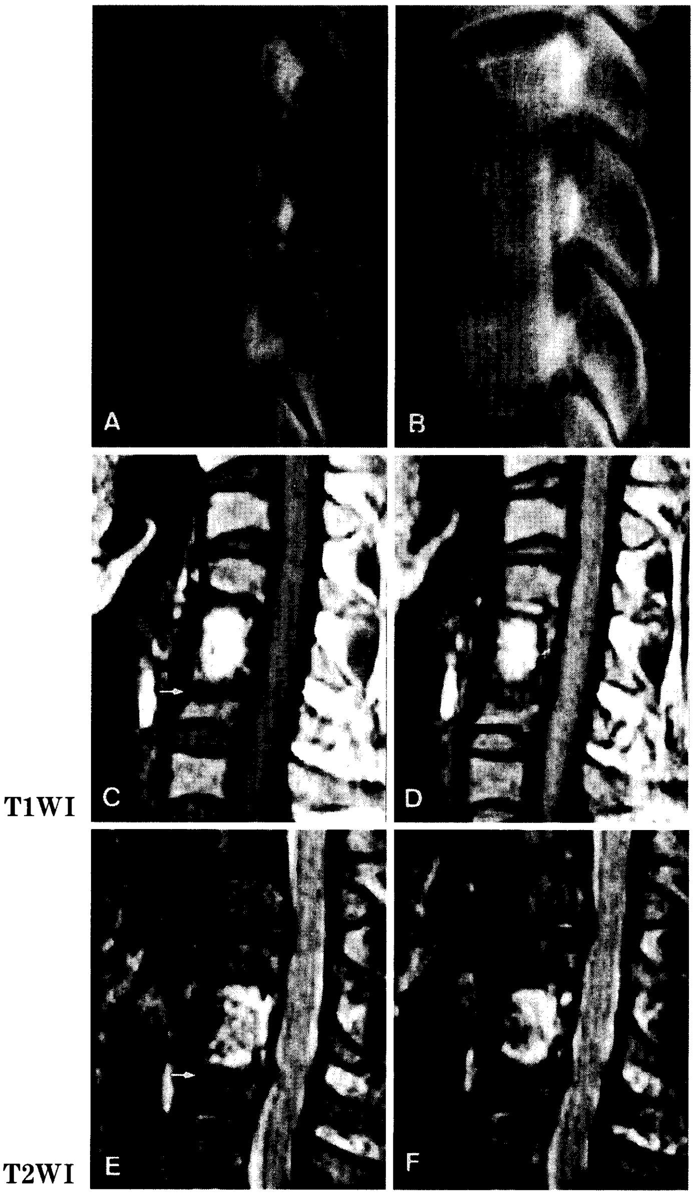

Fig. 3. At eight weeks after surgery, a small collapse develops at the lower edge of the graft (**A**), and a transient widening of the border is observed on both T1-weighted and T2-weighted images (**C** and **E**), exhibiting a PU1 pattern. At five months, the border has disappeared with the completion of bony union (**D** and **F**).

images of bone grafts placed in the cervical and lumbar spines exhibited a high intensity or slightly high intensity, respectively (T1-P1 pattern). From two to four weeks after surgery, the signal intensity progressively decreased, starting from the upper and lower edges of the graft (T1-P2 pattern). After two to three months, the entire graft demonstrated a low intensity, or had a low intensity with a high intensity area remaining in the middle (T1-P3 pattern). At approximately six months, the upper and lower edges of the graft again became isointense, and then this isointense region of the graft gradually widened (T1-P4 pattern). The timing of this change was consistent with the time of radiographic bony union. Another finding was that high intensity areas that had not disappeared by three months tended to persist even after bony union was complete.

T2-weighted images: Bone grafts in both the cervical and lumbar spines were isointense for approximately two weeks after surgery (T2-P1 pattern), and then exhibited a high intensity (T1-P2, T2-P3 and T2-P4 patterns). When it was determined that radiographic bony union was complete, a change to isointensity was observed, starting from the upper and lower edges of the graft (T2-P5 pattern). However, in the lumbar spine, this change to isointensity tended to occur later than the bony union. This change to isointensity was not evident in 3 cases, and the graft remained at a high intensity.

Post-contrast MRI: An enhancement effect was noted in all cases in the upper and lower edges of the graft at two to three weeks after surgery (PC-P1 pattern). One case at two weeks and two cases at four weeks after surgery exhibited the T1-P1 pattern, and thereafter showed the enhancement effect. This contrast-enhanced area gradually increased in size (PC-P2 pattern), and the entire graft became enhanced by the second or third month after surgery (PC-P3 pattern). After this state continued for three or four months, the enhancement effect was attenuated or disappeared at the time of bony union in 14 procedures (PC-P5 pattern).

Changes in the border between the bone graft and adjacent vertebra

This border region appeared immediately after surgery as a thin low intensity band on both T1-weighted and T2-weighted images, and then disappeared or became indiscernible when bony union was complete (T1-P4, T1-P5, T2-P4 and T2-P5 patterns).

An enhancement effect was detected in the border region on post-contrast MR images from two or three weeks after surgery in 14 procedures. It became difficult to distinguish between the border and the graft, as the graft was just beginning to become enhanced in this period (PC-P1 pattern). Subsequently, the enhancement effect of the graft disappeared, and the border again appeared as a thin band (PC-P2 and PC-P3 patterns), which then disappeared when the bony union was complete (PC-P4 and PC-P5

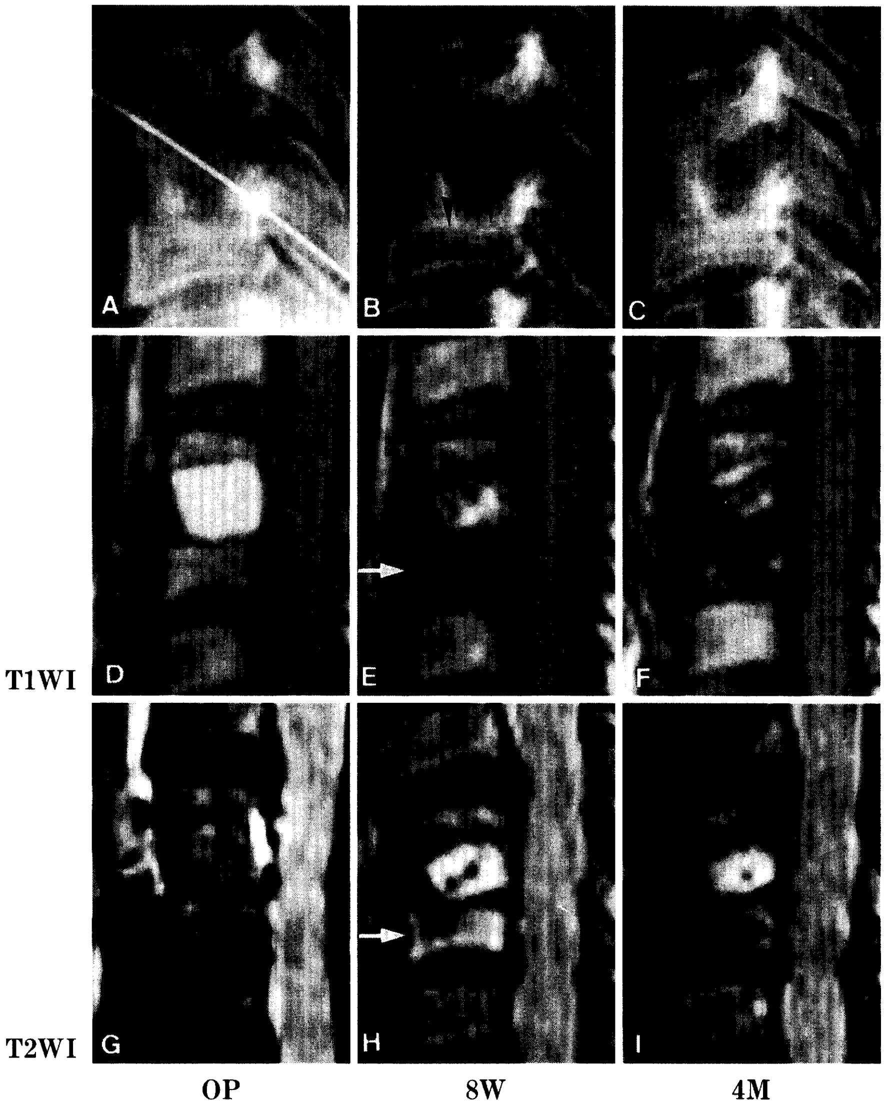

Fig. 4. At eight weeks after surgery, the bone graft is compressed into the lower matrix (**B**), and a low intensity signal on the T1-weighted images (**E**) and a high intensity signal on the T2-weighted images (**H**) of the lower vertebra persists, exhibiting a PU2 pattern. These changes disappear at the time of complete bony union at four months (**F** and **I**).

patterns).

In two cases in which the bony union was complete after a small collapse at the lower edge of the graft, a transient widening of the border was evident when the collapse was noted (PU1 pattern), and thereafter the windening disappeared with the completion of bony union.

Changes in the upper and lower adjacent vertebrae

Changes were detected in the upper and lower adjacent vertebrae at 19 disc levels at two to four weeks after surgery. Slight low intensity and slight high intensity signals were observed on T1-weighted and T2-weighted images (T1-P2 and T2-P2 patterns), respectively, while an enhancement effect was noted on post-contrast images (PC-P1 and PC-P2 patterns). These changes extended to all regions of the adjacent vertebrae at 11 disc levels undergoing cervical vertebral surgery, but were limited to the neighboring end-plates at 7 disc levels undergoing lumbar vertebral surgery.

At three disc levels in which bony union occurred after the bone graft was compressed into the matrix, the changes in the vertebra on the invaginated side persisted, but disappeared by the time bony union was complete.

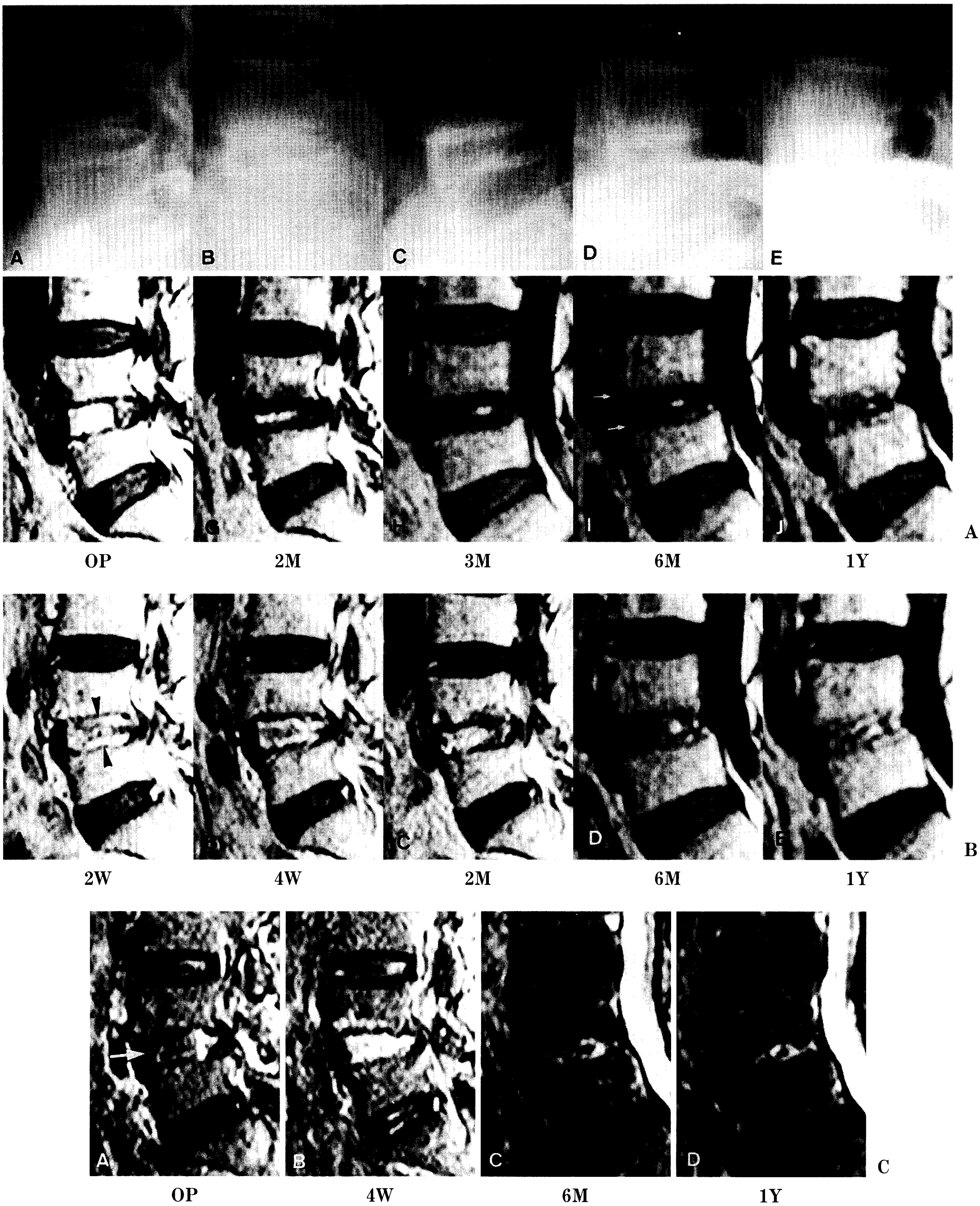

Fig. 5. Legend on the following page.

Cases with an unfavorable course

There were five cases in this study in which bony union was not successfully achieved. In these cases, the image patterns were unclassifiable at some point in time after surgery on all or a portion of the T1-weighted, T2-weighted, and post-contrast images (Table 4).Two of three cases of nonunion exhibited PU1 patterns on all images, and the other one exhibited a T1-PU3 pattern (representative case 2), ultimately requiring an additional posterior fusion surgery, after which the graft eventually united. The T1-PU3 pattern in this case changed to a T1-P5 pattern. Two delayed union cases required more than one year for the completion of bony union. One of these cases also exhibited a T1-PU3 pattern, and required prolonged bracing with eventual union at two years after surgery. The T1-PU3 pattern in this case also changed to a T1-P5 pattern by the time bony union occurred. On the T2-weighted images of these two cases exhibiting the T1-PU3 pattern, one case showed high intensity of the entire graft, and the other a mosaic-like pattern. On post-contrast images, each case exhibited high intensity of the entire graft, which was difficult to distinguish from normal PC patterns.

There were three cases which exhibited duplication of PU patterns. One of these cases transiently exhibited both T1-PU1 and T1-PU2 patterns from two to four months after surgery. The second of these cases exhibited both T1-PU1 and T1-PU3 patterns from six months to one year after surgery, and the third of these cases exhibited both T2-PU1 and T2-PU2 patterns at four months after surgery.

Fig. 3 shows a case exhibiting a transient PU1 pattern. There was a small collapse at the lower edge of the graft during this period, after which the PU1 pattern changed to a P5 pattern when bony union was achieved.

The unclassifiable T1-PU2 pattern appeared almost exclusively in favorable cases where bony union occurred within one year after surgery, with the exception of one case of delayed union. The PU2 pattern typically changed to a P5 pattern by the time of bony union (Fig. 4).

Representative cases

Case 1. 64-year-old female (Fig. 5): Fusion of L4/5 was performed. On the T1-weighted images, the graft, which exhibited a slightly high intensity signal immediately after surgery, gradually demonstrated a low intensity effect starting from its upper and lower edges. The end-plates of the upper and lower adjacent vertebrae also had a transiently low intensity signal. At six months after surgery, it was determined that bony union was complete. At this time, the upper and lower edges of the graft again became isointense, and the border disappeared (Fig. 5A). Post-contrast MR images at two weeks after surgery revealed a band-like enhancement effect extending from the upper and lower edges of the graft to the end-plates of the adjacent vertebrae, after which only the enhancement effect of the graft portion gradually widened. From the eighth week, the entire graft and margin were enhanced, and after bony union was complete, the enhancement effect was attenuated (Fig. 5B). On the T2-weighted images, the graft, which was isointense after surgery, exhibited a persistently high intensity signal from two weeks, while the adjacent end-plates also showed a transiently high intensity change. At six months, the border disappeared, and at one year, the upper and lower edges of the graft became isointense (Fig. 5C).

Case 2. 48-year-old male (Fig. 6) : Fusion of C5/7 was performed. In the early postoperative period, backward tilting and compression of the graft into the lower matrix occurred. On the T1-weighted images, the graft continued to exhibit high intensity until four months after surgery, after which time a mosaic pattern with an intermingling of high intensity and slightly low intensity areas persisted (T1-PU3 pattern). The upper border became unclear on all images at ten months, and radiographic trabecular coales-

Fig. 5A. T1-weighted images (600/30) of representative Case 1. The graft, which exhibited slight high intensity after surgery (**F**), demonstrates low intensity beginnning from its upper and lower edges (**G**). The end-plates of the adjacent vertebrae also have a transient low intensity. At six months, it was determined from plain radiographs that bony union was complete (**D**). At this time, the upper and lower edges of the graft again become isointense (**I**). At one year, the graft and adjacent vertebrae show a uniform isointensity (**J**).

Fig. 5B. Post-contrast MRI of representative Case 1. At two weeks after surgery, an enhancement effect is noted, extending from the upper and lower edges of the graft to the end-plates of the adjacent vertebrae (**A**), after which the enhancement of the graft gradually widens (**B**). From the second postoperative month, the entire graft is enhanced (**C**). After bony union was complete, the enhancement effect is attenuated (**E**).

Fig. 5C. T2-weighted images (2500/120) of representative Case 1. The graft, which was isointense immediately after surgery (**A**), exhibits persistently high intensity after two weeks (**B**). At one year, the upper and lower edges of the graft become isointense, and the border disappears (**D**).

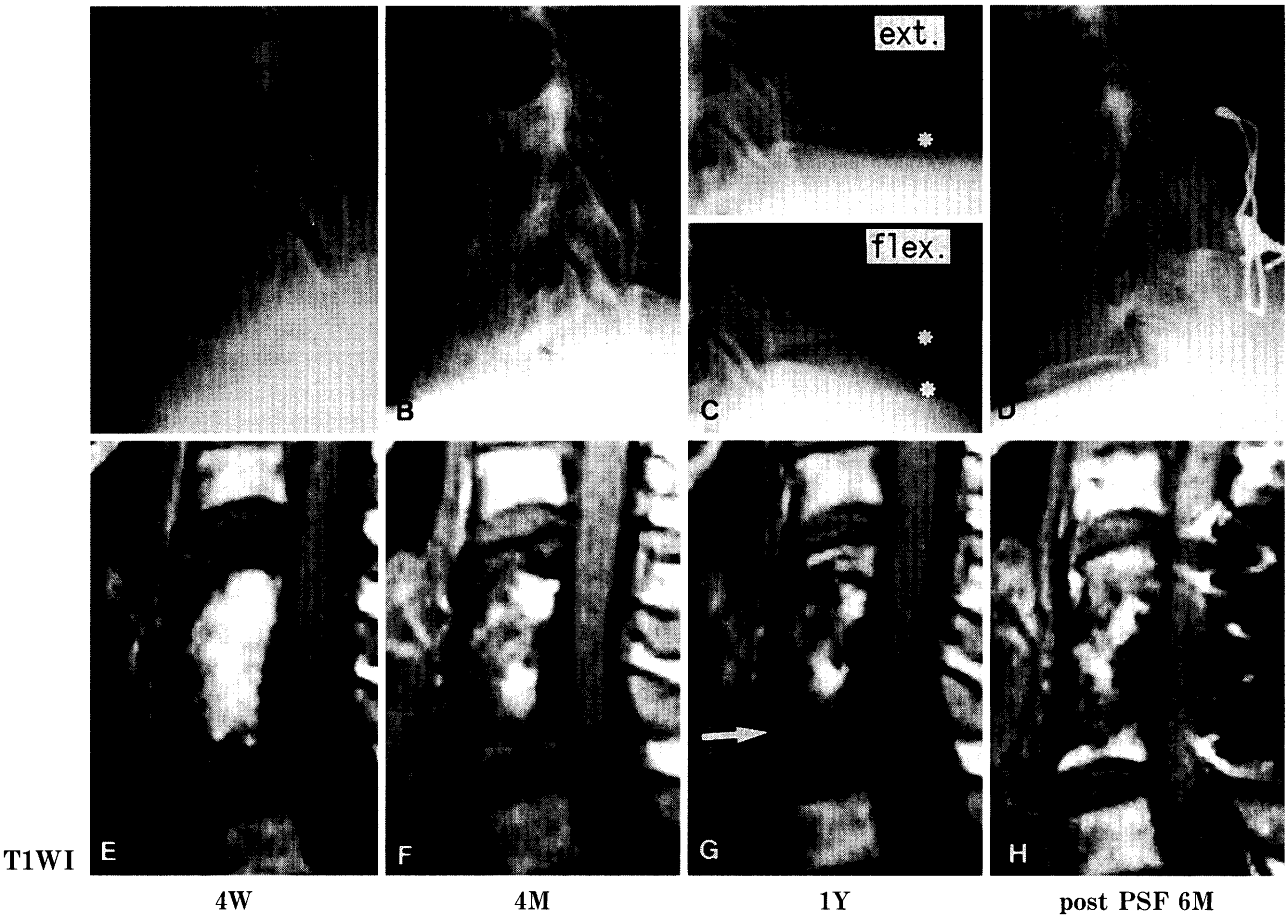

Fig. 6. Representative Case 2. Backward titling and compression of the graft into the lower matrix has occurred (**B**). On the T1-weighted images, the graft shows a mosaic T1- PU3 pattern at four months after surgery (**F**). At one year, both the T1-PU3 and the change to low intensity of lower adjacent vertebra persist. It was decided that union was delayed (**C** and **G**). After additional posterior fusion surgery, the entire graft shows a nearly uniform isointensity on all images, and the change in intensity in C7 is no longer apparent (**H**).

cence was detected. However, the lower border was still discernible more than one year after surgery. Since the change to low intensity in the C7 vertebral body on the T1-weighted images persisted, as well as the enhancement effect of Gd-DTPA (PU2 pattern), it was determined that fusion was delayed. At one year and three months after the initial surgery, a posterior fusion was performed. Six months after this procedure, the entire graft demonstrated a nearly uniform isointensity on all images, and the border, as well as the changes in the C7 vertebral body, were no longer apparent.

Case 3. 43-year-old male (Fig. 7) : Fusion of L4/5 was performed. The course of bony fusion was favorable until three months after surgery. At this time, the upper border gradually widened in the direction of the graft on the T1-weighted, T2-weighted, and post-contrast MR images. After one year, the entire graft exhibited a low intensity signal. Collapse and absorption of the graft became apparent on radiographs from six months. At the time of the 2-year postoperative examination, abnormal mobility was detected on functional radiographs, and pseudoarthrosis was diagnosed.

DISCUSSION

Very few studies are available in the literature on the use of serial MRI to determine the incorporation of grafted iliac bone. In 1987, Ross et al.[1] described the MRI findings of iliac bone grafts and adjacent upper and lower vertebrae after anterior fusion of the cervical spine. They recognized a variety of signal

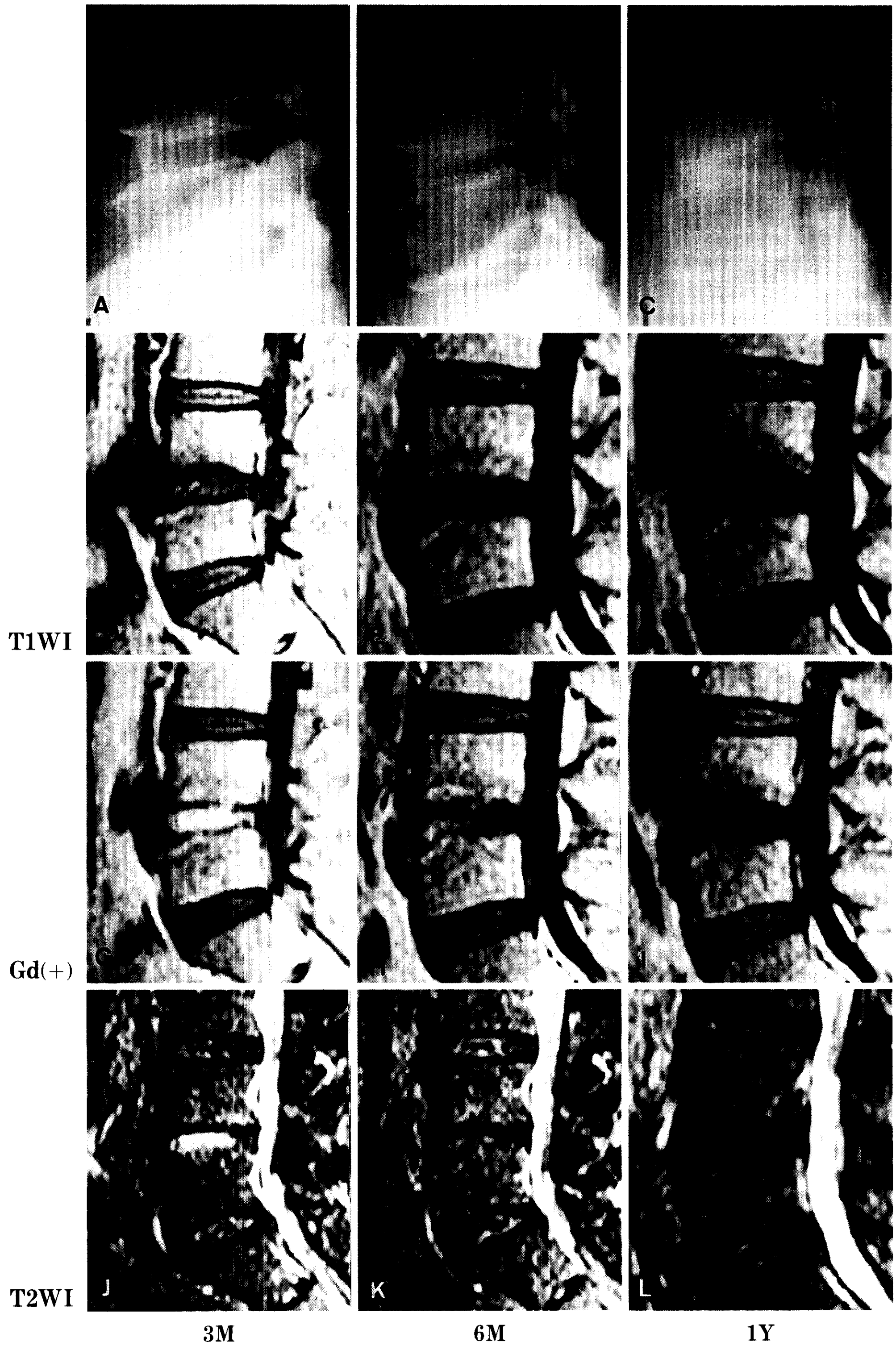

Fig. 7. Representative Case 3. The course of bony fusion was favorable until three months after surgery, at which time the upper border gradually widened on all images (**E**, **H** and **K**). At one year, the entire graft exhibits low intense (**F**, **I** and **L**), and collapse and absorption of the graft are apparent on tomograms (**C**).

intensity changes up to two years after surgery, and suggested that intraoperative injury, postoperative stress, and/or revascularization of the bone graft may influence these signals. Since they did not report any use of serial MRI in the same subjects over time, it was not clear whether a consistent series of changes on MR images occurs or not. In 1992, Sato et al.[2] reported for the first time the results of a systematic study of this issue. They found that the course of bony fusion was characterized by a shrinkage of the high intensity portion of the graft on the T1-weighted images, and by a band-like enhancement beginning from the upper and lower edges of the graft from about three weeks after surgery on the post-contrast MR images. In cases in which bony fusion did not proceed smoothly, the high intensity portion on the T1-weighted images did not decrease in size, while on the post-contrast MR images, the graft was either not enhanced, or a thick low intensity band remained between the graft and matrix. In 1993, Albert et al.[3] reported 7 cases after anterior cervical fusion with serial MRI up to six months after surgery. Their results largely agreed with the findings in our study up to the six-month time point. Other than Sato et al.,[2] however, there are no reported studies which include the assessment of post-contrast MR images, or refer to cases of unsuccessful fusion in order to predict the failure of graft incorporation using MRI.

In the present syudy, we prospectively followed patients in whom spinal interbody fusion was planned, and were able to confirm certain trends in the MRI findings until the completion of bony union. We were also able to identify some changes characteristic of cases where bony union was not successfully achieved. These characteristic patterns are discussed below.

T1-weighted images

The most prominent characteristic on the T1-weighted images was the change in the iliac bone graft from isointensity to high intensity immediately after surgery. This change was thought to reflect the interruption of blood flow to the graft, and represents the signal of the intramedullary fatty tissue. Subsequently, the graft exhibited a low intensity signal at its upper and lower edges. Modic et al.[4] studied cases of degenerative spinal diseases, and compared the findings of MRI to histological changes. They defined a Type 1 change as a low intensity signal on the T1-weighted images and a high intensity signal on the T2-weighted images, and a Type 2 change as a high intensity signal on the T1-weighted images and a moderate or slightly high intensity signal on the T2-weighted images. They explained that a Type 1 image indicated hypervascular fibrous tissue, and a Type 2 image indicated fatty tissue. With this in mind, the change to a low intensity signal in the present study (change from pattern P2 to P3) was thought to reflect the invasion of the graft by fibrovascular tissue (Modic Type 1)[4]. In addition, the change in the graft images to isointensity observed from approximately six months after surgery, as well as the disappearance of the borders between the graft and upper and lower adjacent vertebrae, were thought to indicate that the bone marrow tissue had become equivalent to that of the upper and lower adjacent vertebrae, and that bony union was complete. There was a tendency for a small high intensity area to remain in the center of the graft even after complete bony union. This was thought to reflect a change in the fatty marrow (Modic type 2)[4].

T2-weighted images

The change on the T2-weighted images of the graft from isointensity to high intensity from approximately two weeks after surgery was thought to initially indicate edematous change throughout the graft, and then later reflect invasion of the graft by fibrovascular tissue. Similar to the T1-weighted images, a change to isointensity was detected, starting from the upper and lower edges of the graft. However, this change was inconsistent, tended to be delayed, and did not always coincide with the occurrence of bony union.

Post-contrast MRI

The band-like enhancement effect observed on the post-contrast images from a few weeks after surgery was thought to indicate the invasion of the graft by fibrovascular tissue proliferating in the matrix, including the border region and end-plates. The enhancement effect of the entire graft was thought to represent the completion of the revascularization of the graft. The disappearance or attenuation of the enhancement effect with the completion of bony union was thought to indicate that the hemodynamic status within the graft had become equivalent to that of the adjacent vertebrae. Similar to the T1-weighted images, a small high intensity area tended to remain in the center of the graft, and was thought to reflect the fatty marrow.

Thus, in a favorable course of graft fusion, changes in the graft and adjacent vertebrae were indicated by the gradual change from patterns P1 to P5 in all T1-weighted, T2-weighted, and post-contrast images. Pattern P4 (especially on T1-weighted image) coincided with bony union as determined from plain radiographs. In the postoperative course in this study, we used functional radiographs at four months after surgery to determine the occurrence of bony union and removal of the brace. In one case, the pattern of images quickly changed to P4 at two months after surgery, far earlier than when a functional radiograph would be obtained. It was determined in this case that bony union was complete and that the brace should be removed. When evaluating the course of graft incorporation after spinal interbody fusion, MR images can be employed early in the healing process before plain radiographs become useful.

Findings in the cases with an unfavorable course

The graft did not exhibit a low intensity signal on T1-weighted images when an unfavorable course existed. A possibility of interbody fusion failure was indicated by a prolonged high intensity graft signal, or when the image changed to a mosaic-like pattern with a mixture of high intensity and low intensity areas (pattern T1-PU3). One of three cases of nonunion and one of two cases of delayed union were detected by this change on MR image. One of these nonunion cases required an additional posterior fusion. One of the delayed union cases was followed with prolonged bracing until two years after surgery. Both of these cases eventually resulted in complete bony union with a change in pattern to P5. On the T2-weighted images and post-contrast images, there were no consistent patterns equivalent to the pattern T1-PU3 which particularly showed bone graft failure.

The widening of the border in the direction of the graft on the T1-weighted and T2-weighted images (pattern PU1) was thought to reflect the collapse of the graft. The disappearance of the enhancement effect in this portion of the graft on the post-contrast MR images was thought to reflect the state of interrupted blood flow, with subsequent absorption of the bone graft or the formation of dead bone. Two of the three cases of nonunion were detected by this change. In one of these cases, the border became wider in the direction of the graft on each subsequent image, resulting in a low intensity graft image (representative case 3).

In addition, the persistence of changes in the adjacent vertebrae (pattern PU-2) was thought to reflect the presence of abnormal stress such as compression of the graft into the matrix, and/or abnormal mobility, and was considered to be an indication of interbody fusion failure. One of cases of delayed union was detected by this change. However, this change tended to diminish in the other cases of unfavorable outcome, as well as in cases with a favorable course in which pattern PU-2 transiently occurred.

In summary, the unclassifiable PU patterns indicated unfavorable courses of bony fusion. We were able to detect if a course was a success or a failure long before it was evident on a conventional plain radiograph. Additionally, we were able to detect the detailed significance of the unfavorable course (as indicated by the pattern PU1, PU2 or PU3) so that we could plan subsequent appropriate management.

CONCLUSIONS

1. Serial MRI was performed in 20 patients (21 procedures) undergoing interbody fusion.
2. Re-establishment of interrupted blood flow to the graft, as well as changes in the adjacent vertebrae, were demonstrated on T1-weighted, T2-weighted, and post-contrast MR images as graft incorporation progressed. T1-weighted and post-contrast MR images were extremely useful in evaluating the course of bony fusion.
3. Findings indicative of failure in the course of bony fusion were thought to include a mosaic appearance of the graft on T1-weighted images, widening of the border region, and the persistence of signal intensity changes in the upper and lower adjacent vertebrae.
4. We were able to identify a consistent pattern of bony fusion MRI after spinal interbody fusion.

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