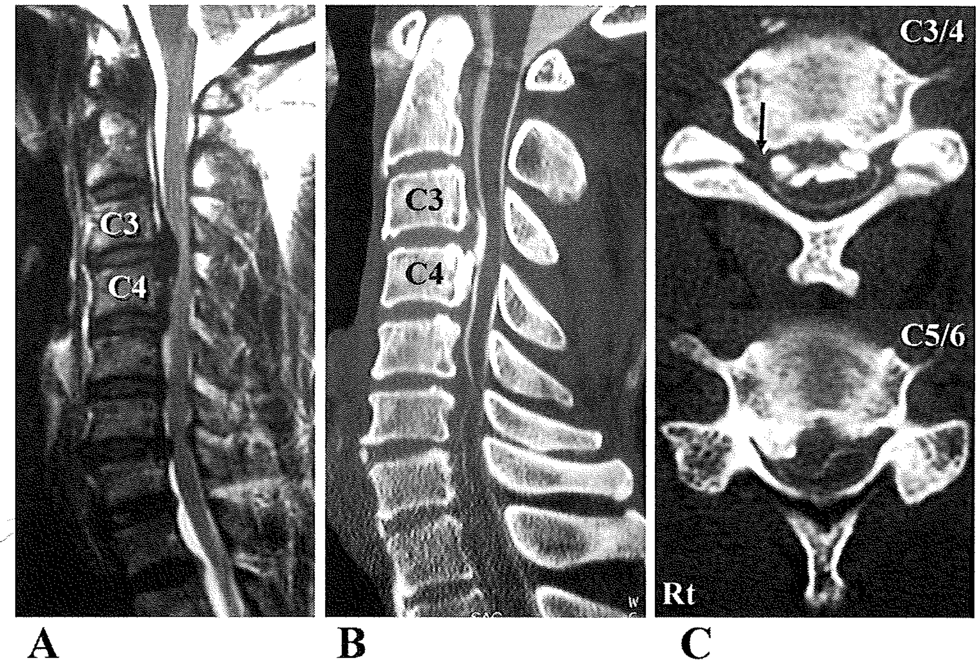

Figure 1. These 3 images of the cervical spine (**A–C**) were obtained before surgery in a 52-year-old man with cervical myelopathy caused by ossification of posterior longitudinal ligament (OPLL). A midsagittal T2-weighted magnetic resonance image (**A**) shows severe compression of the spinal cord anteriorly at multiple levels from C3/4 to C6/7. Midsagittal (**B**) and axial (**C**) computed tomographic images show anterior broad compression of the spinal cord by a large OPLL at C3/4 and anterior right-sided compression of the spinal cord by soft disc herniation at C5/6. An arrow (**C**, upper panel) indicates the site where cerebrospinal fluid leakage and subsequent massive bleeding occurred during surgery.

surgical treatment, which was planned as anterior decompression of the spinal cord and a strut bone graft with autologous fibula at C2–C7. At first, we performed corpectomy of C3, C4, C5, and C6, and extirpated the soft disc herniation at C5/6 and the osteophyte at C6/7. We then attempted to extirpate OPLL at C3–C4. However, the dura matter was ossified, and separation of OPLL from the dura was not possible. Therefore, we modified the surgical procedure from the extirpation of the OPLL to floating the OPLL.

We reduced the OPLL to be as thin as possible. Then, we cut the posterior longitudinal ligament around the thinned OPLL. When we finished cutting the posterior longitudinal ligament around the OPLL, cerebrospinal fluid (CSF) leakage and subsequent massive bleeding occurred at the right edge of the OPLL at the C3/4 level. We placed a collagen-impregnated sheet at the bleeding point, and compressed it with a cotton sheet. Hemostasis with this method was successful, and no further bleeding occurred there.

To confirm decompression of the spinal cord, we performed intraoperative ultrasonography. To our surprise, we found a high-intensity mass lesion at the ventral side of the spinal cord and at the cranial aspect of C5/6, indicating the development of an intrathecal hematoma that compressed the spinal cord (Figures 2A, B).

Immediately after we performed the ultrasonography, we found that the dura mater at the C5–C6 levels bulged and became deeply cyanotic (Figure 3, arrowhead). We considered that rapid growth of the hematoma had progressed and damage to the spinal cord may occur. Thus, we promptly cut the dura longitudinally at the C5–C6 levels to decompress the cord. We found that the arachnoid was intact, and beneath it there was a hematoma. We then cut through the arachnoid, and removed the subarachnoid hematoma.

To identify the bleeding point, we extirpated the OPLL at C3–C4. Because the dura mater was ossified at this region, a large defect of dura mater was formed after

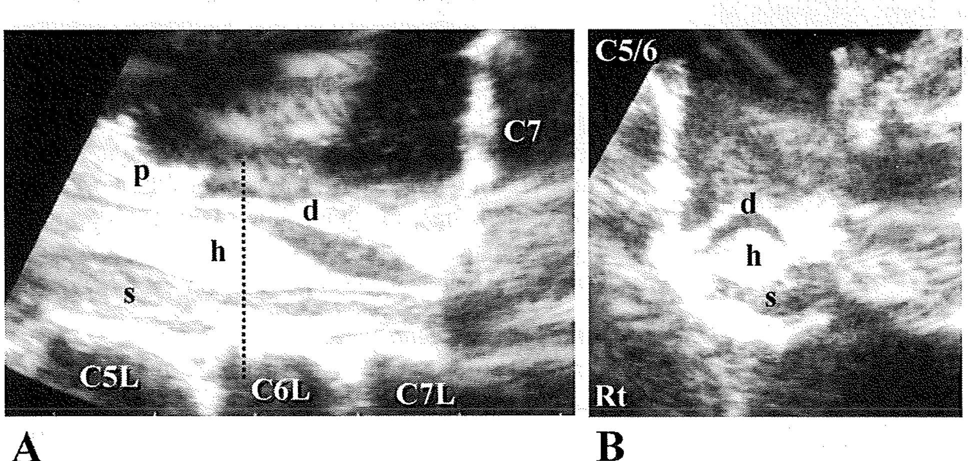

Figure 2. Intraoperative ultrasonographic images (**A, B**) immediately after the anterior decompression procedure from C2/3 to C6/7. A sagittal image slightly shifted to the right side (**A**) shows a high-intensity mass lesion at the ventral side of the spinal cord, indicating an intrathecal hematoma. A dotted line indicates the section depicted in (**B**). An axial image at the C5/6 level (**B**) shows the high-intensity mass lesion at the ventral and right sides of the spinal cord. h indicates intrathecal hematoma; s, spinal cord; d, dura matter; p, remained posterior longitudinal ligament; C4L, C5L, and C6L, lamina of C4, C5, and C6, respectively.

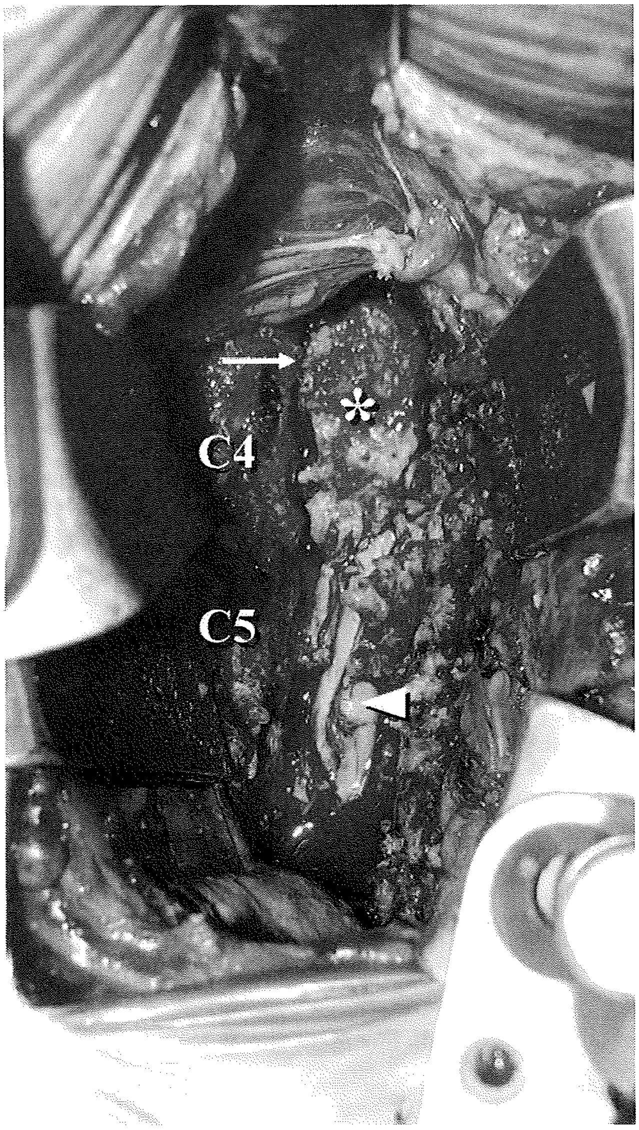

Figure 3. An intraoperative photograph after the anterior decompression from C2/3 to C6/7. Immediately after the OPLL floating procedure, cerebrospinal fluid leakage and massive bleeding occurred at the right edge of the OPLL at C3/4 level (arrow). After the hemostasis, the dura mater at the C5–C6 levels rapidly bulged and became deeply cyanotic (arrowhead). The asterisk indicates the floated OPLL at the C3–C4 levels.

extirpation of the OPLL. After this, we found that the point of bleeding was the radicular artery along the right C4 root (Figure 3, arrow). We coagulated the bleeding point, and completed the hemostasis. We removed the hematoma at the C3–C4 levels, and completed the decompression of the spinal cord. We constructed a dural patch. We then performed a strut bone graft with autologous fibula from C2–C7. The incision was closed, and the patient returned to the recovery room.

Clinical Outcome

After surgery, the patient's myelopathy was improved, and no neurologic deficit related to the SSAH was found. Magnetic resonance images 1 month after surgery showed adequate decompression of the spinal cord. At follow-up 1 year after the surgery, the patient was completely healthy, and returned to his job.

Discussion

Domenicucci et al[2] reviewed 69 cases of SSAH, and summarized its etiologic factors. In 31 (33.3%) of 69 cases, the cause was a lumbar puncture that was performed for anesthesia, CSF control, or myelography. Twelve (17.3%) cases were classified as spontaneous. In 11 (15.9%) cases, SSAH was correlated to trauma. In 9 (13%) cases, SSAH occurred because of coagulopathies, such as from taking anticoagulant medication. Daentzer *et al*[5] reported a case of SSAH after spine surgery, in which misplacement of a screw at surgery for an odontoid fracture caused vertebral artery injury. This caused a pseudoaneurysm and subsequent rupture, leading to a fatal subarachnoid hemorrhage 4 days after surgery.[5] Aghi *et al*[1] reported a case of SSAH after high cervical myelography by C1–C2 lateral puncture. Five days after the myelography, the patient was diagnosed as having SSAH by computed tomography, and the subarachnoid blood clot was surgically removed. In the present case, SSAH occurred during surgery, though the patient did not have any signs of coagulopathy. To the best of our knowledge, this is the first report that describes the occurrence of SSAH during anterior decompression surgery for cervical OPLL. In the present case, the occurrence of SSAH was detected intraoperatively using ultrasonography, and successful removal of the subarachnoid blood clot was performed at an early stage after the SSAH.

Min *et al*[6] analyzed 197 patients who underwent anterior decompression surgery and reported that a dural defect was observed in 25 (12.7%) patients. Similarly, Belanger *et al*[7] reported that 8 (13.1%) of 61 patients with cervical OPLL had absent dura. In the present case, dural ossification was present at the OPLL site at the C3–C4 levels. Because the right C4 root runs near the edge of the OPLL at C3/4, it is possible that we directly injured the radicular artery along the right C4 root when we resected the edge of the OPLL.

The incidence of SSAH has been reported to be low compared with that of spinal epidural hematoma.[8] One reason for the rarity of SSAH is described, in that usually the diluting and redistributing effect of CSF prevents subarachnoid blood from clotting and from forming a solid hematoma.[8] However, when mechanical obstacles are present within the spinal column, such as that occurs in spondylosis, disc herniation, arachnoiditis, or thickening of the yellow ligament, bleeding in the subarachnoid space may result in the formation of an SSAH.[9] In the present case, there was a soft disc herniation at the C5/6 level. We suggest that this is the reason why the SSAH formed at the cranial aspect of the C5/6 level.

Intraoperative ultrasonography has been used during spinal surgery to assess the bony anatomy of the spinal canal as well as the anatomy and pathology of the spinal cord.[10] In the present case, we were able to detect the intrathecal mass intraoperatively by using ultrasonography. On the basis of the findings, we promptly cut the dura and diagnosed that the mass was a subarachnoid hematoma. If we had not performed the examination, we would have overlooked the SSAH. If we had only noticed the SSAH several days after surgery, severe neural deficits may possibly have developed. From this experience, we believe that intraoperative ultrasonography is a useful tool for detecting intrathecal lesions, including SSAH. Previous studies have shown that, immediately after hemorrhage, focal signal intensity by ultrasonography is high.[11] Thus, when anterior decompression surgery for cervical OPLL is performed, if immediately after a high-intensity mass is detected inside of the dura by ultrasonography, the possible occurrence of a SSAH should be considered.

■ Key Points

- We report a surgically treated case of cervical myelopathy caused by ossification of the posterior longitudinal ligament (OPLL), in which subarachnoid hematoma developed intraoperatively.
- The subarachnoid hematoma was diagnosed on the basis of the findings of intraoperative ultrasonography.
- This experience suggests that, when anterior decompression surgery is performed for cervical OPLL patients, we should consider the possible occurrence of a spinal subarachnoid hematoma.

Acknowledgment

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CASE REPORT

Image fusion for preoperative evaluation of vertebral artery in a patient with atlantoaxial vertical subluxation and chronic renal failure

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Abstract For preoperative evaluation of the vertebral artery (VA) at the craniovertebral junction, 3-dimensional (3-D) computed tomography (CT) angiography can simultaneously and precisely depict the location of the VA and the circumferential osseous tissues. However, this procedure has the risk of contrast-induced nephropathy, especially when patients have pre-existing renal impairment. We report the case of a 73-year-old woman with rheumatoid arthritis and concomitant chronic renal failure in whom severe myelopathy developed due to atlantoaxial vertical subluxation and subaxial subluxation. We planned to perform C1 laminectomy and C3–C7 laminoplasty, but to avoid the risk of intraoperative VA injury, we applied a fusion image technique of 3-D magnetic resonance (MR) angiography and co-registered 3-D CT that allowed for virtual assessment preoperatively of the VA courses, instead of 3-D CT angiography. Through the 3-D hybrid MR angiography–CT images, we could predict, in detail, the VA courses and the surrounding bony structures. At surgery, we found that the locations of the VAs were identical to that predicted on the preoperative image fusion analysis. We conclude that our image fusion techniques possess accurate diagnostic value for detecting arterial course, and could be applicable for patients in whom administration of contrast media should be avoided due to specific conditions, such as drug allergy and chronic renal failure.

Keywords Hybrid · Fusion image · Vertebral artery · Craniovertebral junction

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Introduction

Patients with rheumatoid arthritis occasionally suffer from upper cervical lesions such as atlantoaxial vertical subluxation, which, in some cases, necessitates decompression surgery for the treatment of myelopathy. Previous reports of surgeries for cases with severe upper cervical spine deformities have described the utility of three-dimensional (3-D) computed tomography (CT) angiography for preoperative evaluation of the course of the vertebral artery (VA). 3-D CT angiography can distinguish the precise location of the VA and the circumferential osseous tissues simultaneously [5]. However, radiological examinations using contrast media entail the risk of contrast-induced nephropathy, especially in patients with pre-existing renal impairment [3].

In this article, we report the case of a patient with rheumatoid arthritis and concomitant chronic renal failure in whom severe myelopathy developed due to atlantoaxial vertical subluxation. For this patient, we did not perform 3-D CT angiography in order to avoid the risk of contrast-induced nephropathy. Instead, we applied a fusion image technique of 3-D magnetic resonance (MR) angiography and co-registered 3-D CT that allowed virtual preoperative simulation of the VAs at the craniovertebral junction.

Case report

Clinical profile

A 73-year-old woman visited our clinic with complaints of gait disturbance, clumsiness of the hands bilaterally, and occipitalgia. She had suffered from rheumatoid arthritis for 17 years and, as a complication, had developed chronic renal failure with blood urea nitrogen and serum creatinine levels of 40.0 and 1.5 mg/dl, respectively, and a glomerular filtration rate of 28.0 ml/min. At age 65, she had undergone a total right knee replacement surgery and was able to walk without any support following surgery. One month prior to the first visit to our clinic, however, she was unable to stand up without support and was unable to use her hands in daily activities, because of progressive myelopathy. Neurological examinations at the first visit revealed loss of both motor and sensory functions below the C5 level. The patient had received conservative therapy using cervical orthosis, but her myelopathy had not improved.

A cervical lateral radiograph and a mid-sagittal CT with reconstruction showed atlantoaxial vertical subluxation, kyphosis from C4 to C6, and retrospondylolisthesis at C5 (Fig. 1a). A T2-weighted MR mid-sagittal image revealed severe posterior compression of the spinal cord at the C1 level. The MR image also showed multi-level anterior compression of the spinal cord at the middle-lower cervical spine by bulging discs and, posteriorly, by thickened ligamentum flavum (Fig. 1b).

To decide the surgical procedure for the craniovertebral junction, we provided a standardized informed consent for the patient. We explained the relative advantages and disadvantages of C1 laminectomy alone and C1 laminectomy plus occipito-cervical posterior fusion. The patient did not select the addition of occipito-cervical posterior fusion in spite of the possibility of future progression of basilar invagination. Thus, we decided to perform decompression surgery using a posterior approach with a C1 laminectomy and laminoplasty from C3 to C7.

To avoid the risk of VA injury during the C1 laminectomy, we initially planned to perform 3-D CT angiography for evaluating the course of the VAs bilaterally at the craniovertebral junction, but decided against this procedure due to the risk of contrast-induced renal failure. As an alternative, we applied a multimodality image fusion; 3-D MR angiography and 3-D CT was performed sequentially, and then software fusion was used to align the two sets of images.

Image fusion of 3-D MR angiography and 3-D CT

CT data of the patient's cervical spine were acquired with a 16-row multi-detector CT (LightSpeed ULTRA 16, GE Healthcare, Milwaukee, WI) using the following protocol: tube voltage, 140 kV; tube current, auto mA (100–300 mA); rotation time, 1 s; pitch factor, 1.375; beam, 10 mm; matrix, 512 × 512; section thickness, 1.25 mm; configuration, 16 × 0.625 mm; field of view, 96 mm (0.185 mm/pixel); reconstruction 50% overlap. A total of 225 pieces of continuous source axial volumetric data were obtained.

MR angiography was performed with a clinical magnetic resonance imager (Achieva Nova Dual 1.5T, Philips Medical Systems, Einthoven, The Netherlands), using a

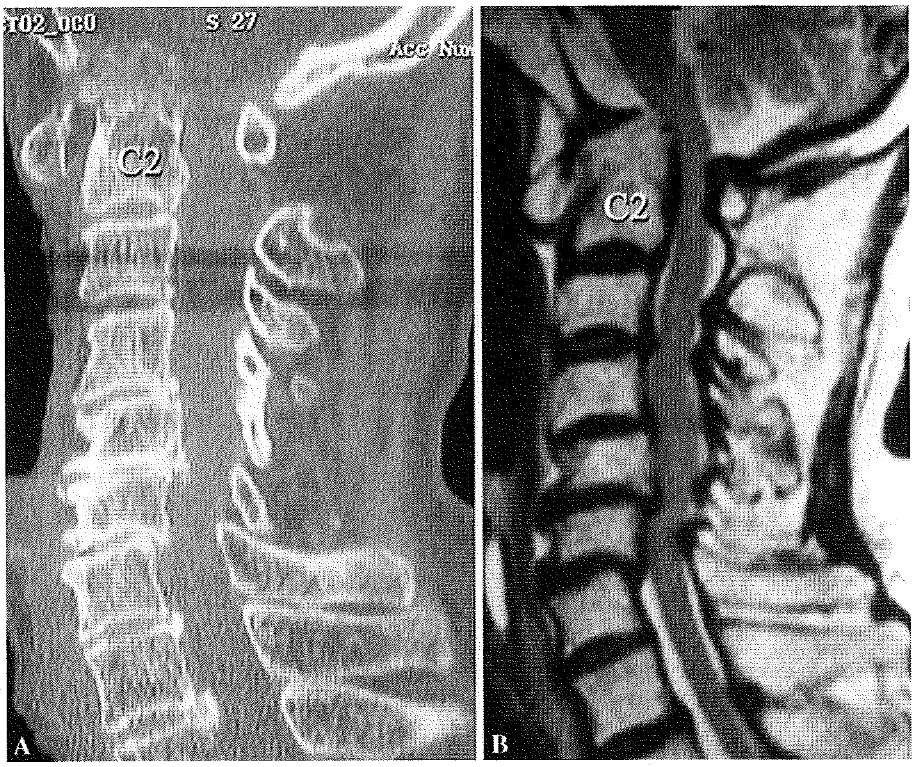

Fig. 1 Preoperative computed tomography (CT) (**a**) and magnetic resonance (MR) (**b**) images of a 73-year-old woman with rheumatoid arthritis and severe myelopathy. A mid-sagittal CT reconstruction image (**a**) shows atlantoaxial vertical subluxation and subaxial subluxation. A T2-weighed MR mid-sagittal image (**b**) demonstrates spinal cord compression at C1 and middle-lower cervical spine

dedicated commercially available 16-channel neurovascular array coil with sensitivity encoding (SENSE, Philips), and data were obtained using a 3-D TOF, FFE sequence. We used the following protocol: TR/TE, 20/6.9; flip angle, 16°; matrix, 256 × 128; section thickness, 1.0 mm; field of view, 180 × 135 mm; SENSE factor, 2.0; scan time, 6 min 13 s. A total of 210 pieces of continuous source axial volumetric data were obtained, and were reconstructed for the 3-D MR angiography images (Fig. 2).

Between the CT and the MR angiography examinations, we adjusted the patient's position. The vertical interval between the headrest and the mat of each device was adjusted to equal height, and we aligned the angle of the patient's mandible between examinations by matching a place mark on the patient's cheek and the devices' aiming beam.

Post-processing was performed on a regular Apple Macintosh 2.5 GHz Power PC G5 running OS X and open-source OsiriX imaging software (Version 3.0.1; OsiriX Foundation, Geneva, Switzerland, http://www.osirix-viewer.com) [1]. The CT images were fused to the 3-D MR angiography images according to the method described in the OsiriX tutorial online seminars (free registration is required for review). Briefly, regions of interest were identified that included the length of the VA and surrounding bony structures from the occipital bone to T2 vertebrae. The OsiriX surface-rendering algorithm was used to produce 3-D reconstructions of the CT images by setting the lower threshold to just above the signal intensity of cortex bone. A second surface-rendered image from the 3-D MR angiography data was superimposed on this image to produce a single false-color reconstruction of the structure. We performed point-base registration among the two sets of images, referring to the foramen transversarium for 5 points. Vessels visualized on angiography were defined as arteries and those appearing on 3-D CT were identified as bones. With this technique, fused images of CT and MR angiography were produced and objectively demonstrated the C1 posterior arc and nearby arteries. The images could be rotated to be viewed from various angles.

Fig. 2 An anterior–posterior view of 3-dimensional (3-D) MR angiography image. *Arrowheads* indicate vertebral arteries (VAs)

In the current case, the C1 posterior arch was translated anteriorly and laterally to the right side. Due to this translation of C1, the left VA was seen to run relatively near the central portion of C1 posterior arch and to enter the spinal canal at the cranial aspect of C1 (Fig. 3a–c).

Operation and postoperative course

We performed a C1 laminectomy and C3–C7 laminoplasty. Intraoperatively, we exposed the C1 posterior arch and identified the courses of the bilateral VAs at the cranial aspect of C1 by Doppler ultrasonography. We found that the left VA localized nearer to the center of C1 posterior arch than the right VA, as predicted preoperatively by the fusion images of MR angiography and CT. All surgical procedures were undertaken carefully so as to avoid injury to the VAs and were accomplished uneventfully.

After surgery, the patient demonstrated intact renal function and her neurological deficits and occipitalgia gradually improved. Postoperatively, the patient's cervical spine was stabilized with a cervical collar for 3 weeks. MR images 1 month after surgery showed adequate decompression of the spinal cord at C1 and C3–C7. At the final follow-up 1 year after surgery, no progression of basilar invagination occurred. She was able to walk without a cane, and no further symptoms had developed.

Discussion

Previous studies have shown that MR angiograms provide useful information for identifying VA anomalies at the regions around the cervical spine [2]. MR angiography has the advantage of being less invasive because no contrast media is required. However, MR angiography cannot simultaneously visualize both the artery and the surrounding osseous tissue, nor can it analyze the reciprocal anatomy of both tissues.

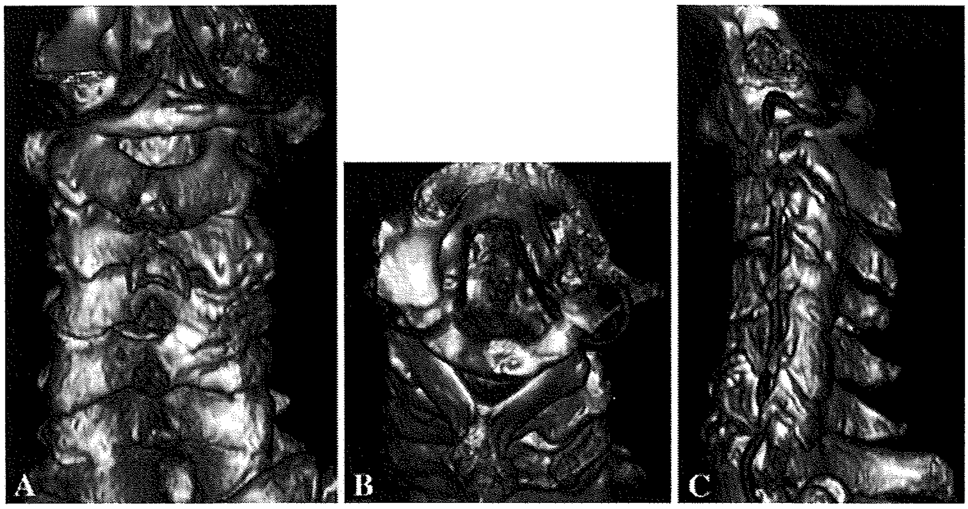

Fig. 3 Hybrid 3-D MR angiography–CT images (**a** posterior view, **b** posterior–superior view, **c** left lateral view) visualizing the relationship between the VAs and the C1 posterior arch. Images of the VA obtained by MR angiography are stained in *red* and those of vertebral osseous components obtained by CT are stained in *gray*

Recently, the utility of 3-D CT angiography has been described for evaluating VA anomalies at the craniovertebral junction [5]. 3-D CT angiography has several advantages in that it can depict VA images more precisely and can reconstruct the image, displaying the VA and surrounding osseous tissue simultaneously [5]. Despite the utility of 3-D CT angiography for preoperative evaluation of the VA, 3-D CT has a disadvantage in that this examination requires contrast media and thus has a possible risk of contrast-induced nephropathy, particularly in patients with pre-existing renal disorders. Previous studies in patients undergoing coronary angiography have shown that the rate of development of contrast-induced nephropathy in high-risk patients is estimated at 20–30% [3]. Thus, when working with a patient suffering from pre-existing chronic renal failure, it is necessary to be extra vigilant for the occurrence of contrast-induced nephropathy following 3-D CT angiography.

In recent years, there has been rapid development of diagnostic imaging using the techniques of multimodality image fusion [4]. Previous studies have shown the usefulness of hybrid images such as PET/CT and SPECT/CT to better understand the combination of anatomy and function [4]. In the present case, because of the presence of pre-existing renal impairment, we avoided the use of 3-D CT angiography for evaluating the VA course at the craniovertebral junction, but performed image fusion of MR angiography and CT. To the best of our knowledge, this is the first report describing the visualization of the VAs at the craniovertebral junction using such a fusion image technique. Through the 3-D hybrid MR angiography–CT images, we could predict, in detail, the course of the VAs as well as the surrounding bony structures. At surgery, we found that the location of VAs was identical to that predicted on the preoperative image fusion analysis. Thus, we believe that our technique of image fusion of MR angiography and CT possesses accurate diagnostic value for detecting the course of arteries, and could be applicable for patients in whom administration of contrast media should be avoided secondary to conditions such as drug allergy and chronic renal failure.

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Conflict of interest statement None of the authors has any potential conflict of interest.

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LETTER TO THE EDITOR

Cervical kyphosis with myelopathy and anomalous vertebral artery entry at C7 treated with pedicle screw and rod fixation

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Dear Editor,
It has been generally accepted that pedicle screws (PSs) at C7 are useful anchors for posterior instrumented fusion of the cervical spine, since vertebral arteries (VAs) enter the transverse foramen at C6 in most cases and little risk of VA injury is present at the insertion of PSs at C7 [1, 3]. We herein present our experience of cervical instrumentation surgery in a patient with an abnormal entrance of a unilateral VA into the C7 transverse foramen.

A 46-year-old man was admitted to our hospital with a 5-month history of sensory and motor disturbances of the upper and lower extremities. On admission, he exhibited bilateral clumsiness in his hands, and his gait was spastic. Lateral radiographs, magnetic resonance (MR) images, and computed tomographic (CT) images demonstrated ossification of the posterior longitudinal ligament (OPLL) associated with severe compression of the spinal cord anteriorly at C4–C6. The sagittal alignment of his cervical spine was kyphotic (Fig. 1a). Extension and flexion radiographs showed evident intervertebral mobility at the cord compression levels. Following our previous studies on the poor surgical outcome after laminoplasty for cervical OPLL [2], for this patient we planned surgery for posterior decompression at C3–C6 with instrumented fusion at C2–C7 using pedicle screws at C2 and C7 as the anchors.

Prior to surgery, we analyzed the VA course with CT angiography [4]. An axial CT angiographic image at the C7 level showed that the size of the transverse foramen on the left side was larger than that on the right side (Fig. 1b, arrow). Three-dimensional (3D) images reconstructed from the CT angiography demonstrated that the left VA entered the transverse foramen at C7 (Fig. 1c, arrowhead). In addition, the diameter of the left VA was almost twice that of the right VA, indicating dominance of the left VA.

Based on the imaging of the abnormal course of the left VA, we believed that there would be an increased risk of VA injury from the insertion of PSs at C7 on the left side. To improve the safety and accuracy of the screw insertion, we performed a resection of the cranial portion of the C7 lamina in addition to posterior decompression at C3–C6, and directly palpated the medial wall of the left C7 pedicle with a sounder. After the insertion of PSs at C7, we also inserted PSs at C2 and lateral mass screws at C3, C4, and C5 bilaterally, and completed the C2–C7 posterior instrumented fusion.

After surgery, the patient gradually recovered muscle strength in his upper and lower extremities and showed improvement of sensory disturbance. At follow-up 1 year after surgery, the patient's neurologic deficits were considerably recovered.

Bruneau et al. analyzed the course of VA in the subaxial cervical spine in 250 patients, and demonstrated that 93% of the VAs ran a normal course and entered the C6 transverse foramen [1]. In the other 7% of VAs, an abnormal entrance level was observed, with the entrance level at C3 in 0.2%, C4 in 1.0%, C5 in 5%, and C7 in 0.8% of cases [1]. In the present case, the left VA entered the transverse foramen at the C7 level, indicating a rare anatomic variation of the VA entrance level. Based on the preoperative finding of the anomalous VA entry, we felt the necessity to increase the accuracy of the PS insertion and

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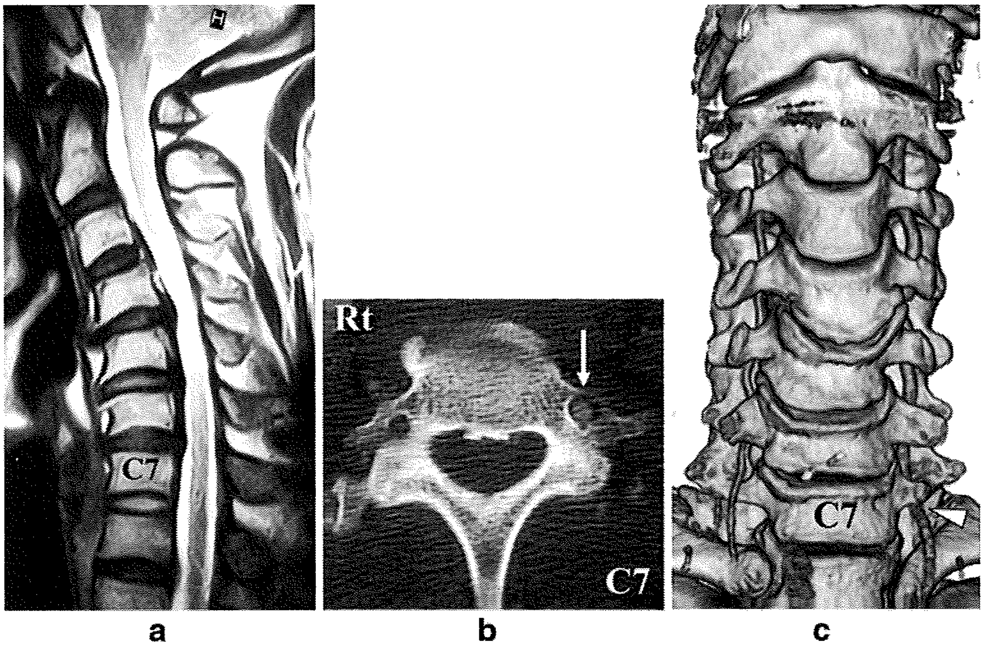

Fig. 1 A T2-weighted midsagittal MR image (**a**) shows severe compression of the spinal cord anteriorly at C4–C6. An axial CT angiographic image at the C7 level (**b**) shows a large transverse foramen on the left side, in which VA is present (*arrow*). A 3D image reconstructed from CT angiography (**c**) shows that the left VA enters the transverse foramen at C7 (*arrowhead*)

modified the surgical method to do this. We directly palpated the medial wall of the left C7 pedicle, and successfully inserted the C7 PS. We believe that C7 pedicle screw insertion might be even safer using computer-assisted navigation.

To detect VA anomalies, there have been several analytical methods including MR angiography and 3D CT angiography [4]. As shown in the present case, 3D CT angiography has significant advantages in that it can depict VA images more precisely and provide image reconstructions from any chosen direction, showing the VA and the circumferential osseous tissue simultaneously. When the size of the transverse foramen at C7 is larger, as is shown in the present case, we should consider the possible presence of VA entry at C7. For such cases, we recommend surgeons precisely detect any VA anomaly using 3D CT angiography.

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Neuroradiology Report

Efficacy and reliability of highly functional open source DICOM software (OsiriX) in spine surgery

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ABSTRACT

We evaluated the feasibility and reliability of open source Digital Imaging and COmmunication in Medicine (DICOM) imaging software, OsiriX (Antoine Rosset, 2003–2009), in spine surgery. CT data were used and processed with OsiriX and with commercial software for comparison. Images were reconstructed and compared in volume rendering (VR) and multi-planar reconstruction (MPR) mode. When all images were compared, the three-dimensional (3D) reconstructed images from both software packages showed considerable consistency in VR mode. Measurements in MPR mode also showed similar values with no statistically significant difference. These results demonstrate that OsiriX has approximately equivalent values to commercial software and provides reliable preoperative 3D information for the surgical field. In addition, any clinician, can obtain information using OsiriX at any time. Thus, OsiriX is a helpful tool in preoperative planning for spine surgery.

1. Introduction

Recent technical advances in spinal surgery have facilitated difficult surgical procedures for patients with severe deformities and for elderly patients with collapsed vertebrae from osteoporosis. These difficult operations require precise anatomical information to be captured preoperatively, which increases the importance of three-dimensional (3D) reconstructed images. However, 3D imaging techniques have several drawbacks, such as their expense, time consumed in printing and reconstructing images, and difficulties in precise communication between doctors and technicians. We have recently been using the freely available Digital Imaging and COmmunication in Medicine (DICOM) software, OsiriX (Antoine Rosset, 2003–2009), as a clinical reference in spine surgery in addition to various other commercial software packages. OsiriX is highly functional DICOM software that allows anyone to reconstruct and manipulate 3D images.[1,2] However, being free software under a GNU Operating System (Free Software Foundation; Boston, MA, USA) General Public License (GPL), the software is used at one's own risk and has not yet been approved as medical software.

To our knowledge there are no reports that describe the reliability of OsiriX in spine surgery. We aimed to evaluate the efficacy and reliability of OsiriX software, and provide some information on how to use this software.

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2. Materials and methods

2.1. Patients and imaging protocol

CT data from 10 patients who underwent cervical spine surgeries at our Institute from 2003 to 2007 were used. The images were examined using a 16-channel multi-detector (MD) CT, Light Speed Ultra 16 (GE Healthcare; Milwaukee, WI, USA) and the slice thickness was 1.25 mm with 0.625-mm intervals (50% overlapping). Images were reconstructed and analyzed on a MacBook Pro 2.16 GHz laptop computer (MA601 J/A with 2 GB random-access memory; Apple; Cupertino, CA, USA), running operating system Mac Operating System X and OsiriX imaging software (Version 2.7.5; http://www.osirix-viewer.com/). As a basis for comparison, the same procedures were also performed with commercial software, Virtual Place Advanced Plus version 2.03 (AZE, Office Azemoto, Japan).

2.2. Image reconstruction with OsiriX

A series of studies were exported from MD-CT to compact disc (CD) in DICOM format. The CD was put into the MacBook Pro and the DICOM data were transferred to a folder. OsiriX was then launched and the data were imported by clicking the "Import" tag on the toolbar and selecting the folder that contained the DICOM data. Anonymization was also performed before the investigation by selecting the "File – Anonymize" option on the menu bar.

Data were reviewed after importing by selecting the series from the list and double-clicking one of the icons that appeared below the list, or by selecting the icon and clicking the "2D viewer" button on the toolbar. Thus, the 2D viewer window was opened and a "2D/3D" button appeared in the middle of the toolbar. 3D images were reconstructed by selecting either "2D multi-planar reconstruction (MPR)" or "Volume Rendering (VR)" from the drop-down menu of the "2D/3D" button. Other types of 3D reconstruction were also available in the drop-down menu, such as "Surface Rendering" and "Virtual Endoscope".

2.3. Image analysis

VR images on each series were reconstructed and the reproducibility of 3D information was visually compared.

In MPR mode, the plane in which the bilateral pedicle showed the widest symmetric diameter was extracted. As the MPR mode of this OsiriX version does not support 3D MPR where all three planes can be inclined freely and symmetrically, the objective plane was acquired by inclining the axial plane and rotating the cross gradually, which corresponds to the sagittal and coronal planes. The anteroposterior (AP) and transverse diameters of the spinal canal were measured from C3 to C7 (Supplementary Fig. 1, Table 1). The measurement was performed three times for each plane and the standard deviation at each level was calculated to evaluate intra-observer error.

Images were reconstructed and interpreted using OsiriX by a spine surgeon with 8 years of experience. Another reconstruction and interpretation with OsiriX was performed by a spine surgeon with 6 years of experience under guidance from the first, for evaluating inter-observer reliability of the package. Data obtained by the two surgeons were expressed as "OsiriX A" and "OsiriX B", respectively.

2.4. Statistical analysis

Statistical analysis was performed using a Mann–Whitney *U*-test. A $p < 0.05$ was considered statistically significant. Results are presented as the mean ± standard deviation of the mean.

3. Results

When all the images were compared, the 3D reconstructed images from both software packages showed significant consistency. The 3D information was investigated from anterior, posterior, lateral and oblique views, which revealed the reproducibility of the information. For example, 3D images generated by both software packages are presented for comparison (Fig. 1).

The AP and transverse diameters of the spinal canal were measured by OsiriX and Virtual Place software (Table 1). There was no statistical difference among the data obtained by Virtual Place, OsiriX A, or OsiriX B, indicating little inter-observer error. In addition, the data obtained by OsiriX had a similar reliability to data obtained using Virtual Place.

Table 1
Anteroposterior and transverse diameters (mm; mean ± standard deviation) of the cervical spinal canal as measured using OsiriX and Virtual Place software

Vertebra	View	Virtual loc. (mm)	OsiriX A	OsiriX B
C3	AP	11.50 ± 1.89	11.60 ± 1.84	11.64 ± 1.91
	Lat	21.11 ± 1.38	21.26 ± 1.21	21.10 ± 1.32
C4	AP	11.27 ± 1.39	11.43 ± 1.33	11.38 ± 1.33
	Lat	22.75 ± 1.33	22.85 ± 1.17	22.70 ± 1.30
C5	AP	11.23 ± 2.02	11.39 ± 1.90	11.35 ± 1.80
	Lat	23.46 ± 1.21	23.72 ± 1.16	23.51 ± 1.36
C6	AP	10.91 ± 2.90	10.80 ± 3.22	10.86 ± 3.19
	Lat	23.42 ± 1.15	23.67 ± 1.24	23.43 ± 1.26
C7	AP	11.30 ± 1.64	11.80 ± 1.31	11.60 ± 1.49
	Lat	22.31 ± 1.21	22.47 ± 1.24	22.34 ± 1.29

AP = anteroposterior diameter, loc. = location, Lat = transverse diameter, OsiriX A and OsiriX B indicate data obtained by two spine surgeons with 8 years and 6 years experience, respectively. See Section 2.1 for software details.

4. Discussion

Since the invention of spinal instrumentation and surgical navigation systems, the importance of 3D anatomical information in the surgical field has increased substantially. OsiriX is free DICOM software developed by Rosset et al. at the University of Geneva, that can provide many types of 3D reconstructed images.[1,2] In particular, VR and MPR images are most useful in preoperative evaluation of disease pathology and for surgical planning. With a sophisticated user interface, not only radiologists, but also clinicians, including spine surgeons, can easily manipulate and generate 3D reconstructed images and acquire whole images of 3D anatomical structures. In addition, 4D or 5D reconstruction of images can be processed with the software.[3] It is also possible to build up a Picture Archiving and Communication System with OsiriX independently, as the DICOM server is also included in the software. Some advanced features are also possible, such as the virtual endoscope and image fusion. These methods are described in OsiriX online tutorials (http://www.osirix-viewer.com/Learning.html) although free registration is required before use.

Several reports have featured the use of OsiriX software in broad clinical and research fields. Sugimoto et al. developed a new and less-invasive method of virtual 3D pancreatography using the OsiriX system and reported its feasibility in minimally invasive pancreatectomy for neoplasms.[4] Melissano et al. demonstrated precise 3D analysis of the Adamkiewicz artery by reconstructing data from MD-CT angiography with OsiriX and reported its potential benefits for planning therapeutic procedures.[5] This may become an important preoperative tool for surgeons. Because clinicians can perform image fusion easily, there are also some reports about the feasibility of processed fusion images in clinical practice. Miller et al. reported a novel technique to identify neurovascular compression in patients with trigeminal neuralgia by image fusion.[6] The authors were able to visualize objectively, nerves, arteries and veins of the cerebellopontine angle using 3D reconstructed balanced fast-field echo images fused with 3D time-of-flight magnetic resonance (MR) angiography and 3D Gadolinium-enhanced images. Nishie et al. evaluated locally recurrent pelvic malignancy by image fusion,[7] in which they compared the sensitivity, specificity and accuracy of various MR image sequences for detecting local tumor recurrence. T2-weighted fast spin-echo, diffusion-weighted echo-planar imaging, dynamic contrast-enhanced fat-suppressed T1-weighted spoiled gradient echo, and T2-diffusion-weighted MRI with image fusion were processed using OsiriX. The authors concluded that image fusion outperformed, or was at least comparable to, sequences generated by other commercial software in detecting locally recurrence of pelvic malignancy.

In spine surgery, VR, MPR and virtual endoscope modes were particularly useful in providing valuable 3D reconstructed images.[8,9] VR mode gives a precise view of the entire severely deformed spine, which helps with the surgical approach. In MPR mode, surgeons can easily capture any slice they want and can acquire the trajectory of the pedicle screw preoperatively. These functions are available on OsiriX and the software is continually being updated and developed.

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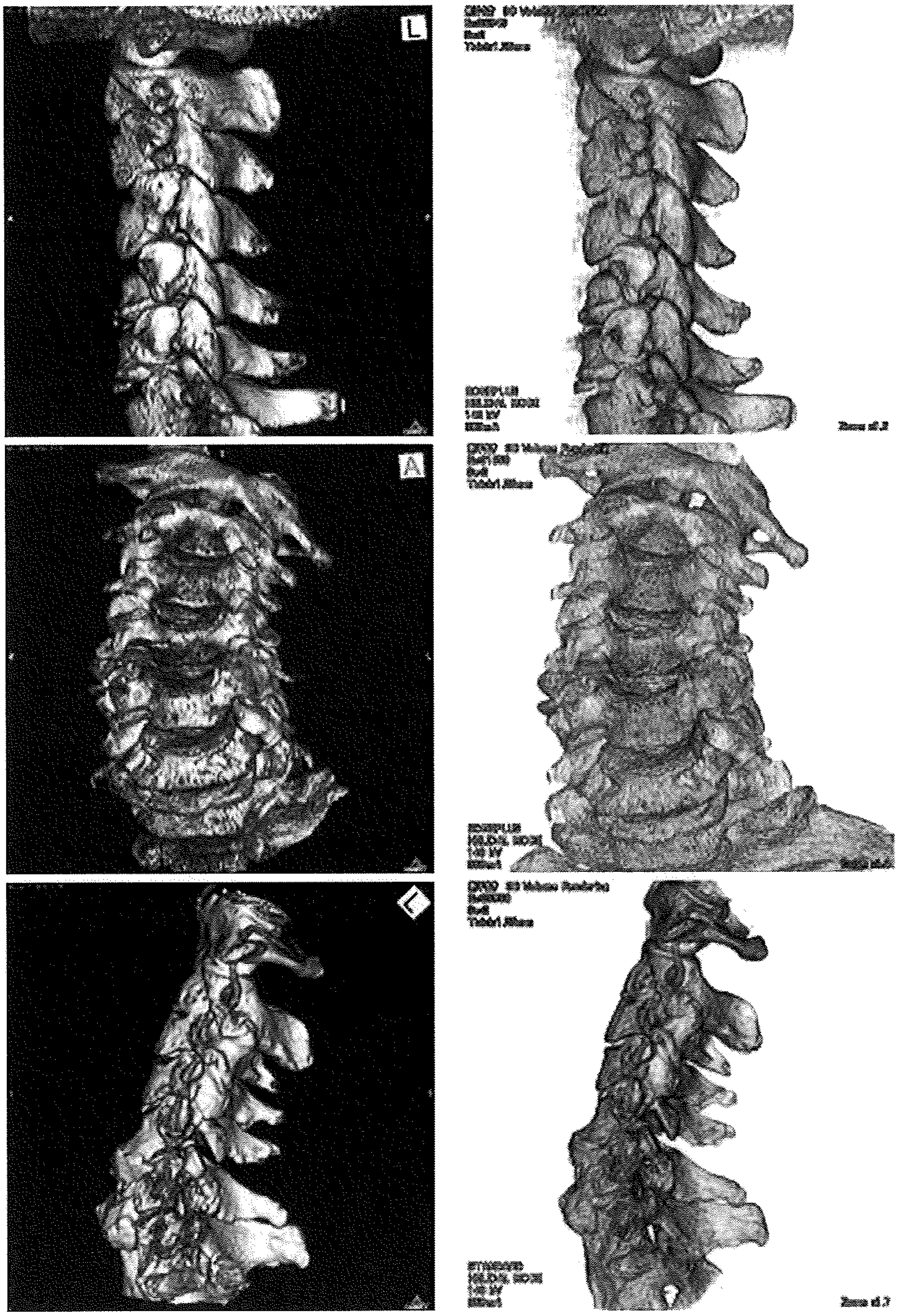

Fig. 1. Comparison of three-dimensional volume-rendered images by OsiriX (left) and Virtual Place software (right) showing the reproducibility of the data between the software packages. The upper and middle panels show the left lateral (L) and anterior (A) views of cervical spine from C1 to C7. The lower panels show the left lateral (L) view of CT angiography of the cervical spine. See Section 2.1 for software details. (This figure is available in color at www.sciencedirect.com.)

The current study was performed to evaluate the efficacy and reliability of the software and the results showed that it was comparable to commercially available software. However, the MPR mode of OsiriX could not manipulate the 3D MPR so that all three planes could be freely moved and inclined. Thus, it was difficult to extract exactly the same plane with OsiriX as with the commercial software, Virtual Place, where the planes were easily manipulated in all three planes. Increased contortion of the cervical spine and anatomical variation might have contributed to the difficulty in extracting good images with OsiriX.

In conclusion, in modern highly complex spine surgery, 3D reconstructed images attained preoperatively have an important role. Accordingly, OsiriX, which is free and easy-to-use DICOM software, could be a helpful tool. Although it has not been certified as commercial medical software, OsiriX provides any individual surgeon a means to analyze the surgical procedure preoperatively. We conclude that OsiriX should be considered an important tool for preoperative planning in spine surgery.

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(Department of Orthopaedic Surgery, Chiba University Graduate School of Medicine) for his kind support in the present analysis.

Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.jocn.2009.09.037.

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ORIGINAL PAPER

Autogenous iliac crest bone graft versus banked allograft bone in scoliosis surgery in patients with Duchenne muscular dystrophy

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Abstract A total of 36 consecutive nonambulatory DMD patients underwent scoliosis surgery. Patients were divided into two groups: the autogenous iliac crest bone graft group (the ICBG group; 20 patients) and the allogenous bone graft group (the ALBG group; 16 patients). The mean preoperative curves measured 87° and 31° at the last follow-up in the ICBG group and 83° and 28° in the ALBG group. In the ICBG group, three (15%) patients had intraoperative sacroiliac joint penetration, five (25%) had iliac crest inner cortex penetration and three (15%) had postoperative prolonged wound drainage at the donor site. At three months after surgery, donor site pain caused by bone harvest was found in 50% with severe pain limiting their physical function and causing difficulties in sitting in a wheelchair in 40% of the patients, whereas patients in the ALBG group returned to their preoperative level of function soon after surgery.

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Introduction

Posterior spinal fusion in nonambulatory Duchenne muscular dystrophy (DMD) patients has been accepted as the optimal procedure to prevent progression of scoliosis and maintain upright and comfortable sitting [1, 4, 17, 20, 22].

Harvesting autogenous or allogenous bone graft to increase the fusion rate using segmental instrumentation for scoliosis has been a standard procedure. Advantages of autogenous bone graft over allogenous bone graft have been well established. The posterior iliac crest is the most common donor site for autogenous bone graft for spinal fusion. However, donor site morbidity caused by bone harvest remains a concern. Furthermore, this procedure is accompanied by many complications because of longer operative time and greater blood loss [18, 24]. Several studies have reported minor and major complications, with a wide range of incidences varying between 1% and 39% [2, 8, 18, 20, 25].

The aim of this study was to compare the outcome and complication rates of scoliosis surgery in nonambulatory patients with DMD using either autogenous posterior iliac crest bone graft (ICBG) or allogenous bone graft (ALBG).

Materials and methods

From March 2003 to October 2006, a total of 36 consecutive DMD patients underwent posterior spinal fusion and instrumentation (thoracic hooks and lumbar screws) for scoliosis. The patients were prospectively collected and followed. The minimum follow-up period was two years. Patients were divided into two groups: the iliac crest bone graft group (the ICBG group; 20 patients in whom posterior iliac crest bone graft was used) and the allogenous bone graft group (the ALBG group; 16 patients in whom banked allograft bone was used).

Surgical technique

All the patients had standard posterior spinal fusion performed by the same surgeon (M.T.). The posterior elements of the spine were exposed from the upper thoracic spine to the sacrum by stripping the muscles subperiosteally. Spinal cord function was monitored throughout the procedure. Autotransfusion via preoperative storage and intraoperative collection was used. Distal fixation comprised 6-mm pedicle screws in the lumbar spine. Apical and proximal fixation comprised hooks in the thoracic spine. The rods were contoured to recreate the sagittal profile and coronal balance was achieved by sequential reduction of the segments toward the rods. In the ALBG group, allograft bone obtained from Kitasato University Bone Bank (KUBB) was used. The bone was again cleaned of all the attached soft tissue, and the bone mill morselised the grafts and further separated the soft tissue from the bone (Fig. 1). Alternatively, in the ICBG group, a conventional approach to the iliac crest was used to obtain autogenous bone grafts. Grafts were harvested from both iliac crests. The posterior elements were decorticated and bone grafts were placed on the decorticated bed along the length of the instrumentation from T3 or T4 to L5.

Clinical and radiological assessments

Assessment was performed clinically and with radiological measurements. All of the patients were reviewed clinically and questioned about whether they felt back pain at one week and at a three-month interval for 24 months after surgery. Intraoperative complications, along with postoperative complications, were recorded.

The patients in the ICBG group were specifically questioned about whether they had local pain at the donor site at one week and at a three-month interval for 24 months after surgery.

The questions consisted of the following:

1. Do you have pain in the back hip area where the iliac crest bone graft was harvested? If yes, rate your pain on a scale of 1 to 10.
2. Do you have any problems with daily activities (difficulties in sitting in a wheelchair) due to the pain?

Sitting anteroposterior and lateral radiographs were taken and evaluated the day before surgery, at one week, three and 24 months after surgery and at the last follow-up. The deformity in the coronal plane was measured by the Cobb angle method. Clinical evaluation was made by the senior author.

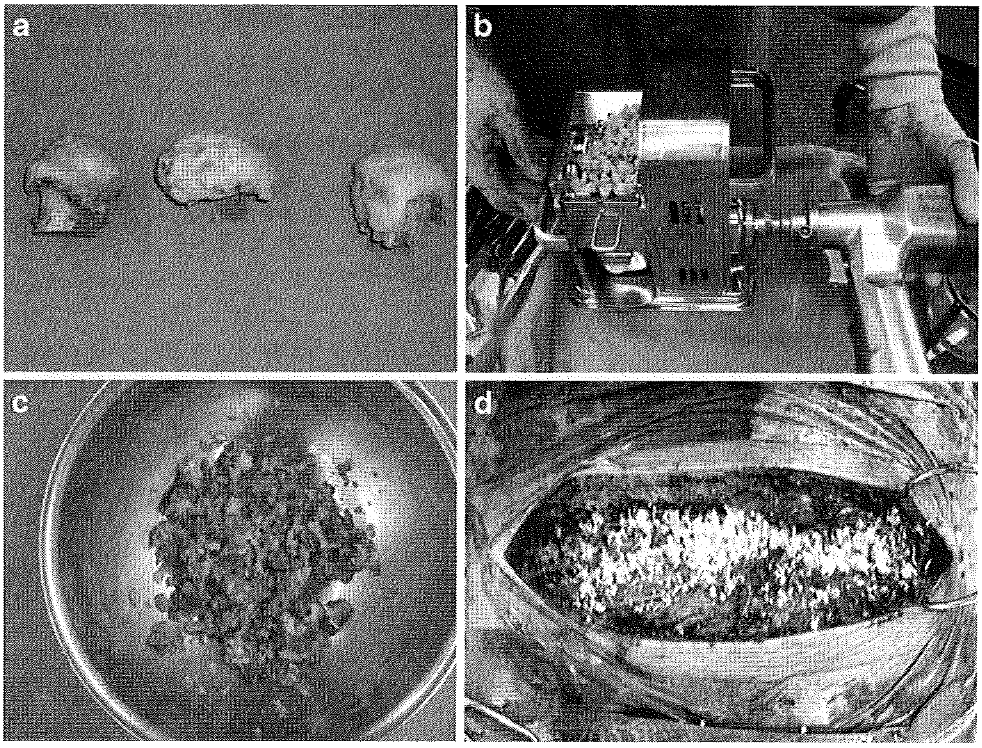

Fig. 1 **a** Banked allograft bone obtained from Kitasato University Bone Bank. **b** Banked allograft bone placed into the bone mill. The bone mill morselises the bone graft. **c** A large quantity of milled bone graft is obtained. **d** Adequate quantity of bone grafts for the fusion were placed on the decorticated posterior elements of the spine

Fusion was defined as: first, stable coronal and sagittal alignment over the follow-up period; second, no clinical complaints; third, no evidence of nonunion radiographically; fourth, stable hardware. All four criteria must be present for definition of fusion in this study. CT scans were not available in every patient in this study, and therefore not used for assessment of fusion.

Results

A total of 36 patients (20 in the ICBG group and 16 in the ALBG group) were enrolled in the study. No patients were lost to follow-up. The mean follow-up period was 4.3 years (range, 2.5–6.1 years). Demographic details and surgical parameters are shown in Tables 1 and 2.

There were no significant differences in age, the preoperative and postoperative Cobb angles, or the number of levels fused between the two groups. The operative time and intraoperative blood loss were higher in the ICBG group than in the ALBG group (253 min. versus 233 min.; 850 ml vs. 775 ml).

The ICBG group

There were three (15%) instances of sacroiliac joint penetration and five (25%) instances of iliac crest inner cortex penetration possibly due to a poor pelvis. Prolonged wound drainage at the donor site was observed in three (15%) patients, and treated only with observation resolving in two weeks. There were no neurological complications or infections. There was no instrumentation failure during the follow-up period. Paralytic ileus occurred in four (20%)

Table 1 Details of the patients and operative parameters in the ICBG group

Patient number	Age (y)	Scoliotic curvature (°)					Operative time (min)	Intraoperative blood (ml)	Donor site pain (>3months) and other donor site complications or morbidity
		The day before surgery	Immediately after operation	Three months after surgery	Two years after surgery	Last follow-up			
1	11	100	38	40	40	42	249	889	-
2	13	60	20	20	22	23	230	860	Pain for 9 months; sacroiliac joint penetration
3	13	52	18	19	19	20	205	920	Pain for 3 months; prolonged wound drainage
4	13	55	13	12	13	15	250	866	-
5	12	93	35	36	37	36	267	867	-
6	12	91	32	33	33	33	271	921	-
7	14	81	27	27	28	30	264	964	-
8	13	93	20	20	22	22	268	868	-
9	14	130	38	40	44	43	327	933	-
10	11	100	38	37	37	37	268	968	Pain for 3 months
11	17	101	40	40	42	44	256	856	Pain for 9 months; sacroiliac joint penetration
12	11	81	32	30	32	32	267	767	-
13	13	98	35	35	35	37	266	866	-
14	13	128	28	28	32	32	277	820	Pain for 3 months; prolonged wound drainage
15	13	100	35	36	36	38	301	944	Pain for 6 months; sacroiliac joint penetration
16	12	85	30	32	32	33	266	806	-
17	11	95	35	35	37	37	270	960	Pain for 6 months; sacroiliac joint penetration
18	12	90	18	20	20	22	276	860	Pain for 6 months; sacroiliac joint penetration
19	13	50	23	22	22	24	260	860	Pain for 3 months
20	13	60	20	22	22	23	255	978	Pain for 6 months; sacroiliac joint penetration
Mean	13	87	29	29	30	31	253	850	

ICBG iliac crest bone graft

Table 2 Details of the patients and operative parameters in the ALBG group

Patient number	Age (y)	Scoliotic curvature (°)					Operative time (min)	Intraoperative blood loss (ml)
		The day before surgery	Immediately after operation	Three months after surgery	Two months after surgery	Last follow-up		
1	12	60	26	26	27	28	192	580
2	14	62	23	22	22	24	205	460
3	16	62	15	15	16	16	240	800
4	19	64	27	25	25	27	280	970
5	13	66	25	27	27	27	210	450
6	12	78	20	20	20	22	295	660
7	15	85	30	30	34	34	235	1150
8	13	96	20	20	22	24	280	670
9	13	130	38	40	41	42	225	733
10	13	82	19	19	20	20	228	777
11	13	65	9	12	12	12	165	1010
12	13	101	40	40	42	44	235	656
13	20	60	15	15	19	19	215	900
14	13	82	25	25	27	27	255	850
15	12	110	38	38	40	41	230	865
16	14	120	30	30	34	34	236	875
Mean	13	83	25	25	27	28	233	775

ALBG allogenous bone graft

patients, and cleared after 48 hours following observation without oral intake. There were no secondary operations for any reason, nor any second hospital admissions related to surgery.

At one week after surgery, all of the patients reported back pain in the region of the instrumentation surgery. At three months after surgery, 30% (6/20) reported back pain. At six months, 5% (1/20) reported back pain and at nine months 5% (1/20) reported back pain. At 12 months after surgery, none of the patients reported back pain. Therefore, no clinical complaints in the region of the instrumentation surgery were noted at one year after surgery.

Ninety percent (18/20) of the patients reported donor site pain at one week after surgery. The self-reported pain values ranged from 4 to 7 with a mean of 6. All of the patients with documented pain reported that they had problems with daily activities (difficulties in sitting in a wheelchair) due to pain. At three months after surgery, 50% (10/20) of the patients reported continued pain at the donor site and 40% (8/20) reported problems with daily activities. The self-reported pain values ranged from 1 to 7 with a mean of 5. At six months after surgery, 40% (8/20) of the patients reported continued pain at the donor site and 30% (6/20) reported problems with daily activities. The self-reported pain values ranged from 1 to 7 with a mean of 5. At nine months after surgery, 15% (3/20) of the patients reported continued pain at the donor site and 5% (1/20) reported problems with daily activities. The self-reported pain values were from 1 to 3 with a mean of 2. At 12 months after surgery, none of the patients reported continued pain and problems with daily activities.

The mean preoperative deformity in the coronal plane was 87°. The mean postoperative deformity was 29° at three months after surgery, 30° at 24 months and 31° at the last follow-up. There was a significant difference in the preoperative and postoperative Cobb angles. We noticed less than 4° in the loss of correction at the last follow-up.

The ALBG group

There were no neurological complications or infections. There was no instrumentation failure during the follow-up period. Paralytic ileus occurred in 19% (3/16) of the patients, which was treated by observation without oral intake and cleared in 48 hours. Transient tachycardia, possibly due to the underlying cardiomyopathy, occurred in 19% (3/16) of the patients, and resolved with adequate medication. There have been no further operations for any reason, nor any second hospital admissions related to surgery.

At one week after surgery, all the patients reported back pain in the region of the surgery. At three months after surgery, 31% (5/16) reported back pain. At six months, 13% (2/16) reported back pain, and at nine months none of the patients reported back pain. Therefore, no clinical complaints in the region of the instrumentation surgery were noted at nine months after surgery. None reported pain in the pelvis over the follow-up period. All the patients sat in their wheelchairs by the third postoperative day and returned to their preoperative level of function by the seventh postoperative day.

The mean preoperative deformity in the coronal plane was 83°. The mean postoperative deformity was 25° at three months after surgery, 27° at 24 months and 28° at the last follow-up. There was a significant difference in the preoperative and postoperative Cobb angles. No significant loss of correction was noted between postoperative time and the last follow-up.

Figure 2 shows a radiographic example in the ALBG group.

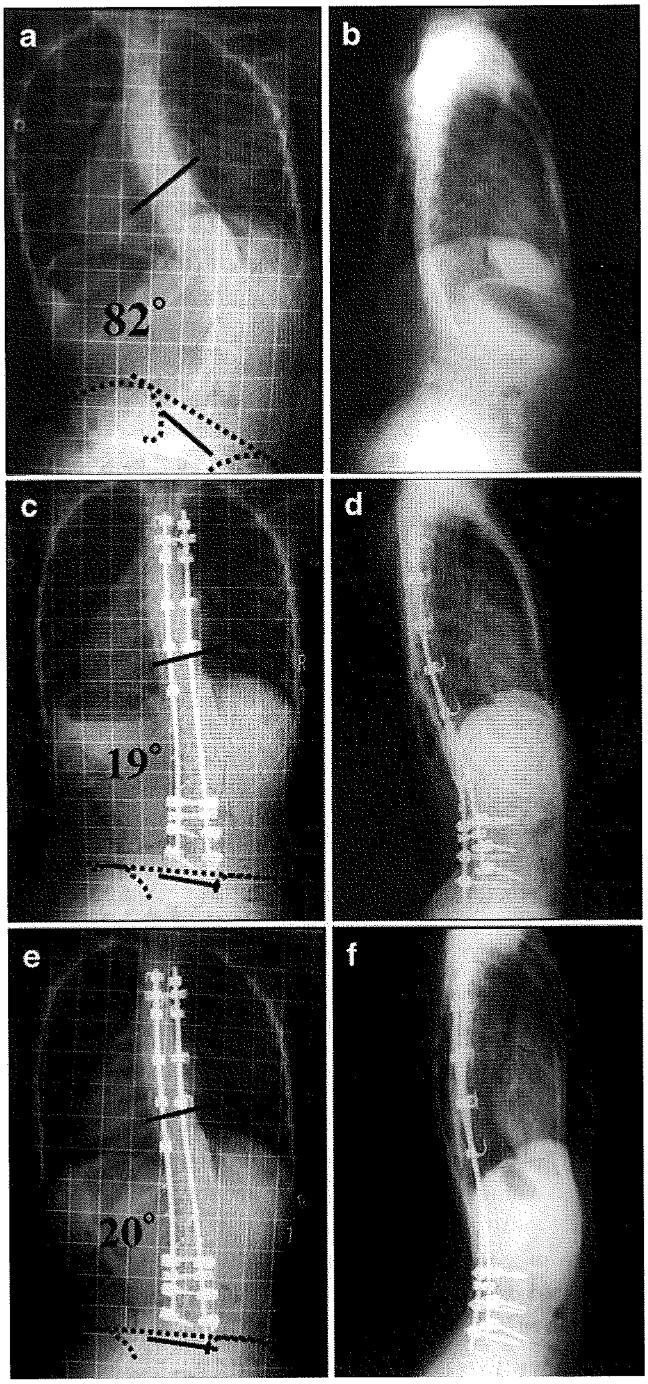

Fig. 2 **a** and **b** Radiograph of a 13-year-old boy. Sitting anteroposterior preoperative radiograph demonstrates a significant thoracolumbar curve of 80° from T9 to L5. **c** and **d** At the time of surgery, banked allograft bone was used. Postoperative radiograph at 1 week after surgery is demonstrated. The postoperative deformity measures 19°. **e** and **f** Radiograph at a long-term follow-up of 3.2 years after surgery demonstrates the absence of loss of correction and instrumentation failure, which indicates the probability of the absence of pseudarthrosis

Discussion

Scoliosis is almost universal in DMD patients. Natural history studies on DMD demonstrated an almost invariable progression in the scoliosis with progression of the underlying disease [1, 4, 14, 20, 22]. Posterior spinal fusion for scoliosis in DMD has been widely accepted as the optimal procedure to prevent progression of scoliosis and maintain sitting balance and comfort [1, 4, 14, 20, 22].

The posterior iliac crest is the most common donor site for autogenous bone graft for posterior spinal fusion. However, donor site morbidity caused by bone harvest, which can interfere with daily activity of wheelchair-dependent patients, has remained a concern.

The advantages of autogenous bone graft over allograft have been well recognised. Large quantities and good quality of corticocancellous bone graft may be obtained from the iliac crest. However, harvesting ICBG involves an additional surgical procedure, blood loss, postoperative morbidity and complications. The complications of harvesting ICBG have been also well recognised [12]. The complication rate reported in the literature varies widely, ranging from 1% to 25 % for major complications and 9.4% to 39% for minor complications [2, 8, 18, 21]. Major complications included large haematoma, wound infection, reoperation, unsightly scar, severe pain interfering with daily activity, and chronic pain limiting physical function [2, 18, 25]. Minor complications included dysaesthesia, prolonged wound drainage, and superficial infection [2, 18, 25]. Robertson et al. [16] reported on donor site morbidity, significant pain, tenderness, and local sensory loss, which were worst at six months after surgery and improved by one year. Although the major complication rate in most of the reports is relatively small, the minor complication rate is significant.

Donor site pain after harvesting from iliac crest is common. Lehmann et al. [13] reported this complication in 55% of the adult patients. Skaggs et al. [19] found this complication to be 24% in children. They reported pain severe enough to interfere with daily activity was noted in 15% in children at a more than four-year follow-up. In our series, at three months after surgery, 50% (10/20) of the patients reported continued pain at the donor site, and 40% (8/20) reported problems with daily activities and difficulties in sitting in a wheelchair due to the pain in the back hip area even though the pain improved gradually by one year.

Indeed, in adolescent idiopathic scoliosis surgery, a large quantity and good quality of corticocancellous bone may be obtained from the iliac crest. However, in our experience, the pelvis in this group of patients with DMD who cannot walk is often small. We felt the amount of bone obtained from the iliac crest, even if bone grafts were harvested from both iliac crests, were inadequate for long posterior spinal fusion in DMD scoliosis. Also, a high rate of intraoperative sacroiliac joint and iliac crest inner cortex penetration was observed. These complications may have led to continued postoperative donor site pain and prolonged wound drainage.

To resolve the problems, we began to use banked allograft bone for posterior spinal fusion in DMD scoliosis. We have routinely used banked allograft bone obtained from the Kitasato University Bone Bank (KUBB). Banked allograft bone has both osteoinductive and osteoconductive activities, although less active than those of autografts [10, 11, 24]. In a study of 87 consecutive patients who underwent idiopathic scoliosis surgery, Grogan et al. [9] showed the ability of allograft bone to produce reliable results compared with autograft bone. Fabry [7] concluded that there was no significant difference in the clinical and radiographic results (loss of correction, fusion rate, complication) between the two groups of scoliosis patients operated using either autograft (iliac crest) or allograft (femoral heads) and recommended the use of allograft bone to prevent problems of discomfort at the donor site scar. Dadd et al. [6] concluded that even in the presence of adequate iliac crest, the use of bank bone is superior for grafting in adolescent idiopathic scoliosis surgery. Thus, allograft bone seems to give good results [3]; however, banked allograft bone is not always available in many countries for spine surgery. Potential risks of bacterial contamination and viral transmission have also been suggested, although such a risk is very small [5, 15, 23].

In Japan, there are two kinds of bone banks—regional bone banks and institutional bone banks. A regional bone bank retrieves, processes and preserves bone and supplies bones to other institutions. Our bone bank (KUBB) is one of the regional bone banks, of which there are two such institutions in Japan. Therefore, banked allograft bone is always available for spine surgery at any time in Japan.

To the best of our knowledge, there have been no previous articles in the literature comparing autogenous ICBG and banked allograft bone in instrumented posterior spinal fusion in DMD scoliosis. This study shows a comparable overall radiological fusion rate and clinical outcome using either autogenous ICBG or banked allograft bone but with reduced morbidity, complications, operative time and blood loss in the ALBG group. Curve correction and maintenance of correction were excellent in the both groups, with minimal loss of correction. There was no pseudarthrosis, infection or instrumentation failure in either group. However, intra/postoperative morbidity or complications that could be attributed to the donor site were observed in the ICBG group. Scoliosis surgery in non-ambulatory DMD patients should be aimed at maximising function and improving QOL. However, donor site pain in the ICBG group was severe enough to interfere with daily activity and caused difficulties in sitting for nonambulatory DMD patients, although the incidence of pain decreased with time. With the results of this study, we do not recommend the use of autogenous ICBG for posterior spinal fusion in nonambulatory DMD patients.

Study limitation

There are some limitations to this study. The number of cases in both groups was relatively small. Radiological assessment of fusion was never perfect. Determination of fusion has been a difficult issue, with no methods having been shown as reliable. In this study, a definition that combined radiological minimal loss of correction and no clinical complaints was selected. However, the lack of progression of spinal deformity and the absence of instrumentation failure during a minimum two-year follow-up period indicate the probability of the absence of pseudarthrosis.

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