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Long-Term Results of Cemented Total Hip Arthroplasty for Dysplasia, With Structural Autograft Fixed With Poly-L-Lactic Acid Screws

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Abstract: This study reviewed a series of cemented total hip arthroplasty (THA) for dysplasia, with structural autograft fixed with poly-L-lactic acid screws. Grafted bone union was confirmed radiologically in every case, and there were no cases of early collapse or extravasation of grafted bone. Kaplan-Meier survivorship analysis of socket revision, radiologic loosening of the socket, and the appearance of a radiolucent line greater than 1 mm in the graft-socket interface as the end points indicated survival rates of 99%, 97.1%, and 63.5% at 10 years and 96.6%, 90.2%, and 56.1% at 15 years, respectively. The results of this study indicated that poly-L-lactic acid screws are safe and useful for the fixation of acetabular bone graft concomitant to cemented THA with a careful rehabilitation program. **Keywords:** THA, acetabular bone graft, PLLA, survivorship analysis, radiolucent line.

Poly-L-lactic acid (PLLA) is characterized by its biocompatibility and biodegradability and is used clinically [1,2]. A clinical study from our institution reported on the use of osteosynthetic screws, pins, and nails made of PLLA in the fixation of grafted bone, fractured fragments, or osteotomized bone in 143 patients who were followed up for 2 to 6 years [3]. Bone union was achieved in all but one case, and no abnormal hematologic examination, infection, or foreign body reaction occurred. In another clinical study, PLLA screws were used in the fixation of acetabular fragments in rotational acetabular osteotomies, and their clinical results were similar to those associated with fixation by Kirschner wires (K-wires), although ectopic bone formation occurred more often in patients treated with PLLA screws [4]. In our hospital, we started to use PLLA screws instead of metallic or ceramic screws in the fixation of acetabular bone grafts in total hip arthroplasty (THA) in 1990 because there were concerns about the use of rigid and non-bioabsorbable screws, which might contribute to the absorption of the grafted bone and induce metallosis or third-body wear when breakage of the screws occurs. The purpose of this study was to review a series of cemented THA with acetabular bone graft fixed with PLLA screws. We focused on the survival rate of the acetabular component and radiologic change of the grafted bone-socket interface.

Materials and Methods

Between July 1990 and December 1995, 257 consecutive cemented primary THAs were performed by several senior surgeons at our hospital, and acetabular bone grafting was performed in 167 cases (65.0%), and PLLA screws were used for graft fixation in 118 cases (94 patients, 70.7%). Of these 94 patients, 10 were lost to follow-up and 4 died. Therefore, this study included 104 cases (80 patients). All patients were followed for 10 years and reviewed retrospectively. The patients comprised 6 men and 74 women, whose average age was 55.0 years (range, 29-76 years), weight was 51.8 kg (35.0-76.5 kg), and body mass index (BMI) at the time of surgery was 22.8 kg/m^2 (16.1-36.1 kg/m^2). The original diagnosis was osteoarthritis secondary to hip dysplasia in all patients. The degree of subluxation was categorized according to the classification of Crowe et al [5], and this series included 47 hips (45.2%) in group 1, 30 hips

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(28.8%) in group 2, 13 hips (12.5%) in group 3, and 14 hips (13.5%) in group 4. Total hip arthroplasty was performed through Charnley transtrochanteric approach (24 cases) or Dall's direct lateral approach (80 cases). The applied conventional polyethylene sockets included physio-hip-system PHS (Japan Medical Materials [JMM], Osaka, Japan) in 103 cases and a Charnley Long Posterior Wall cup (DePuy, Blackpool, UK) in 1 case. The outer diameter varied from 42 to 50 mm. The applied cemented femoral prostheses were PHS type 6 (6 cases), KC (97 cases), and PHS type 7 (1 case) (JMM), all of which were made of titanium alloy. The applied modular heads (JMM) were 22-mm alumina in 95 cases and 26-mm alumina in 9 cases.

Bone grafting and acetabular component fixation were performed according to the method described by Wolfgang [6] as follows. First, the inferomedial portion of the dysplastic acetabulum (true acetabulum) was reamed according to the preoperative planning. After confirming the size and configuration of the superolateral acetabular defect formulated above the presumed socket position, a crescent-shaped graft was trimmed from the excised femoral head and fixed transiently with 2 K-wires to the defect portion. The grafted bone was then fixed rigidly with 1 or 2 PLLA screws (cancellous lag screws 6.5 mm in bore diameter and 4.1 mm in grove diameter) (Fixsorb; Takiron Co, Ltd, Osaka, Japan). The flanged socket was then fixed with polymethyl methacrylate bone cement.

Postoperative gait exercise started according to the center-edge (CE) angle as described by Sugano et al [7], which represents the angle formed by the vertical line from the inner head's center and the linear line connecting the inner head's center and the medial edge of the grafted bone. In detail, gait exercise with one-third partial weight bearing started 2 to 6 weeks after surgery if the CE angle was plus, that is, the vertical line from the inner head's center situated medially to the medial edge of the grafted bone. On the other hand, if the CE angle was minus, gait exercise with one-third partial weight bearing started 6 to 12 weeks after surgery. There was variation about the time point when the partial weight bearing gait exercise started because of the patients' conditions, and there was a tendency that weight bearing gait exercise started earlier in the late cases.

The mean follow-up period was 12.7 years (range, 10-16.3 years). Hip function was evaluated using the Japanese Orthopaedic Association (JOA) score, which is based on pain (40%), range of movement (20%), ability to walk (20%), and activities of daily living (20%) [8]. The total score is 100 for a normal hip. A paired *t* test was used to compare preoperative and final follow-up JOA scores.

Standard anterior-posterior radiographs were taken immediately after the operation; 2, 4, 6, and 8 weeks after the operation; 3, 6, 9, and 12 months after the operation; and every 6 or 12 months thereafter. The standard anterior-posterior radiographs confirmed whether the traces of the radiolucent screws were visible. The resorption of the grafted bone was defined as positive if the resorption expanded, and the lateral border of the grafted bone shifted medially beyond the vertical line from the lateral edge of the socket, because such a resorption pattern is never observed in the normal remodeling process of the grafted bone. The grafted bone was categorized into 3 groups according to the radiolucency of the grafted bone in the x-ray photograph just after the operation compared with that of the adjacent iliac bone positioned superiorly to the socket. The groups were higher radiolucency group (group H) (19 cases, 18.3%), isoradiolucency group (group I) (67 cases, 64.4%), and lower radiolucency group (group L) (18 cases, 17.3%). Cases with an obscure difference in the radiolucency were categorized into group I. The radiolucent line around the socket was evaluated in the zones described by DeLee and Charnley [9] and was defined as positive if a radiolucent line greater than 1 mm was found in a part of the zones. Radiographic loosening was assessed according to the criteria of Hodgkinson et al [10] and was confirmed as type 3 (complete demarcation) or type 4 (socket migration).

Kaplan-Meier analysis was used to evaluate the time to socket loosening and socket revision and the appearance of a radiolucent line greater than 1 mm in zone 1, which corresponded to the graft-socket interface. The log-rank test was used to test the relationships between possible risk factors and socket loosening, socket revision, or radiolucent line–free survival. The possible risk factors included sex, surgical approach, head diameter, radiolucency of the grafted bone, Crowe classification, age at surgery, BMI, body weight, socket diameter, socket inclination angle, and the CE angle [7]. In log-rank tests for the last 6 variables, the cases were divided into 2 groups based on the average value of each variable. All statistical analyses were carried out using JMP IN (version 5.1.2; SAS Institute Inc, Cary, NC) and SAS software version 9.1 (SAS Institute Inc). Two-sided *P* values of less than .05 were considered significant.

Results

The mean JOA score improved from 45.3 before the operation to 83.2 at the final follow-up. Revision surgery was performed in 4 cases. The reasons for revision were socket loosening in 2 cases and stem loosening in 2 cases. For the former 2 cases (both in group H), one socket revision was performed with the stem retained and one with the stem exchanged using the cement-in-cement technique [11] 8 and 13 years after the primary THA, respectively. For the latter 2 cases, one stem revision was performed in another hospital 12 years after the primary THA and one was performed in our hospital 17 years after the primary THA. When the stem revision was performed in our hospital, the supralateral portion of the socket

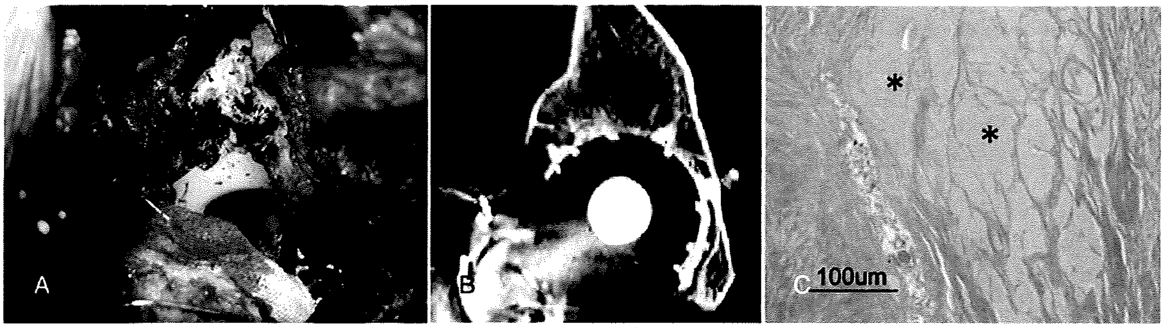

Fig. 1. (A) Photograph showing the surgical exposure of the grafted site just above the acetabular component 17 years after primary THA. (B) Preoperative computed tomography image of the coronal section. (C) Hematoxylin-eosin staining of the curetted soft tissue in the cave where the PLLA screw existed. Arrow, a cave on the grafted bone. Arrowhead, bone defect corresponding to the cave found in the revision surgery. Asterisk, amorphous eosinophilic fibrous tissue.

was exposed and the surface of the bone was inspected carefully. We found soft tissue in a hole (5 mm in depth) in the bony surface, which was curetted and examined histologically, and the inner part of the hole was found to be filled with bony tissue (Fig. 1A). This finding corresponded to that of the preoperative computed tomography examination, which showed that no remnant of the PLLA screws could be found except the hole (Fig. 1B). Histologic examination revealed that the specimen included amorphous eosinophilic fibrous tissue with bone fragments, and the infiltration of inflammatory cells could not be confirmed (Fig. 1C).

Kaplan-Meier survivorship analysis with socket revision for any reason as the end point gave survival rates of 99% (95% confidence interval [CI], 93.4%-99.9%) at 10 years and 96.6% (95% CI, 85.6%-99.2%) at 15 years (Fig. 2A).

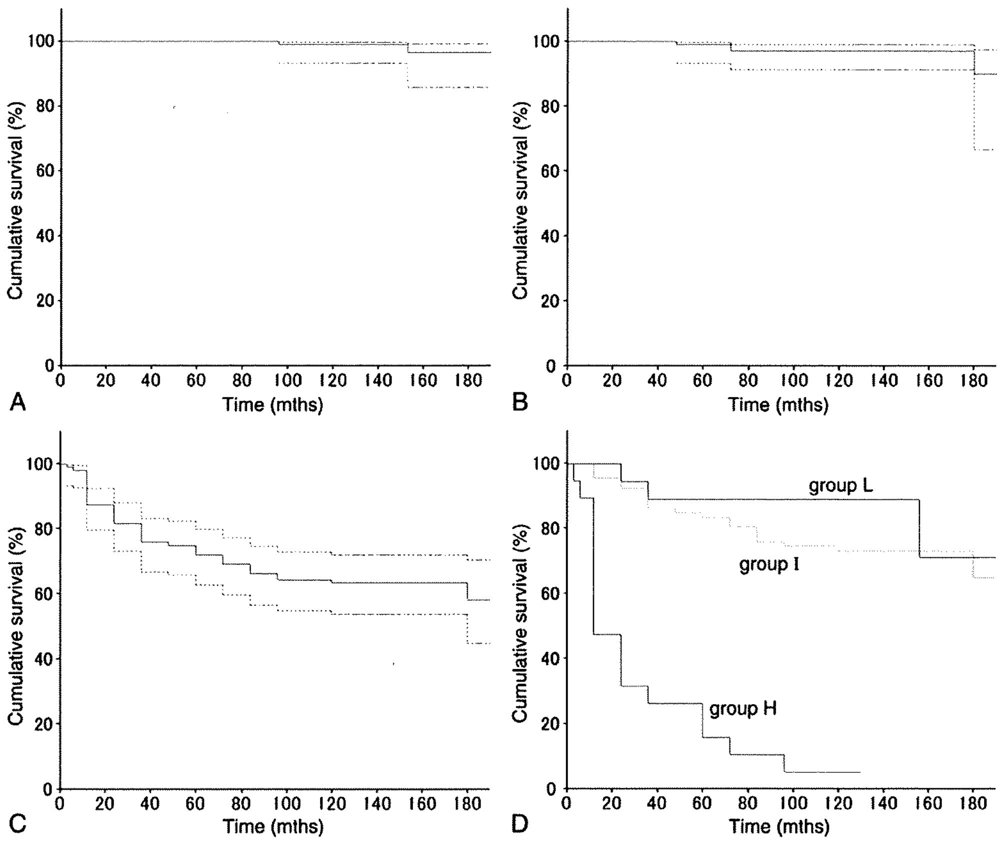

Fig. 2. Kaplan-Meier analysis with socket revision (A), radiologic loosening of the socket (B), and the appearance of a radiolucent line greater than 1 mm in zone 1 (C) as the end points. Comparison of radiologic survival without the appearance of a radiolucent line greater than 1 mm in zone 1 groups H, I, and L (D). The dotted lines indicate the 95% CIs.

Table 1. Variables Examined as Possible Factors Using Log-Rank Tests

	P		
Variable	Socket revision	Socket loosening	Zone 1 radiolucent line >1 mm
Sex	.71	.20	.67
Surgical approach	.30	.076†	.13†
Head size	.54	.19	.076‡
Age at surgery*	.79	.51	.56
BMI*	.23	.92	.74
Body weight*	.15	.24	.69
Socket diameter*	.21	.46	.13§
Socket inclination angle*	.89	.22	.92
CE angle*	.13‖	.28	.89
RL of grafted bone	.019¶	.19	<.0001#
Crowe classification	.80	.75	.84

RL, radiolucent line.
* For log-rank tests, cases were divided into 2 groups based on the average for each variable.
† Survival rates were higher using Charnley transtrochanteric approach than Dall's approach.
‡ Survival rate was higher with a 26-mm head than with a 22-mm head.
§ Survival rate was higher with larger diameter sockets than with small diameter sockets.
‖ Survival rate was higher with larger CE angles than with smaller CE angles.
¶ Group H vs group I, $P = .012$; group H vs group L, $P = .21$.
# Group H vs groups I and L, $P < .0001$; group I vs group L, $P = .34$.

The log-rank test indicated that the socket revision–free survival rate of group H was significantly lower than that of group I ($P = .012$) or of group L ($P = .21$; Table 1). It also indicated that the socket revision-free survival rate was higher with larger CE angles than with smaller CE angles, although the difference was not significant ($P = .13$ Table 1).

Radiologic Analysis

X-ray photographs taken just after the primary operation showed an obscure but still visible radiolucent region corresponding to the inserted PLLA screws in many cases. However, x-ray photographs at the final follow-up showed an unclear radiolucent zone at the sites of the PLLA screws, and the osteosclerotic line surrounding the site where the radiolucent zone had been found was confirmed in only 4 cases (Fig. 3). Bone union was confirmed radiologically at the grafted site in every case, and there were no cases of early collapse or extravasation of the grafted bone. No positive resorption of the grafted bone was observed in any case. Ectopic bone formation was observed in 5 cases (4.8%) (grade 2 in 3 cases, grade 3 in 2 cases), but this did not affect their clinical results at the final follow-up. Socket loosening occurred in 4 cases (2 in group H and 2 in group I). Kaplan-Meier analysis with socket loosening as the end point indicated survival rates of 97.1% (95% CI, 91.3%-99.1%) at 10 years and 90.2% (95% CI, 64.6%-97.6%) at 15 years (Fig. 2B). The log-rank test indicated that the socket-loosening–free survival rates did not differ significantly between groups H, I, and L (Table 1). It also indicated that the socket-loosening–free survival rates were higher when Charnley transtrochanteric approach was used than when Dall's approach was used, but the difference was not significant ($P = .076$; Table 1).

A radiolucent line greater than 1 mm in zone 1, in which the graft bone-cement interface was situated, appeared in 40 cases during the follow-up period. These included 18 cases in group H (94.7%), 19 cases in group I (28.4%), and 3 cases in group L (16.7%). An apparent osteolysis in zone 1 was found in 5 cases in group H (26.3%), 4 cases in group I (6.0%), and none in group L. Kaplan-Meier analysis with the appearance of a radiolucent line greater than 1 mm in zone 1 as the end point indicated survival rates of 63.5% (95% CI, 53.4%-71.9%) at 10 years and 56.1% (95% CI, 41.9%-68.1%) at 15 years (Fig. 2C). A comparison of the radiolucent line–free survival in groups H, I, and L is shown in Fig. 2D. The log-rank test indicated a significant difference between groups H and L and between groups H and I ($P < .0001$) (Table 1). It also indicated that the radiolucent line–free survival rates were higher using Charnley transtrochanteric approach than Dall's approach ($P = .13$), with a 26-mm head than with a 22-mm head ($P = .076$), and with larger rather than smaller diameter sockets ($P = .13$) (Table 1).

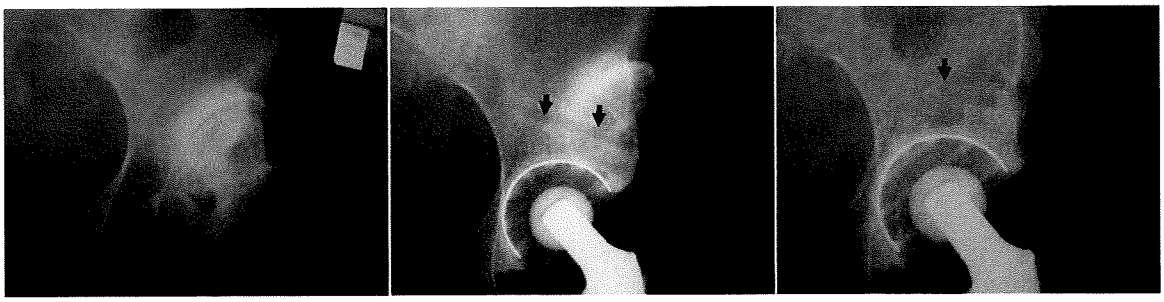

Fig. 3. Radiographs of a woman with osteoarthritis secondary to dysplasia who had primary THA at the age of 62 years. The grafted bone in this case belonged to group L. Anteroposterior radiographs just before surgery (left), just after surgery (center), and 12 years after surgery (right). Arrows indicate the sites of the PLLA screws.

Discussion

The PLLA screws used in this study were manufactured as follows. Poly-L-lactic acid with a molecular weight of 400 000 was melted, extruded, and drawn uniaxially to obtain a rod, which was then machined to the shape of a screw [12]. The initial bending strength was 240 MPa [13]. This drawn PLLA has uniform structure and is not subject to longitudinal breakage. The initial mechanical strength decreases by 10% in 8 weeks, 40% in 12 weeks, and almost 100% in 20 weeks [13]. In animal experiments, PLLA rods implanted into the medullary cavity of the rabbit femur showed no inflammatory or foreign body reaction for 52 weeks and maintained a bending strength exceeding that of human cortical bone for 8 weeks [14]. In our series, no early collapse or extravasation of grafted bone occurred, indicating that the mechanical properties of the PLLA screws were sufficient for the acetabular bone graft. However, postoperative gait exercise started slowly in these patients compared with recent rehabilitation programs for patients with THA [15]. Because of concern about the mechanical insufficiency of the PLLA screws for THA with an early weight-bearing rehabilitation program, we have used mechanically stronger and bioabsorbable screws made of forged composites of hydroxyapatite and PLLA since 2003 [16].

Although a long-term in vivo implantation study found that PLLA screws showed no signs of inflammatory foreign body reactions during the 3- to 5-year follow-up period [17], there is concern about the inflammatory reaction to biodegradable PLLA implants used especially in the joint [18]. Such tissue reactions may cause late aseptic swelling and osteolysis [19]. In our series, osteolysis occurred in zone 1 in 9 cases where PLLA screws might have been involved. However, there were no continuous abnormal findings indicating that inflammatory reactions were induced by the PLLA screws, such as pain, tenderness, local heat, redness, or swelling around the screws, and there was no radiologic evidence of progressive osteolysis proceeding along the PLLA screws. Radiologic examination indicated that the PLLA screws were replaced by bone tissue to some extent, a finding that was supported by the retrieved case in which histologic examination could be performed with stem revision.

In this series, the clinical results of the cemented THA with acetabular bone graft fixed with PLLA screws were satisfactory. The screws had no adverse effect on the long-term results because bone union was obtained at the grafted site in every case, and the survival rate of THA in this series was good compared with other studies [20-22]. However, no prospective randomized study was performed with the same operative procedure using other fixation devices, and we cannot identify the use of PLLA screws as the main reason for the good clinical results.

The radiolucency of grafted bone had a significant influence on the socket revision and zone 1 radiolucent line greater than 1 mm. Total hip arthroplasty with bone graft in the higher radiolucency group had a higher rate of socket revision and the appearance of zone 1 radiolucent line greater than 1 mm. Because the digital image processing of x-ray examination influenced the radiolucency of the grafted bone, we determined the radiolucency of the grafted bone relative to that of the adjacent iliac bone. In addition, several factors presumably affected the radiolucency, such as the anteroposterior width of grafted bone, bone mineral density, and cyst formation, which is often observed in the deformed femoral head concomitant with secondary osteoarthritis. Our results indicate that such bone grafts are desirable if they have sufficient anteroposterior width and greater mineral density and include few cysts.

Many reports have focused on the clinical results of THA with acetabular bone grafting [6,22], although there are no reports in English on the clinical and radiologic results of THA using a bioabsorbable device for bone grafting. We have reported on the long-term results of cemented THA with acetabular bone grafting in 133 hips, using mainly alumina-ceramic screws for the graft fixation [22]. The survival rate of the acetabular component with radiologic loosening as the end point was 75% at 15 years, which was inferior to that of the present study. The difference in clinical results cannot be ascribed only to the difference of the fixation device because several factors, such as the surgeons, implants, and surgical approaches, also differed. However, alumina-ceramic and metallic screws used in the previous study had some demerits. First, they are not bioabsorbable, and absorption of the grafted bone may occur because of the disturbance of stress distribution by the rigid screws. Absorption of the grafted bone or osteolysis around the ceramic screws was observed often in our previous series [13]. Second, metallic or ceramic screws may induce aggressive osteolysis via metallosis or third-body wear when the breakage of the screws occurs subsequent to socket loosening. On the other hand, the PLLA screws used in the current study were absorbed and lost their mechanical strength completely within 20 weeks after implantation [13]. These results suggest that there would be no concern about the disturbance of stress distribution and third-body wear associated with the PLLA screws and that there is no need to remove the screws when socket revision is required. Although mechanically stronger and bioabsorbable composite screws have been used recently in our institution, as mentioned above, our series demonstrates that PLLA screws are safe and useful for the fixation of grafted bone concomitant with THA. Further retrieval studies should be performed to confirm the biodegradability and biocompatibility of PLLA screws.

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ORIGINAL ARTICLE

Subaxial subluxation after atlantoaxial transarticular screw fixation in rheumatoid patients

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Abstract The most common cervical abnormality associated with rheumatoid arthritis (RA) is atlantoaxial subluxation, and atlantoaxial transarticular screw fixation has proved to be one of the most reliable, stable fixation techniques for treating atlantoaxial subluxation. Following C1–C2 fixation, however, subaxial subluxation reportedly can bring about neurological deterioration and require secondary operative interventions. Rheumatoid patients appear to have a higher risk, but there has been no systematic comparison between rheumatoid and non-rheumatoid patients. Contributing radiological factors to the subluxation have also not been evaluated. The objective of this study was to evaluate subaxial subluxation after atlantoaxial transarticular screw fixation in patients with and without RA and to find contributing factors. Forty-three patients who submitted to atlantoaxial transarticular screw fixation without any concomitant operation were followed up for more than 1 year. Subaxial subluxation and related radiological factors were evaluated by functional X-ray measurements. Statistical analyses showed that aggravations of subluxation of 2.5 mm or greater were more likely to occur in RA patients than in non-RA patients over an average of 4.2 years of follow-up, and postoperative subluxation occurred in the anterior direction in the upper cervical spine. X-ray evaluations revealed that such patients had a significantly smaller postoperative C2–C7 angle, and that the postoperative AA angle correlated negatively with this. Furthermore, anterior subluxation aggravation was significantly correlated with the perioperative atlantoaxial and C2–C7 angle changes, and these two changes were strongly correlated to each other. In conclusion, after atlantoaxial transarticular screw fixation, rheumatoid patients have a greater risk of developing subaxial subluxations. The increase of the atlantoaxial angel at the operation can lead to a decrease in the C2–C7 angle, followed by anterior subluxation of the upper cervical spine and possibly neurological deterioration.

Keywords Atlantoaxial transarticular screw fixation · Atlantoaxial subluxation · Subaxial subluxation · Rheumatoid arthritis · Operative complications

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Introduction

Rheumatoid arthritis (RA) infamously presents joint inflammation, bone and cartilage destruction and ligament laxity, all of which lead to joint instability. The cervical spine is one of the most frequently affected and the most severely damaged part in RA patients [20]. The resulting neurological impairment can lead to even a shortened life expectancy [14]. The most common cervical abnormality associated with RA is atlantoaxial subluxation, representing two-thirds of rheumatoid cervical subluxations [4], and if evidence of spinal cord compromise exists at the atlantoaxial level on MRI, neurological deterioration requiring surgical intervention is more likely to happen than with subaxial lesions [9]. Therefore, serious consideration should be paid to the treatment of such instabilities, and an operative intervention is frequently inevitable.

Atlantoaxial transarticular screw fixation, first introduced by Magerl and Seemann [13], has proved to be one of the most reliable, stable fixation techniques for treating atlantoaxial subluxation [7, 16]. However, this operation has its own risks, notably one of which is an intraoperative injury to the vertebral artery [17, 18]. Another early complication could be non-union of either the atlantoaxial facets or the posterior bone graft, if combined, and we recently reported that this complication largely depends on the RA status of the patient and the material used for the posterior bone graft fixation [10].

On the other hand, late complications of atlantoaxial transarticular screw fixation have not been fully reported so far. Yoshimoto et al. [23] previously showed that hyperlordotic fixation of C1–C2 would eventually lead to the development of subaxial kyphosis. This was supplemented by a report that constant inclination of C1 and anterior shift of C2 are also associated with subaxial sagittal alignment changes after C1–C2 transarticular screw fixation [15]. While Kraus et al. [12] reported that subaxial subluxation requiring surgery did not develop in patients after C1–C2 fusion compared with those after occipitocervical fusion, there have been a few reports dealing with subaxial cervical spine instability following C1–C2 arthrodesis. Agarwal et al. [1] reported that 3 of 55 patients who had required C1–C2 fusion developed subaxial subluxation and had a second procedure after a mean interval of 9 years. Clarke et al. [3] also showed that 39% of their patients with atlantoaxial subluxation developed non-symptomatic or symptomatic/unstable subaxial subluxations after C1–C2 fusion. Furthermore, while the rigidity of any fixation can presumably affect biomechanical environment on the other levels that can lead to subluxations, only Mukai et al. [15] have reported subaxial subluxation after atlantoaxial transarticular screw fixation. They showed that neurological deterioration recurred in four patients because of the postoperative development of subaxial subluxation but with no details of those patients. So far, how the subaxial subluxastion progresses and what factors contribute to the development after C1–C2 fusions have not fully been analyzed, and, moreover, whether RA status affects the incidence rate remains to be proved.

In this study, we evaluated subaxial subluxation after atlantoaxial articular fixation in a consecutive series of patients who had RA as well as non-RA backgrounds, aiming to find radiological factors that might contribute to the subluxations.

Materials and methods

All of RA patients included in this study fulfilled the revised criteria of American College of Rheumatology [2]. From September 1994 to February 2006, a consecutive series of RA and non-RA patients who had atlantoaxial subluxation and intractable pain or progressive neurological involvement were evaluated medically and radiologically. Of these, 11 patients (7 RA, 4 non-RA) underwent the occipitocervical fixation and 1 (non-RA) did the atlantoaxial fixation combined with subaxial fixation because of, at least, one of the following reasons; substantial vertical and/or subaxial subluxation, irreducible atlantaxial subluxation or osseous fusion between the occiput and the altas. An RA patient received the atlantoaxial fixation only with posterior wiring and strut autograft. In the remaining patients, 56 underwent elective atlantoaxial transarticular screw fixation with a posterior strut autograft, and 12 patients (6 RA, 6 non-RA) went back to their local hospitals or were lost to follow-up within 1 year after the operation. One patient underwent concomitant cervical laminoplasty and was excluded from this study. The remaining 43 patients (33 RA, 10 non-RA) were closely followed up for more than 1 year by functional lateral X-rays and were included in this study. The mean follow-up period was 4.2 years (range 1–11 years and 8 months).

All operations were performed under fluoroscopic guidance. For transarticular screw fixation, the Reunion bone screw system (Surgical Dynamics Inc., Norwalk, CT) or the Universal cannulated screw system (SofamorDanek, Memphis, TN) was used. All types of screw had a diameter of 4 mm. In case of substantial destructive atlantoaxial instability, the Olerud cervical system with an atlas claw was used (NordOpedic AB, Uppsala, Sweden) in two cases. A unicortical iliac bone strut was fixed on C1–C2 supported with morselized bone chips, mostly according to Gallie [6] using a metal wire or cable, or a polyethylene cable (Secure Strand; Surgical Dynamics Inc.). In cases when we used an atlas claw to fix the C1–C2 arches, only bone chips were grafted. The detail of the overall surgical techniques has been described elsewhere [17, 19].

All patients were asked to wear hard or soft collars for 3 months and were closely followed up by clinical examinations and functional X-rays that were performed 3 and 6 months after the operation and every 6 months thereafter. We did not observe any intraoperative complication directly related to the initial atlantoaxial transarticular screw fixation in any of the 43 cases. However, two patients developed substantial subaxial subluxation after certain periods of time (5 years and 1 month, and 6 years and 5 months, respectively) and submitted to an operative correction because of neurological deterioration (Fig. 1). In these cases, the last X-ray dates before the reoperation were defined as the latest follow-up. Two patients developed non-fused C1–C2 with only slight motion between them and were included in this study [10]. Neutral lateral radiographs were taken with the patients standing or sitting in their natural posture before and 3 months after the operation and at the latest follow-up. Flexion-extension radiographs were taken by asking each patient to achieve his or her maximum

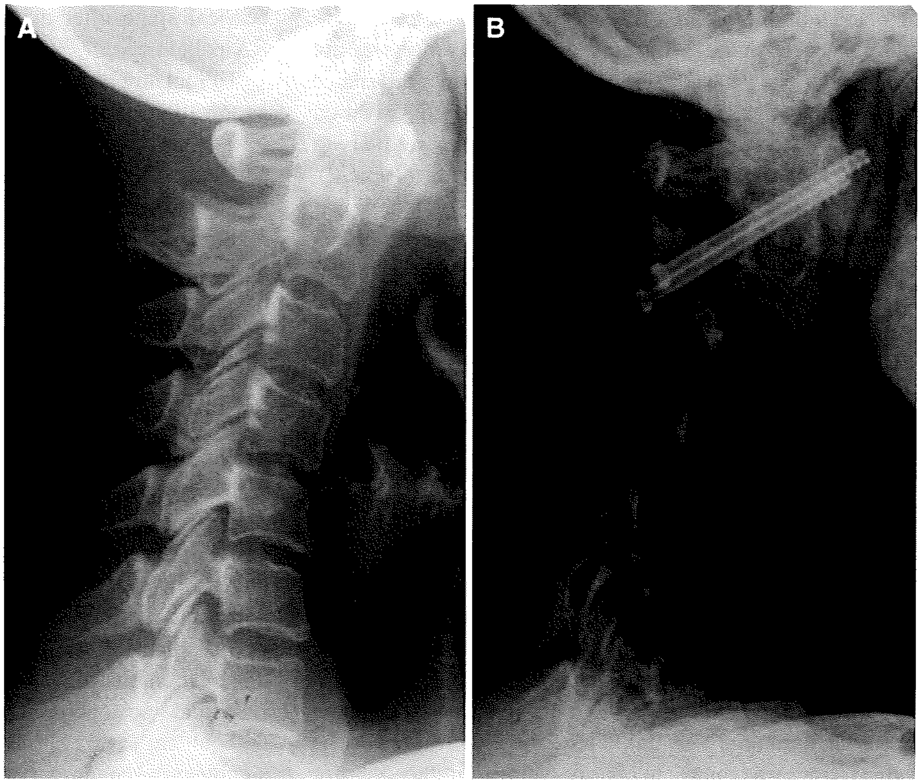

Fig. 1 **a** A 64-year-old RA woman who had severe anterior atlantoaxial subluxation underwent the atlantoaxial transarticular screw fixation. **b** She developed a substantial anterior subluxation in C4–C5 with severe neurological deterioration 6 years and 5 months after the operation

effort at flexion and extension at the same time. All of the patients' records and the radiographs were blindly evaluated and measured by the author (H. I.) who was not the responsible operator in this series of operations. The atlantoaxial angle (AA angle) was defined as the angle between an extended line connecting the centres of the anterior and the posterior arches of the atlas (C1) and an extended line connecting the inferior endplate of the axis (C2). The C2–C7 angle was defined as the angle subtended by the lines of the inferior endplate of C2 and the superior endplate of C7 [21]. A vertebral subluxation was measured on the upright lateral radiographs as the anteroposterior distance from the posteroinferior corner of the upper vertebra to the posterosuperior corner of the inferior vertebra on the superior endplate line of the inferior vertebra [21]. A distance of more than 1 mm was recorded and evaluated later. A distance of 2.5 mm or greater was defined as a subluxation, and a change of 2.5 mm or greater between the preoperative and the follow-up distances was defined as an aggravation of a subluxation. Anterior and posterior atlantodental intervals (AADI and PADI, respectively) were also measured. The intraobserver reliability was calculated from three independent measurements and was less than 0.2 mm in distance and 1° or less in angle, respectively. Two patients who had unsuccessful C1–C2 fusion were excluded in the postoperative AA angle measurement. Two patients preoperatively had substantial posterior subluxations whose levels were non-operatively fused at follow-up and were classified as no subluxation, even though it could have meant an anterior correction of the subluxation.

To examine the effect of RA status on the subaxial subluxation rate, we divided the patients into two groups: RA (33 patients) and non-RA (10 patients). We then subdivided them into groups with an anterior, posterior, anteroposterior (a combination of anterior and posterior subluxations), or no subluxation. The non-RA group consisted of four patients with os odontoideum, five with degenerative spondylosis, and one with odointoid fracture. Data are expressed as the mean ± SD. Ratios between groups were evaluated by Fisher's exact probability or by a 2×2 χ^2 test. Any difference in the means between two groups was assessed using Mann–Whitney non-parametric U test. Correlation and regression analysis was performed using Spearman's correlation approach. Significance was set at $P < 0.05$.

Results

The follow-up periods of the RA and non-RA groups were 4.2 ± 2.4 and 3.7 ± 2.1 years, respectively, which does not yield a statistical difference. First, pre- and postoperative subaxial subluxations were compared between the

RA and non-RA groups. Preoperative subluxations were more frequent in the RA group, but the difference was not significant. However, after the operation, the difference became statistically significant (Table 1). Any aggravation of the subluxation was then assessed. It was more likely to happen in RA patients than non-RA patients (Table 2). Substantial subluxation aggravation (3 mm or more) was more likely to happen in the RA (8/33 patients, 9/165 levels) than in the non-RA group (0/10, 0/45), but smaller subluxations between 2 to 2.4 mm occurred similarly in the RA (12/33 patients, 9/165 levels) and in the non-RA group (2/9, 2/45), indicating that RA patients had a greater risk of developing substantial subaxial subluxation after this operation than non-RA patients.

Next, the direction and level of the subluxation was assessed in RA patients. The preoperative subluxation was dominantly in the posterior direction (7/33 patients, 21.2%: 9/165 levels) rather than in the anterior direction (1/33 patients, 3.0%: 1/165 levels, $P = 0.023$ and 0.010, respectively, Fig. 2a). In contrast, the postoperative subluxation rates were similar between posterior and anterior subluxation directions (13 patients in the anterior vs. 11 in the posterior direction: 15 levels in the anterior vs. 13 in the posterior direction: Fig. 2a). Thus, the aggravation of the subluxation was more likely to happen in the anterior direction (11/33 patients) than in the posterior (4/33, $P = 0.040$). Evaluation of the subluxation level revealed that an increase of the anterior subluxation was more likely to happen in the upper cervical lesions ($P = 0.024$; Fig. 2b). Taken together, postoperative subluxation was more likely to occur in the anterior direction in the upper cervical spine after atlantoaxial transarticular fixation in RA patients.

To find any associated factors leading to the subluxation aggravation, preoperative AADI and PADI, and pre- and postoperative AA and C2–C7 angles were evaluated in RA patients. Table 3 shows that the incidence of anterior subluxation aggravation did not have any significant correlation with any of the preoperative AADI, PADI values or with AA, or C2–C7 angle. However, these cases did have significantly smaller postoperative C2–C7 angle and showed a tendency to have a bigger postoperative AA angle. The postoperative AA angle negatively correlated with the postoperative C2–C7 angles (Fig. 3a), although those measured preoperatively did not (data not shown). More importantly, the anterior subluxation aggravation cases had significantly bigger AA and smaller C2–C7 angle changes, respectively (Fig. 4). These two changes strongly correlated with each other (Fig. 3b), indicating that an increase in the AA angle led to a decrease in the C2–C7 angle, probably followed by subaxial subluxation. Indeed, in those patients who had an anterior subaxial subluxation aggravation, the C2–C7 angle significantly decreased in the immediate postoperative period (3 months after operation) without any aggravation of the subluxation but did not significantly change after that time even with the occurrence of the aggravation (Fig. 5). Thus, 67.9% of the total incidence of a decreased C2–C7 angle occurred during the first 3 months after the operation. On the contrary, no correlation was found between the postoperative AA and C2–C7 angles in non-RA group (data not shown).

Table 1 Comparison of the pre- and postoperative subaxial subluxation (slip) between RA and non-RA patients

	n	Preop.		Postop.	
		Slip	Rate (%)	Slip	Rate (%)
RA	33	8	24.2	19	57.6*
Non-RA	10	1	10.0	1	10.0

* $P < 0.05$

Table 2 Comparison of the slip aggravation rate in terms of patient numbers and levels, between RA and non-RA patients

	Patient			Level		
	n	Slip aggravation	Rate (%)	*n*	Slip aggravation	Rate (%)
RA	33	13	39.4*	165	15	9.1*
Non-RA	10	0	0	50	0	0

* $P < 0.05$

Discussion

Atlantoaxial transarticular screw fixation combined with posterior bone graft has established itself as a reliable surgical management for atlantoaxial subluxation [5, 7, 8] with a few serious problems, including intraoperative vascular impairments [17, 18] and non-union of bone grafts between C1 and C2 spinous processes and/or non-fused C1–C2 facets [10]. However, only a few of the late complications have been reported, one of which is subaxial sagittal alignment change [11, 15, 23]. We have encountered several patients with serious subaxial subluxations, two of whom presented with progressive neurological deterioration and required operative interventions. From this retrospective study, we found that RA patients have a greater risk of developing subaxial subluxations after atlantoaxial transarticular screw fixation. Moreover, a perioperative increase in the AA angle leads to a decrease in the C2–C7 angle, followed by new or aggravated anterior subluxations of the upper cervical spine and possibly neurological deterioration.

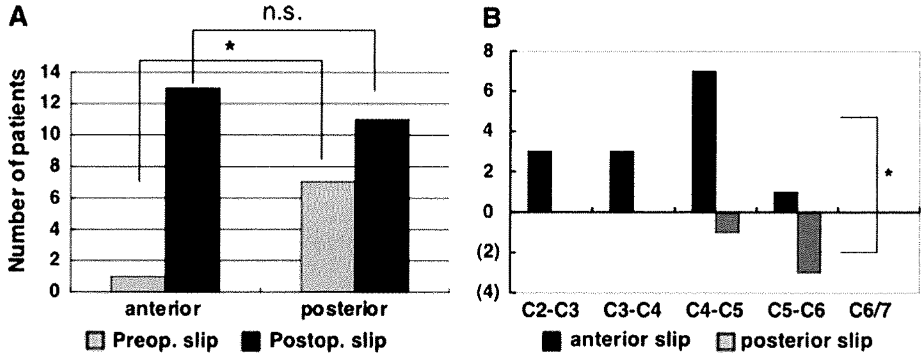

Fig. 2 **a** Pre- and postoperative subluxation (slip) in RA. **b** The level of the increased anterior and posterior slip. * $P < 0.05$

Table 3 Differences of preoperative AADI and PADI, and the pre- and postoperative AA and C2–C7 angles between patients with anterior subaxial subluxation (slip) and those with no slip

	Preop				Postop	
	AADI	PADI	AA angle	C2–C7 angle	AA angle	C2–C7 angle
Ant. slip. aggravation	10.6 ± 2.4	12.0 ± 3.5	16.3 ± 10.3	13.5 ± 3.9	24.8 ± 6.0	−3.1 ± 14.1*
No aggravation	8.7 ± 3.2	12.8 ± 3.3	18.2 ± 12.3	20.5 ± 13.5	21.2 ± 6.1	15.3 ± 13.6
Total	9.1 ± 3.0	12.6 ± 3.2	19.0 ± 12.6	18.1 ± 11.3	23.0 ± 7.5	10.6 ± 15.0

Of note, the total averages were calculated from all four groups (anterior, posterior, combination, and no slip groups)
* $P < 0.05$

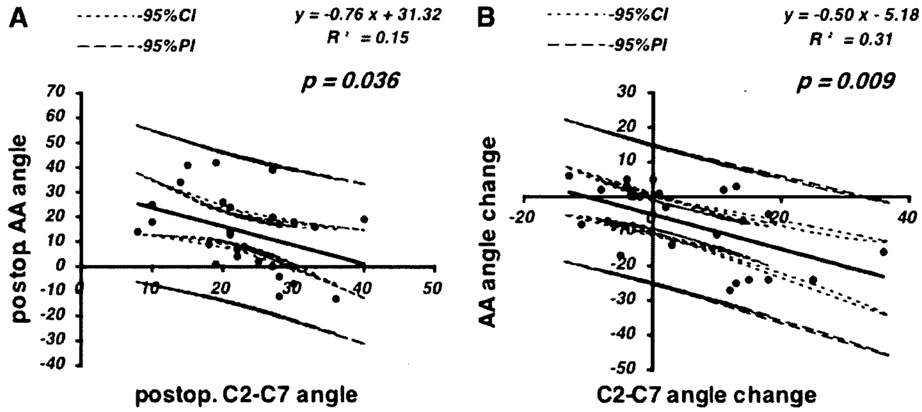

Fig. 3 **a** Correlation between the postoperative AA and C2–C7 angles. **b** Correlation between the AA and C2–C7 angle changes

One reason why such a complication has not been reported is that RA patients are not the majority of the reported cases using atlantoaxial transarticular screw fixation. RA consisted of only one-third of 191 [7] and 75 patients [8] in two of representative cohort studies, respectively. Even in one report that included 35 RA patients only, subaxial subluxation was not a major focus even though it was mentioned that the subluxation led to neurological deterioration [15], and there has been no comparative report between RA and non-RA patients. However, 13 of 33 RA cases in our series showed unmistakable, worrisome subaxial subluxation after a certain period of time (4.2 years in average) in this study. Indeed, two patients required subsequent corrective operations, and several needed further attention, while non-RA patients did not develop this instability after the operation.

The non-RA group surprisingly did not show even any correlation between the postoperative AA and C2–C7 angles, although the number in this group may be insufficient to draw a clear conclusion. One possibility is that non-RA patients would have had a similar risk but tended to have fewer biomechanical compensatory changes caused by rigidity. In contrast, the cervical spines of RA patients are susceptible to biomechanical changes caused by local instability, leading to a disruption of the cervical alignment. Mukai et al. [15] reported, indeed, an example of biomechanical compensation after C1–C2 fixation, namely an increase in C1–C2 lordosis, a progressive ventral shift of

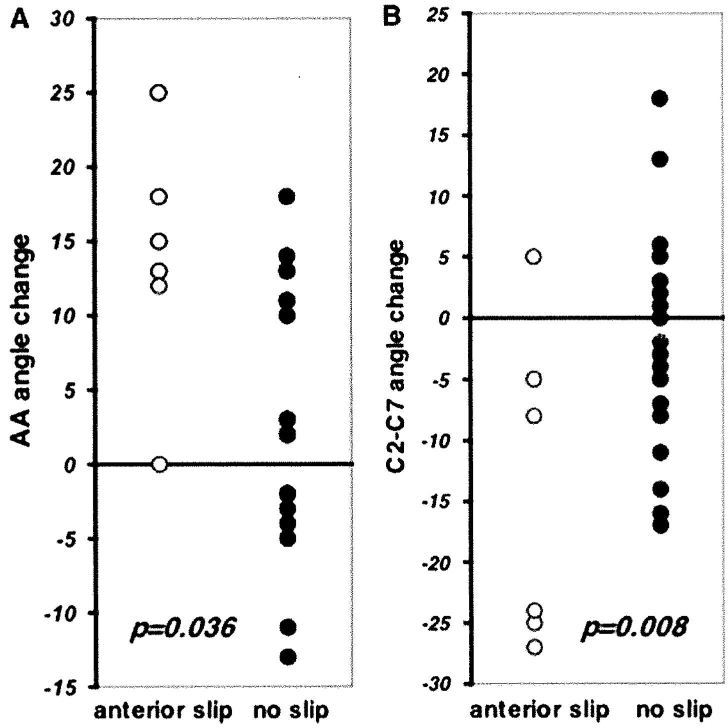

Fig. 4 **a** Difference in AA angle changes between patients with anterior subluxation (slip) and those with no slip. **b** Difference in C2–C7 angle changes between patients with anterior slip and those with no slip

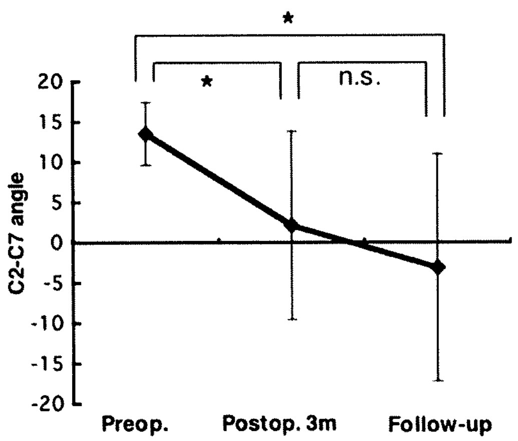

Fig. 5 C2–C7 angle changes at the preoperative, the immediate postoperative (3 months after the operation) and the latest follow-up in patients with anterior subluxation (slip). * $P < 0.05$; *n.s.* not statistically significant

C2 relative to C7, a progressive decrease in C2–C7 lordosis and a tendency for C1 inclination to return to preoperative inclination. However, none of the previous reports analyzed more crucial subaxial subluxations. Here, we demonstrate for the first time the importance of perioperative AA angle changes along with subsequent changes in C2–C7 angles, possibly leading to subaxial subluxation.

Another reason may be that causative factors of subaxial subluxation are too many to dray any conclusion from a cohort study. For one, an argument could be that subaxial subluxation is one of the possible deformities associated with RA in the natural course, similar to atlantoaxial subluxation, and is not a late complication. In RA patients, anterior subaxial subluxation does indeed tend to occur in the lower cervical spine without C1–C2 fixation, compared with posterior subluxation in patients with cervical spondylosis [22]. However, before the operations in this study, RA patients predominantly had posterior rather than anterior subluxations and developed new or aggravated anterior subluxations after the operation (Fig. 1), and the change occurred within a relatively short time (3 months) after the operation but not thereafter (Fig. 5). Moreover, the anterior subluxation followed a significant decrease in the perioperative C2–C7 angle (Fig. 5), not vice versa. In addition, the levels of anterior subluxation were significantly different between pre- and postoperative changes (Fig. 2b), as previously reported [22]. Thus, those sequential changes indicate that anterior subluxation should be considered as a late complication of this operation or, at least, can be accelerated by C1–C2 fixation. This complication probably results from the broken balance of the entire cervical alignment if an inadvertent correction of anterior atlantoaxial subluxation is performed.

On the other hand, one can easily name some of the possible causative factors such as osteoporosis in rheumatoid arthritis, the activity of the disease, the effect of medication, or the age of the patient. Indeed, Yonezawa et al. [22] reported that anterior subaxial slip significantly correlated with the average daily dose of corticosteroid and the class or stage of RA among RA patients without any operation during their follow-up period. However, we have found no difference in the medical treatment between anterior slip and no slip patients (data not shown), and the sequential changes after the operation described above strongly indicate the direct relationship between the C1–C2 fusion and the subaxial subluxation. Indeed, Yoshimoto et al. [23] demonstrated that postoperative AA and C2–C7 angles showed a negative linear correlation and that C2–C7 angle changes showed a negative correlation with AA angle changes, and Yonezawa et al. [22] demonstrated a positive association between a lordo-kyphotic deformity and anterior slip occurrence, both of which supports our finding of the sequential changes that an increase of AA angle leads to a decrease of C2–C7 angle, resulting in anterior subaxial subluxation. With all possible factors taken into account, not denied are the probable effects from the disease activity and the medication to cervical deformities in RA patients, and even preventive contributions from recently developed or developing medications such as biologics are expectable. We have no definite data or published reports on that issue, but it is hopeful that sufficient subsidence of the disease by medication will enables the cervical spine of RA patients to resist any deformative forces and to behave as if the one of non-RA patients, as described in this study.

One of the limitations of this study was the definition of a subluxation. One could define a subluxation as 2.0, 2.5, or 3.0 mm and possibly draw different statistical results. However, Yonezawa et al. [22] reported that even 2 mm of anterior subluxation is more likely to occur in RA patients than non-RA patients, and the present study clearly showed that more substantial subluxations (3 mm or more) than smaller subluxations (2–2.4 mm) were observed in RA patients. Thus, RA patients will probably be shown to have a greater risk of postoperative subaxial subluxation if a sufficient number of cases are collected and if the degree of the subluxation is defined broadly enough. As Yonezawa et al. [22] showed that even 2 mm of anterior subluxation can lead to damage in the cervical spinal cord in RA patients, the higher rate of subluxation among RA patients must not be underrated. Taken together, our study apparently indicates that AA angle should be carefully decided with reference to C2–C7 angle when C1–C2 fixation is performed in RA patients. Otherwise, subaxial subluxation is likely to occur within several years of follow-up, and neurological deterioration can be expected.

Conclusions

RA patients are more likely than non-RA patients to develop subaxial subluxations after atlantoaxial transarticular screw fixation. The increase in the AA angle occurring during the operation can lead to a decrease in the C2–C7 angle followed by anterior subluxation of the upper cervical spine and possibly neurological deterioration.

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Navigated Anterior Approach to the Upper Cervical Spine After Occipitocervical Fusion

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Study Design. Technical note.

Objective. To introduce the application of navigation system with software for brain surgery to the upper cervical spine of patients who have previously had occipitocervical (O-C) fusion.

Summary of Background Data. The anterior approach to the spine using a navigation system with software for spine surgery is difficult because the registration tends to be inaccurate. However, after O-C fusion, the upper cervical spine is considered part of the skull, and a navigation system with software for brain surgery in which the registration is performed using the head with several markers attached to it can be applied.

Methods. Three patients with previous O-C fusion—2 with upper cervical chordoma and 1 with a disc herniation at C2/3—were treated using this technique.

Results. In the first case, with a huge retropharyngeal C1 chordoma, this technique was very helpful in blindly dissecting the nonvisible parts of the tumor. In the second case, with a C2 chordoma, the vertebral arteries were successfully exposed under the guidance of the navigation system at both primary and revision surgery. In the third case, with disc herniation at C2/3, the herniated disc was removed successfully with the totally fused spine. In this application, computed tomography images can be merged freely with magnetic resonance images, which is helpful to clarify the soft tissues such as tumor, disc herniation, or the dural tube.

Conclusion. This technique greatly supports surgeons inexperienced in the anterior approach to the upper cervical spine or surgeons at revision surgery who may be lost in and daunted by an unfamiliar operation field surrounded by important structures. Although an anterior approach to the upper cervical spine in the patient with O-C fusion may rarely be required, this application should be considered.

Key words: computer-assisted navigation, upper cervical spine, anterior approach, occipitocervical fusion. **Spine 2009;34:E800–E805**

In recent years, computer-assisted navigation systems have been popularized as essential tools for some spine surgeries. They optimize preoperative planning, allow safe implantation, clarify resection limits of a lesion, decrease radiograph exposure, and reduce overall surgical morbidity. However, an anterior approach to the spine using a navigation system is limited because of technical difficulties.[1] That is, there are no suitable parts on which to fix the reference arc and the anterior surface of the vertebral body has few anatomically characteristic landmarks, which makes registration inaccurate. Although a few articles have reported that a navigation system with software designed for brain surgery can be used successfully in the anterior approach to the upper cervical spine,[2,3] obtaining acceptable accuracy is often difficult because of occipitocervical (O-C) or atlantoaxial (C1–C2) mobility.[4,5] However, if there is O-C fixation, the upper cervical spine is then considered part of the skull, and navigation software for brain surgery should be able to be applied more accurately in the anterior approach to the upper cervical spine. Although such cases are rarely encountered, we report 4 successful trials of the application in 3 patients, and discuss its utility.

Materials and Methods

From 2003 to 2008, 2 patients with a chordoma in the upper cervical spine and 1 patient with C2/3 disc herniation were selected for a navigated operation using software designed for brain surgery, and the navigation system was applied successfully 4 times. A rigid O-C fusion with metal implants had been performed before the operation in all patients.

A frameless stereotactic image guidance system (StealthStation Tria; Medtronic Sofamor Danek, Memphis, TN) was used. In this system, the software for brain surgery allowed possible error of within 2 mm, while the software for spine surgery allowed that of within 1 mm. On the day before the operation, 6 to 10 markers were attached to the head, and computed tomographic (CT) and magnetic resonance images (MRI) of the cranium, including the upper cervical spine, were taken. The imaging data sets were transferred to the workstation of the navigation system. On the day of operation, the patients were positioned in the supine position with the head fixed in a Mayfield clamp. A reference arc was fixed to the Mayfield clamp, and point registration was performed using the attached markers on the head, followed by surface registration (Figure 1). In all patients, the registration was done successfully with a possible error of less than 1 mm. After disinfection, the operation field was covered with sterile drapes, and the reference arc was exchanged for a sterile one, enabling intraoperative navigation. Then, the upper cervical spine was explored anteriorly, and the accuracy of the navigation in the upper cervical region was confirmed using spinal landmarks, tumor surface or implants, if any, as markers. In all trials, this revealed that the navigation was accurate enough to continue the operation.

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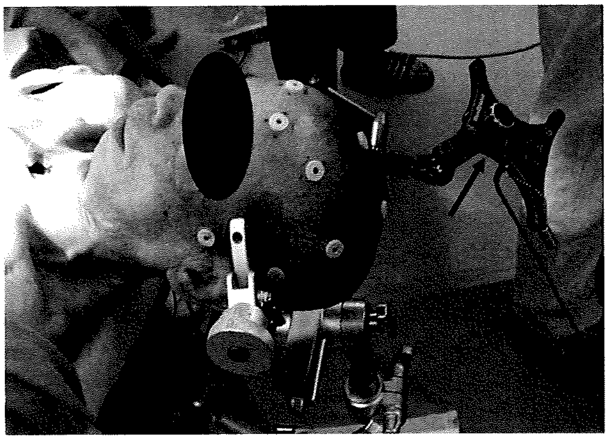

Figure 1. Preparation for registration. Patients with several head markers were positioned in the supine position with the head fixed in a Mayfield clamp, to which a reference arc (arrow) was fixed.

■ Case Presentations

Case 1

A 19-year-old man with a large retropharyngeal chordoma was introduced to us following a transoral biopsy. The details of this case were reported elsewhere, focusing on the utility of transmaxillary and transmandibular approaches.[6] In short, the tumor originated on the right side of the anterior arch of C1 and was large (about 6 cm in diameter) and ossified. It extended from the clivus to the C2–C3 intervertebral disc in the sagittal plane.

A posterior occipitocervical (O-C3) fusion and an iliac bone graft were performed first to prevent any instability that resection of the anterior arch of C1 would produce.

Ten days after the fusion, the tumor was resected through a transmaxillary and transmandibular approach. Because the tumor was large, hard, and immovable due to adhesion to the anterior arch of C1, it was impossible to see or identify the tissues behind it. Therefore, the dissection was continued under the guidance of a computer-assisted navigation system with software for brain surgery. Checking the location of the anterior arch of C1 and the bilateral vertebral arteries (VAs) on the navigation monitor (Figure 2), blind *en bloc* resection of the main part of the tumor from the anterior arch of C1 was performed using an osteotome. The right part of the C1 anterior arch, the origin of the tumor, was then resected *en bloc*. The navigation system was also helpful in deciding the range of the C1 osteotomy. The retropharyngeal mucosa was reconstructed using a vascularized radial forearm flap.

Pathologically, tumor cells were only exposed on the cross section between the main tumor mass and the resected anterior arch of C1. Postoperative radiation therapy (60 Gy) was administered.

Thereafter, the patient's course was uneventful. No recurrence or metastasis was observed 5 years after the operation. The patient had no complaints and has returned to his previous job as a manual laborer.

Case 2

A 72-year-old man was brought to hospital because of a sudden onset of severe neck pain and quadriplegia. At the hospital, he was diagnosed with a pathologic fracture of the axis (C2), and posterior decompression, biopsy and O-C5 fusion with transarticular screws were performed. The pathologic diagnosis was a chordoma. Fortunately, his paralysis recovered without sequelae. He was introduced to us several months after the above operation, with a large retropharyngeal tumor still invading the area posterior to the bilateral VAs in C2 (Figure 3).

Piecemeal resection was performed through a transmandibular approach using a navigation system. MRI data were useful in the resection of the prevertebral tumor, and

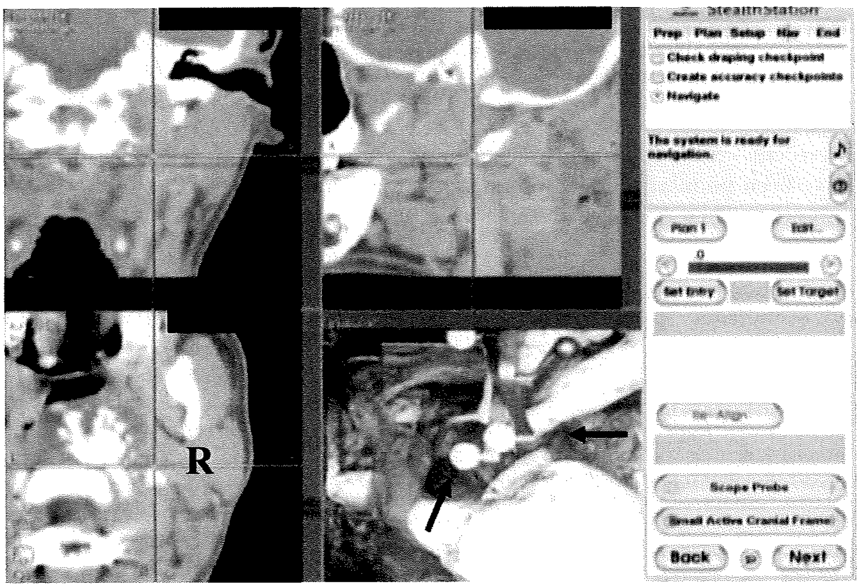

Figure 2. Case 1: Navigation monitoring during blind dissection of the tumor. The tip of the pointer (indicated by the intersection point of the 2 green lines) was positioned near the right transverse process of C1 and the vertebral artery, which was invisible behind the large tumor mass (arrows) in the operation field.

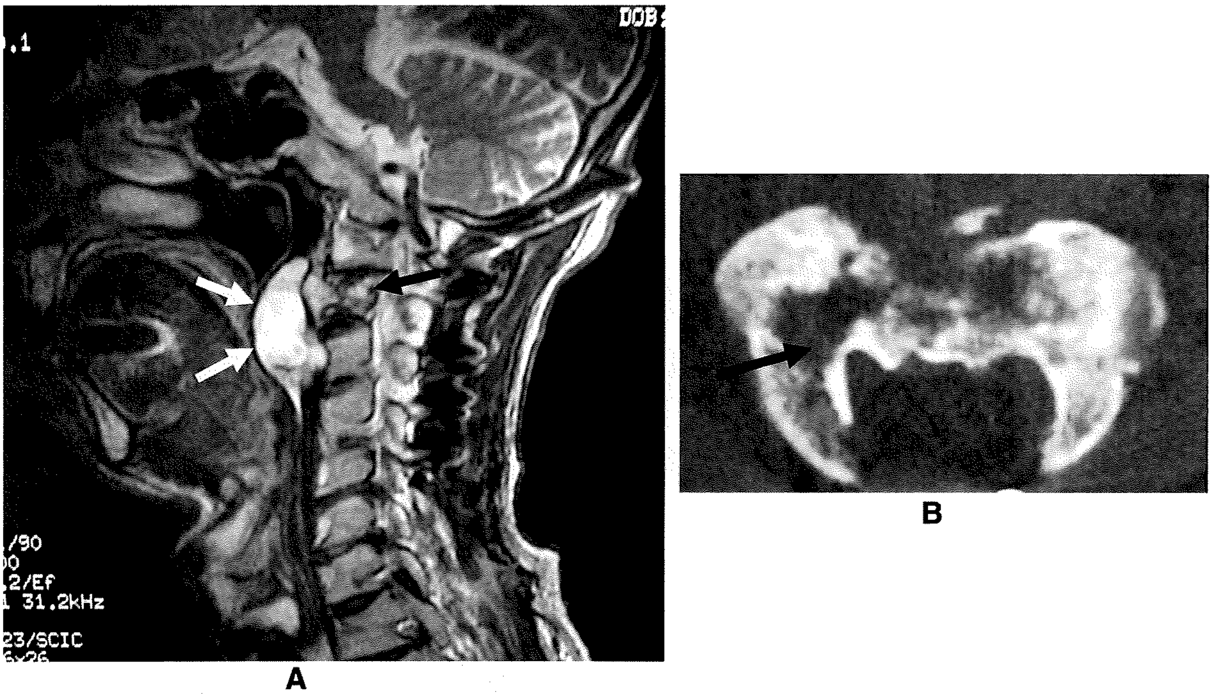

Figure 3. Case 2. Images taken when the patient was introduced to us. **A**, Sagittal T2-weighted MR image of the cervical spine. A retropharyngeal tumor (white arrows) and pathologic fracture of C2 (black arrow) were demonstrated. **B**, CT image of C2. In this section, the osteolytic lesion expanded posterior to the right vertebral artery (arrow).

CT data were helpful in the resection of the vertebral tumor. Supported by the navigation system, the VAs were exposed bilaterally and the tumor behind the VAs was resected. We were able to confirm on the navigation monitor that all the parts we had before surgery planned to remove were curetted (Figure 4). After resection of the tumor, an anterior cervical fusion was performed using vascularized radial forearm flap-fibula graft. The vascularized fibula was fixed between the C1 anterior arch and C3 with a buttress plate, and successfully united in 3 months.

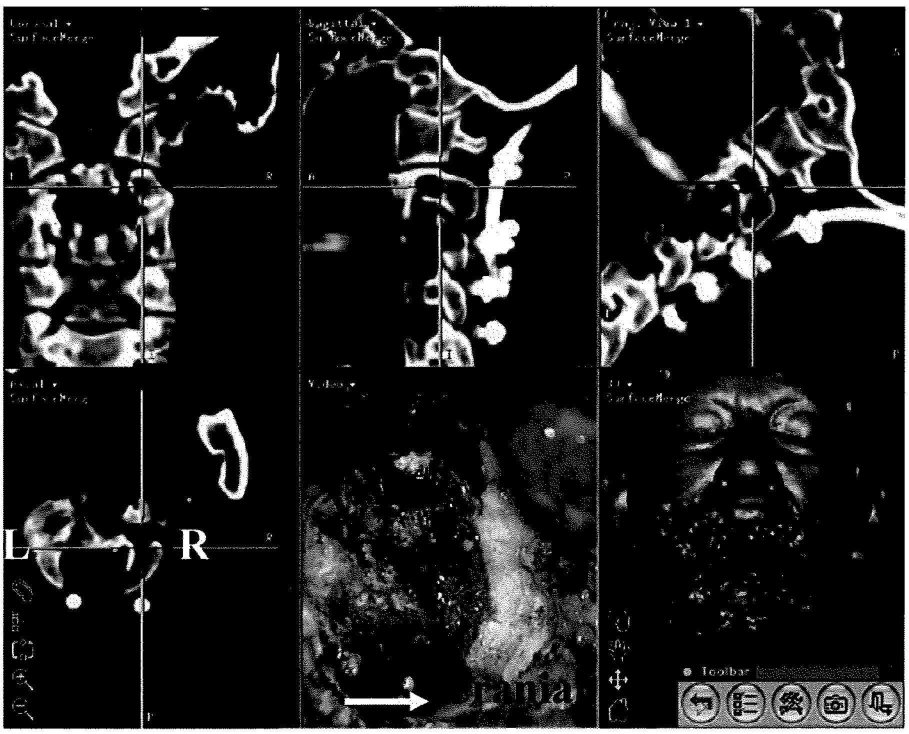

Figure 4. Case 2. Navigation monitoring after piecemeal resection of the tumor. The lower center image is a microscope view of the operative field. The intersection point of the 2 green lines indicates the tip of the pointer. It was confirmed that the most posterior part of the tumor, behind the right vertebral artery, was curetted as planned. The pointer is indicated by the arrow in the microscope view.

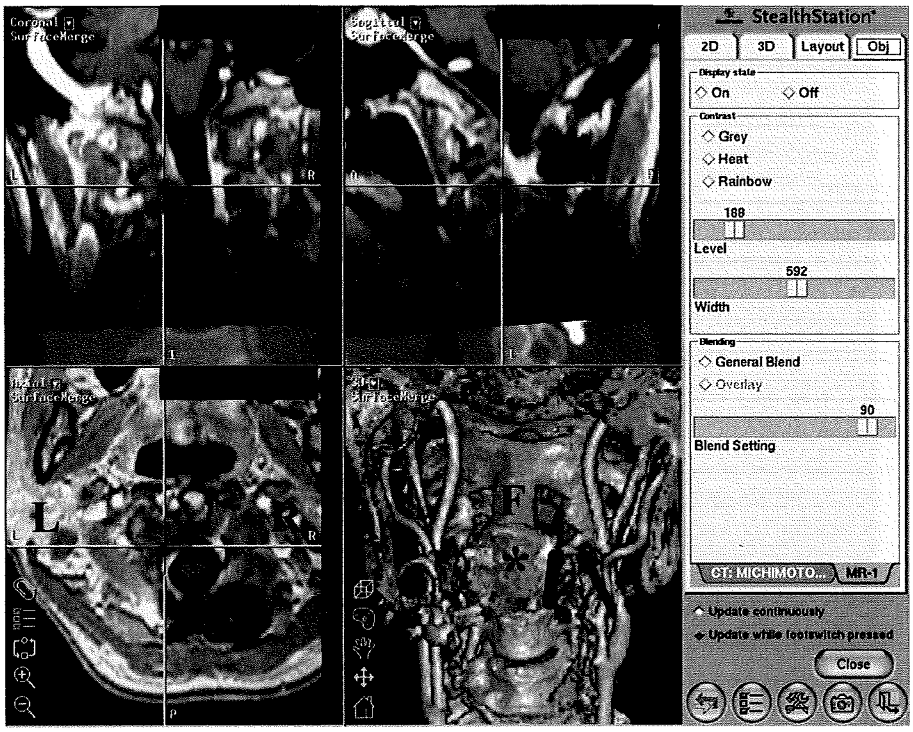

Figure 5. Case 2. Navigation monitoring during the revision surgery. The right lower image is from 3-dimensional-constructed CT angiography, and the others are MR images. In the CT angiography image, the left vertebral artery involved in the recurrent tumor is apparent (black arrow). The blue arrow indicates the position of the pointer in the operation field. Its tip was positioned near the dura, which was also not visible, being covered by the scar tissue in the operative field. The asterisk indicates the buttress plate, which had been implanted to prevent dislodgement of the vascularized fibula (F).

Although the postoperative course was uneventful, follow-up MRI 2.5 years after the operation revealed that the tumor had recurred on the left side of C2. The patient elected to undergo revision surgery rather than heavy-particle radiotherapy, and the tumor was resected in the same way as in the previous operation. This time, CT angiography was used as a base image for the navigation to confirm the left VA position, which was involved in the recurrent tumor (Figure 5). The VA was successfully exposed beside the grafted fibula and the buttress plate, with guidance by the navigation system. MRI was useful to identify the tumor position, and to locate the dura covered by scar tissue (Figure 5). As in the previous surgery, we were able to confirm that we had curetted all the parts planned.

No recurrence has been observed to date, 11 months after the operation.

Case 3

The third case was a 58-year-old woman with rheumatoid arthritis (RA). Between 1995 and 2003, she underwent 7 surgeries because of spinal destruction by RA, resulting in C1–C2 and C6-sacrum fusion. During this period, she twice experienced Frankel C paralyzes because of spinal canal stenosis and instability adjacent to the previous spinal fusions. These paralyzes improved after emergency decompression and extension of the fixation, and she had managed to live independently.

She complained of deterioration consisting of bilateral numbness in her hands and weakness of all 4 extremities, resulting in becoming bedridden again in 2008. It was difficult to decide the responsible pathology, because her advanced RA status, with multiple joint destructions and muscle atrophy, and the sequelae of the previous paraplegia made neurologic diagnosis difficult. However, MRI revealed that central disc herniation at C2/3 combined with anterior listhesis of C2 compressed the spinal cord (Figure 6A). Anterior decompression and fusion was abandoned at first because the approach was difficult due to little neck motion and the location of the herniation behind the mandible, and obtaining bony fusion was considered difficult because of osteoporosis, instability at C2/3 and mechanical stress concentration on

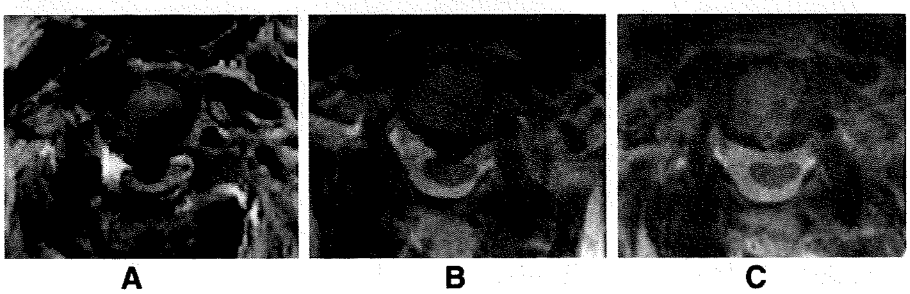

Figure 6. Case 3. Axial T2-weighted MR image at C2/3. **A,** Preoperative image. **B,** Image taken 6 weeks after posterior decompression. **C,** Image taken 1 week after anterior removal of the herniation.

C2–C6 after wide spinal fusion. Therefore, laminectomy from C2 to C3/4 and extension of the posterior fusion with instrumentation and local bone grafting was selected, which resulted in total spine fusion from the occiput to the sacrum. Although acceptable decompression of the cord was obtained (Figure 6B), the patient's symptoms did not change and she asked for removal of the herniated disc. Two months after the posterior surgery, an anterior approach to the cervical spine was performed using a navigation system for brain surgery. It was difficult to approach C2/3 in the totally fixed spine, but the multiple herniated fragments were removed through a corpectomy of the upper half of C3. The navigation system was helpful in locating the median line and clarifying the resection limits for the disc herniation. No anterior fusion was performed. After surgery, MRI demonstrated complete decompression of the spinal cord at C2/3 (Figure 6C). The finger motion of the patient improved slightly and she became able to transfer from the bed to a wheelchair by herself.

■ Discussion

Several articles have reported the successful application of navigation systems using software designed for brain surgery in the anterior approach to the upper cervical spine.[2,3] However, mobility in O-C and C1–C2 often decreases accuracy and makes this application unreliable.[4,5] However, in this study, rigid O-C fixation with metal implants had been performed in all patients, and therefore a navigation system for brain surgery was used successfully even in the upper cervical spine. Imaging artifacts from posterior metal implants did not disturb the navigation procedure.

As for the navigation system that we used (Stealth Station Tria), the software for spinal surgery has proved to be useful, especially in posterior implantation.[7,8] However, anterior applications pose problems in registration, and have therefore been seldom performed.[1] In the presented method using software for brain surgery, a reference arc was fixed to a Mayfield clamp allowing registration with head markers to be easily and quickly done with accuracy of less than 2 mm. Furthermore, our application has other merits compared with usual spine navigation. First, MRI images can be merged freely with CT images on the monitor, which is helpful in clarifying resection limits of soft tissue such as in tumors or disc herniation. In case 2, it was useful in locating the dura buried in postoperative scar and in case 3 for locating the disc herniation.

Second, CT angiography can be used as a base image, because the spine surface is not used for registration. With the software for spine surgery, contrast media would disturb the registration procedure. In case 2, CT angiography was helpful to locate a VA buried in recurrent tumor and postoperative scar.

Recent advances in technology have allowed the combination of intraoperative CT or MRI with a navigation system, and these techniques may overtake the application presented here as these systems can be used without O-C fusion because preoperative images and registration procedure are not necessary.[5,9,10] However, the image quality of intraoperative CT is not adequate and special equipments such as radio-transparent head clamps or operation tables are necessary. As for intraoperative MRI, it is very expensive and the surgical circumstances allowed are highly limited. Furthermore, it is impossible to use MR and CT images simultaneously, as in our application.

The application of our technique may not always be necessary, particularly with highly experienced surgeons. However, it greatly supports surgeons unfamiliar with the anterior approach to the upper cervical spine and surgeons performing revision surgery. They may be daunted by a narrow or deep corridor surrounded by important structures, or lost in the postoperative scar and abnormal anatomy. In such a situation, the navigation provides them with a less stressful and safer operation.

We do not know if this technique is applicable to the middle or lower cervical spine, even with a large enough range of posterior fusion, because the operative field is far from the registered skull, which may result in decreased accuracy.

Lastly, we emphasize that a reasonable surgical strategy should not be changed in order to use a navigation system. This application should be strictly limited to the cases, in which posterior fusion has already been done or initial posterior fusion is reasonably indicated.

In conclusion, this application is worthy of consideration as a tool for use in anterior upper cervical spine surgery in a few selected cases.

■ Key Points

- A frameless stereotactic image guidance system with software for brain surgery can be applied to the anterior approach to the upper cervical spine in patients who have previously undergone occipitocervical (O-C) fusion as the upper cervical spine can then be considered part of the skull.
- Chordomas of the upper cervical spine in 2 patients and disc herniation at C2/3 in 1 patient were successfully removed using an anterior approach using this technique.
- In this application, computed tomographic images can be freely merged with magnetic resonance images, which is helpful in clarifying soft tissues such as tumor, disc herniation, or the dural tube.
- Although an anterior approach to the upper cervical spine in the patient with O-C fusion may rarely be required, this application should be considered.

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