Atlantoaxial Screw Fixation (Magerl's technique)

D. Grob
Schulthess Clinic. Spine Center. Zürich. Switzerland.

The goal pursued by atlantoaxial arthrodesis is the elimination of any motion of the atlas and axis bones with respect to each other. The screw fixation procedure described by Magerl leads to higher stability rates than conventional posterior arthrodesis techniques. The greater stability afforded by C1/C2 screws makes it possible to perform short fusions, e.g. between the occipital bone and C2, whereas with other techniques fixation must be extended up to C4/5 in order to obtain a satisfactory lever arm.

In this study, we used transarticular screw fixation in order to stabilize a series of 54 patients suffering from rheumatoid arthritis, who presented with atlantoaxial instability. They were studied retrospectively with a mean follow-up of 6 years (range: 2-13 years). The pain score on examination, as assessed by means of the Visual Analog Scale (0-10), was 2, as compared with a preoperative score of 6. Seventy-nine percent of patients stated that they would subject themselves to the same surgical procedure if they found themselves in the same situation; 16% were not sure as to whether they would or would not and 5% said that they would not. Seventy-eight percent of patients declared themselves highly satisfied with the result obtained; 18% found the result satisfactory and 3% declared themselves dissatisfied with the result obtained.

Atlantoaxial arthrodesis is indicated in the event of instability. Clinically, instability can manifest itself as persistent pain or as myelopathy, resulting from repetitive microtrauma to the spinal cord. Conventional fusion techniques, based on the use of wires, are simple to perform but lead to considerable rates of pseudoarthrosis, particularly in patients with rheumatoid arthritis. Transarticular atlantoaxial screw fixation provides higher rates of stability and reduces the rate of pseudoarthrosis. Placement of the screws requires a detailed anatomical study, especially of the C2 pars interarticularis, through CT- or NMRi-scans. The surgical technique is rather challenging, but leads to a low rate of complications.

Corresponding author:
D. Grob.
Schulthess Clinic.
Spine Center.
Lengghalde 2.
CH-8008 Zürich, Switzerland.
E-mail: dieter.grob@kws.ch

Received: September 2007
Accepted: October 2007

Key words: *cervical spine fusion, C1/C2 fusion, rheumatoid arthritis, cervical spine.*

Atornillado transarticular C1/2 (técnica de Magerl)

El objetivo de la artrodesis entre el atlas y el axis es eliminar el movimiento relativo entre ambos. El atornillado descrito por Magerl muestra una estabilidad superior a las técnicas de artrodesis posterior convencionales. El aumento de la estabilidad proporcionado por los tornillos C1/C2 nos permite efectuar fusiones cortas, por ejemplo entre el occipital y C2, mientras que con otras técnicas es necesario prolongar la fijación hasta C4/5 para conseguir un brazo de palanca suficiente.

Hemos estabilizado mediante un atornillado transarticular una serie de 54 pacientes con artritis reumatoide, que presentaban una inestabilidad entre el atlas y el axis. Fueron estudiados de forma retrospectiva, con un seguimiento medio de 6 (2-13) años. El dolor en el momento de la revisión, valorado mediante la escala visual analógica (0-10) fue de 2, en comparación con un valor de 6 en el preoperatorio. El 79% de los pacientes respondió que volvería a repetir el procedimiento quirúrgico si se encontrase en la misma situación, el 16% no se mostró seguro en la respuesta a esta pregunta y el 5% respondió negativamente. El 78% de los pacientes se declaró muy satisfecho con el resultado obtenido; el 18% indicó que el resultado era satisfactorio y el 3% no se mostró contento con el resultado obtenido.

La artrodesis entre el atlas y el axis está indicada cuando existe una inestabilidad. Clínicamente, la inestabilidad puede manifestarse como un dolor persistente o como una mielopatía, consecuencia de un microtraumatismo repetitivo sobre la médula. Las técnicas de fusión convencionales, mediante alambres, son sencillas de efectuar pero comportan una considerable tasa de pseudoartrosis, en particular en condiciones desfavorables, como ocurre en la artritis reumatoide. El atornillado transarticular entre el atlas y el axis proporciona una estabilidad superior y disminuye la tasa de pseudoartrosis. La colocación de los tornillos requiere de un minucioso estudio anatómico, en particular de los istmos de C2, mediante cortes de tomografía axial computarizada o resonancia magnética nuclear. La técnica quirúrgica es delicada, pero presenta una baja tasa de complicaciones.

Palabras clave: *fusión columna cervical, fusión C1/2, artritis reumática columna cervical.*

BIOMECHANICAL ASPECTS OF ATLANTOAXIAL SCREW FIXATION

The purpose of an arthrodesis between the atlas and the axis is to eliminate the relative motion between both. The main physiological movement in this segment is axial rotation; the existence of alterations like fractures, ligament lesions or odontoid process pseudoarthrosis could cause instability on the transverse plane. Since the structure of the vertebrae is not ideal to provide intrinsic stability, except for the case of a posterior atlas dislocation with an intact odontoid process, any implant must provide multidirectional stability. As several lab studies have shown, the type of screw fixation described by Magerl shows a degree of stability equal or even higher than conventional posterior arthrodesis techniques[1-3]. The immediate stability conferred by the C1/C2 screws obviates the risk of loosening that has been observed with posterior wire or cable fixation[1], and enhances graft incorporation (fig. 1).

In cases where occipitocervical fixation is performed, transarticular atlas-axis screws constitute a significant contribution to the stability of the instrumentation since they get rid of atlantoaxial rotation. Furthermore, screws permit a genuine integration of the atlas to the construct, since they firmly fiaxate both lateral masses. The success of conventional posterior techniques, whereby the posterior arch of the atlas is fixated by means of wires, depend on the quality and integrity of the said arch. The increased stability afforded by the C1/C2 screws makes it possible to carry out short arthrodeses, e.g. between the occiput and C2, whereas other techniques make it necessary to extend fixation to C4/5 to achieve an efficient lever arm.

INDICATIONS

Degenerative pathology

A usual indication for segmental fixation with transarticular screws is pain caused by osteoarthritis in the atlas-axis joint[4,5]. In cases where it is necessary to include the atlanto-occipital joint in the fixation, screw fixation can be integrated with the occipital instrumentation[6].

Rheumatoid arthritis

The instability caused by the destruction of the C1/C2 osteoligamentous complex leads to multidirectional instability, which may be stabilized by means to transarticular screw fixation. Use of a halo and intraoperative manipulation allow for fixation to occur in an anatomically reduced position (fig. 2). Atlantoaxial arthrodesis at an early stage of the disease prevents neurological damage and progression of the cranial migration of the odontoid process in the foramen magnum[6,7]. For secure screw insertion, a preoperative assessment of potential anatomic alterations is mandatory.

Traumatic pathology

Atlas ring fractures can be stabilized by means of C1/C2 transarticular screws. If there is a lateral dislocation, a halo traction or an intraoperative manipulatgion will be necessary before screw placement. The presence of an unstable fracture of the posterior atlas ring will require the reconstruction of the latter[8] or the use of an intraarticular autologous graft[9]. Atlantoaxial fixation can stabilize fractures of the odontoid process that cannot be fixed by means of a screw or by an anterior approach. The same applies to odontoid process pseudoarthroses with instability between C1 and C2[10].

Figure 1. *(A) Tridimensional computerized axial tomography-aided reconstruction in a 76-year-old patient with suboccipital pain caused by advanced osteoarthritis of the left atlantoaxial joint. (B) and (C) Anteroposterior and lateral x-rays showing ideal screw placement and good incorporation of the posterior graft between C1 and C2.*

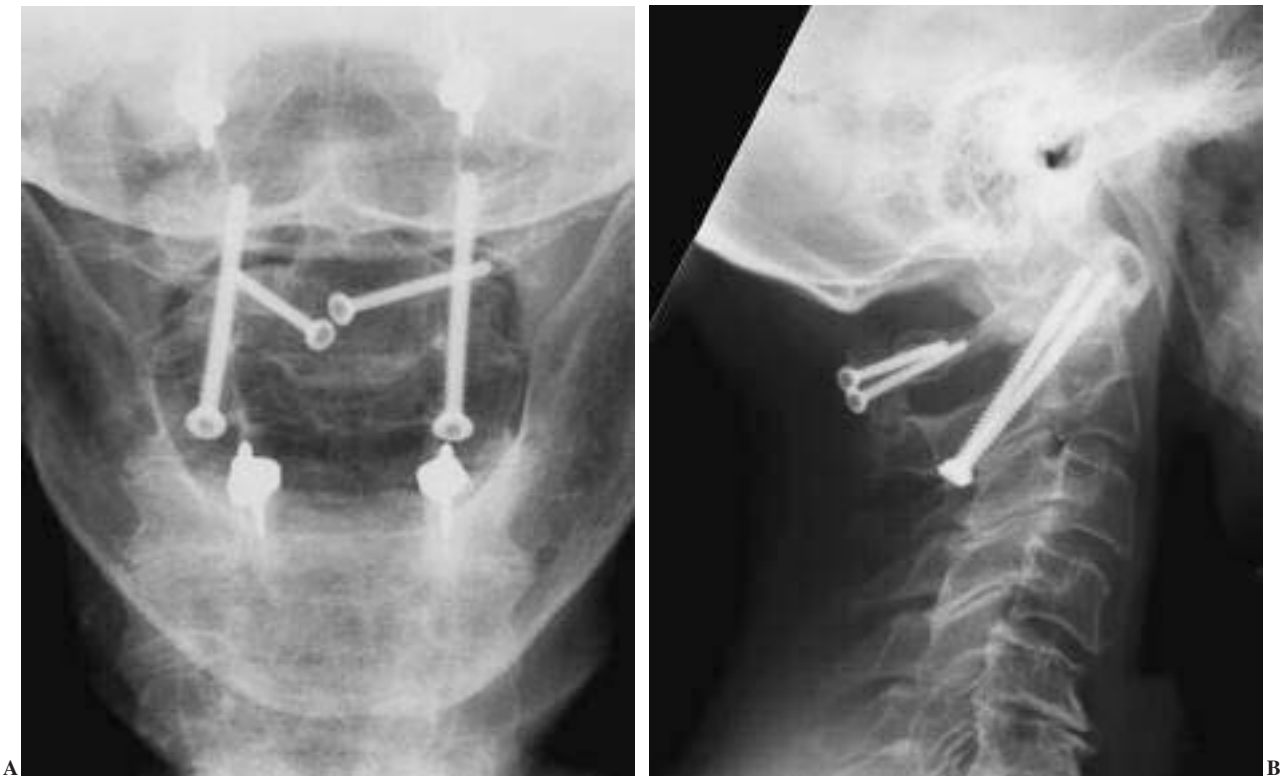

Figure 2. *(A) and (B) Anteroposterior and lateral post-op x-rays of a patient presenting with C1/C2 instability caused by rheumatoid arthritis. Owing to the presence of spina bifida in the atlas, the graft placed in the midline was used in the same procedure to reconstruct and fuse the arch of the atlas.*

Congenital alterations

Occipitocervical or *os odontoideum* disruptions can also be stabilized by means of posterior fusion with the transarticular screw fixation technique between the atlas and the axis. It is mandatory to exclude vascular anomalies preoperatively.

Infections/tumors

Instabilities due to insufficient bone stock caused by tumor sor infections require an appropriate reconstruction, which could be combined with transarticular screw fixation. Bone resections in the presence of metastasis could lead to instability at the occipitocervical junction. Transarticular screw fixation constitutes a reinforcement to the stability of the occipitocervical fixation.

Pediatric indications

Recurrent rotational subluxations between atlas and axis in children could require reduction and stabilization[11]. The use of appropriately sized screws following an anatomical study of the C2 isthmi, will permit the application of the technique to pediatric patients[12].

SURGICAL TECHNIQUE

To guarantee a safe introduction, the anatomy and dimensions of the C2 pedicles must be verified preoperatively by means of a computerized axial tomography (CAT) or nuclear magnetic resonance (NMR) with two-plane reconstructions in sagittal slices.

As regards anesthesia and monitoring of patients with atlantoaxial instability, anesthesia must be administered by means of fiberoptic intubation. This technique avoids extending the head and the risk of neurological alterations caused by a dislocation during the anesthetic procedure. The use of perioperative neurological monitoring will detect possible intra-operative injuries to the spinal cord. During surgery, the anesthetist and the monitoring equipment will be placed at the feet of the patient.

Patient positioning

Patient positioning is crucial for correct screw introduction. The arms must be placed alongside the thorax. The posterior iliac crest will be made sterile for graft harvesting. Placing the subaxial cervical spine in a straight position and flexion at the junction between the occiput and the atlas will make it possible for the hand bearing the drill to descend far enough into the cervicothoracic region in order to obtain an

appropriate drilling orientation. This position can be easily achieved by means of a cranial traction that permits rotation around a transverse axis in the suboccipital region.

Surgical approach

A posterior incision in the midline from the occiput to the middle cervical region (approximately 10-12 cm) will be made to divide the nuchal ligament longitudinally, taking care to remain at the midline in order to minimize hemorrhage.

The prominence of the C2 spinous process will serve as a reference point when performing the incision. The muscular attachments shall be preserved by mobilizing them to both sides, with a bone fragment of the bifid spinous processes, which will have been cut off with the oscillating saw[13]. These attachments can be reattached to the spinous process at the end of the procedure.

The C2 laminae will be dissected subperiostically. The landmarks to be considered and controlled are the C2/C3 joint and the medial border of the C2 isthmus. This region, where the vertebral canal reaches its greatest width, can be identified by subperiostically following the internal curved contour of the lamina and the pedicle, detaching the atlantoaxial membrane as much as possible laterally. If the use of an intraarticular graft has been planned, subperiostic dissection should proceed until the anterior region of the isthmus surface until the capsule attachment point is reached. Opening the capsule will make the joint visible.

Screw placement

In order to facilitate screw insertion, te technique of CT-guided navigation[14,15] and other instruments[16] have been developed recently. In the future, when their usefulness and accuracy have been demonstrated, these techniques will help the surgeon place the screws accurately and safely, but currently the standard technique is mainly base don the surgeon's anatomical knowledge and on the aid provided by intraoperative x-ray images, obtained with the image intensifier.

Screw placement should be carried out by means of continuous control on both planes. On the frontal plane, the position of the screw, i.e. more medial or more lateral, must be controlled directly in the surgical field. The most important landmark is the medial border of the C2 isthmus. The drill should run between 2 and 4 mm laterally to this curved border, which represents the lateral boundary of the spinal canal. The drill should be orientated strictly on the sagittal plane so that the bit is always inside the bone, between the vertebral artery laterally and the spinal canal medially, and should not advance past the lateral mass of the atlas frontally. The entry point of the bit is 2-3 mm cranial to the lower margin of the C2 lamina, sparing the cortical lamellar bone (fig. 3). On the lateral plane, the position of the screw on the sagittal plane must be controlled on the image intensifier. The image on the screen should show a clear profile of the atlas and the axis. If there was rotation between C1 and C2 it would not be possible to observe the profile of both bones simultaneously, and it would be impossible to fixate them. On the screen, the drill should be seen to start at the entrance to the C2 lamina, run through the atlas-axis joint in its posterior third and reach the upper half of the lateral portion of the anterior atlas ring, which should appear oval-shaped on the screen (fig. 1). To achieve an ideal position of the drill it may be necessary to introduce it percutaneously and place the screws by means of an extra-large bit and driver.

The landmarks above define the position of the screw. Moreover, it is advisable to insert the drill slowly, advancing one or 2 millimeters and then going back, in order to subsequently check, with the tip of the bit, that we are indeed inside the bone, i.e. we should feel the resistance of the bone *(*tap drilling technique*)*. If there is no bone resistance at the tip of the bit, drilling must be stopped to avoid a potential injury to the vertebral artery. When in presence of osteoporotic bone, as is the case of patients with rheumatoid arthritis, application of this technique could be difficult.

Bone grafting

Bone grafting should not be omitted. From the mechanical point of view, this step of the technique is essential to deliver a stable construct based on three supporting points.

The graft application technique follows the classical principles laid down by Gallie[17]. After harvesting a mono- or bicortical posterior iliac crest graft the graft bed is carefully prepared. Extra care must be taken when decorticating the posterior arch of the atlas, since this area contains only a minimal amount of cancellous bone that can provide a viable bed for the graft (cases of non-union tend to occur at this level, in the cranial-most portion of the graft, where a lack of ossification is observed). The cortical bone of the C2 spinous process is refreshed and the graft fixated between the arch of the atlas and this process with wires or a non-resorbable suture.

Postoperative care

If the transarticular screw fixation technique was correctly performed and if bone grafting was used, prolonged postoperative immobilization will not be necessary. A simple soft neck brace to accommodate the standing position will be enough. The degree of stability achieved with this kind of fixation, together with the comfort it provides postoperatively, have been greatly appreciated both by disabled patients and by those with rheumatoid arthritis.

Figure 3. *(A) 26-year-old patient who presented with nonunion of the odontoid process further to a type II fracture treated with a halo-vest for 12 months. (B) X-ray view at 12 months following C1C/2 fusion.*

DIFFICULTIES AND POSSIBLE ERRORS

Alteration of the anatomy of C2

A preoperative CT-scan will reveal details of the patient's anatomy that are essential for secure screw placement. A reconstruction of the C2 isthmus on the sagittal plane will allow us to calculate the right screw size needed (normally 3.5 mm cortical screws). Rheumatic patients tend to experience bone erosion. Placement of a transarticular screw must not be attempted unless it has been demonstrated that the bone stock on at least one of the sides is sufficient. It has been shown that placing a single screw on one of the sides could deliver a satisfactory healing rate[18], but rigid immobilization is required for 2 months.

Assymmetry of the vertebral artery

In our daily practice we do not routinely carry out an angiographic exploration of the vertebral artery. We only perform it in cases in which symptoms suggest a vascular pathology. If unilateral vertebral artery hypoplasia is observed, screw insertion should be limited to a unilateral fixation on the side where hypoplasia has been identified.

Screw placement on the lateral plane

Patient placement is of crucial importance. Maximum atlantooccipital joint flexion and extension of the subaxial cervical spine must be attempted. This position places the anatomy in a favorable situation with respect to the rib cage. Thus, it is possible to go down with the drill sufficiently to insert the screw in an ideal position. In patients who are obese or who have marked thoracic kyphosis, the technique could be impossible to carry out and should be replaced by some other technique such as wire-assisted grafting or the use of pedicled screws in the atlas and the axis.

Screw placement on the frontal plane

Special care must be taken to place the screw in a strictly sagittal position. This may be difficult in cases where the bit is inserted from a separate incision, at a distance, and the drill is not appropriately oriented because of soft tissue interference.

Since at this level the spinal canal provides ample space for the spinal cord, perforation of the cortical bone at the level of the isthmus, on its medial aspect, is less dangerous than placing the screw too laterally, where the vertebral artery is attached to the vertebral foramen. This fact justifies placing the screw in the medial-most portion of the isthmus.

SALVAGE PROCEDURES

Screw placement

Should difficulties arise to appropriately place some of the screws, placement of one single screw could be tolerated. This provides sufficiently solid fusion if rigid immobilization is used, and provided that a bone graft is applied at the level of the midline.

If intraoperatively it is seen that one of the screws has been incorrectly placed, the relevant screw must be withdrawn, leaving a unilateral instrumentation in place.

It should be remembered that it is possible to carry out a fixation at the level of the lateral masses of the atlas and the C2 pedicle as an alternative to the technique described. New implants with appropriately sized screws and a polyax-

ial head facilitate this technique. However, since according to Judet the insertion of screws into the lateral mass of the atlas and screw fixation of the C2 pedicle do not reduce the risk of injury to anatomic structures, require a wide dissection and doubles the risk (4 screws instead of 2), transarticular screw fixation remains our standard procedure.

Injury to the vertebral artery

The presence of a massive hemorrhage after drilling into the isthmus could be indicative of an injury to the vertebral artery. As a precautionary measure, in these cases the contralateral screw must not be placed (unless it has already been). As a first hemostasis measure, the screw will be inserted into the hole. Blood pressure and neurological monitoring will indicate if the desired compression has occurred or whether bleeding persists. In the latter case, artery ligation may be attempted, but in order to succeed a significant amount of bone will have to be resected.

Hemorrhage outsider the perforated hole may stem from the venous plexus surrounding the vertebral artery. In these cases screw insertion often provides adequate hemostasis.

Reinstrumentation following failure of an arthrodesis

If graft incorporation fails, screws could break at the level of the atlas-axis joint and subsequently become loose. The persistence of instability and pain will be an indication for a new fixation of the C1/C2 segment. In these cases, a careful study must be performed of the anatomy ando f the position of the screws at the level of the C2 isthmus, in order to detect possible alternatives and new screw placement options.

The same approach can be used as in the first surgery (through the midline). The screws must be extracted; if they are loose and the C2 isthmus is thick enough, the 3.5 mm screws can be exchanged for 4.5 mm cortical screws. If a screw is broken, the posterior fragment can be extracted and a new 3.5 mm screw can be inserted, either inside or outside the atlas, depending of the patient's anatomy.

The appearance of pseudoarthrosis or the breakage of the transarticular screws could be a sound indication to carry out a 4-screw fixation technique. After withdrawing the posterior fragments of the screws in C2, the same hole can be used to introduce a new shorter and thicker screw. Only if the patient's anatomy prevents this will it be necessary to look for a new position for the screw in the pedicle. The screws of the lateral masses of the atlas can be placed safely after visualizing the entry point, subperiostically dissecting the caudal surface of the atlas. The subperiostic dissection makes it possible to clearly identify the masses. The existence of a venous plexus at this level could lead to significant hemorrhage.

Extended resection of the fibrous scar tissue and decortication of the graft bed are mandatory to enhance the osteointegration of the new iliac crest graft.

RESULTS

Transarticular screw fixation has been used to stabilize a series of 54 patients with rheumatoid arthritis, who presented with atlantoaxial instability. They were studied retrospectively with a mean follow-up of 6 (2-13) years. Review of the data showed a mean OR time of 78 (50-145) minutes and a mean blood loss of 250 cc. The pain score at the time of follow-up, measured by means of the Visual Analog Scale (0-10) was 2, as compared with a pre-op value of 6. Seventy-nine percent of patients stated that they would undergo the procedure again if they found themselves in the same situation, 6% were not sure what to answer to this question and 5% responded negatively. Seventy-eight percent of patients claimed they were highly satisfied with the result obtained, 18% indicated that the result was satisfactory and 3% were dissatisfied with the outcome.

Analysis of the x-rays of this group of patients, affected by rheumatoid arthritis, showed a reduction of the gap between the atlas and the odontoid process, from a mean 9.3 mm preoperatively to 3.6 mm postoperatively. In 47 patients we observed solid fusion on the radiographs; in 6 of the remaining 7 patients the screws broke, which was an indirect sign of delayed fusion, but only 2 patients presented with persistent instability and pseudoarthrosis (3,9%). There were no complications in this series.

CONCLUSIONS

Arthrodesis between the atlas and the axis is indicated when there is some degree of instability. Clinically, this instability could manifest itself as persistent pain or as a myelopathy resulting from repetitive multi-trauma on the spinal cord. Conventional wire-based fusion techniques are straightdorward but are associated to a significant rate of pseudoarthrosis, particularly in unfavourable conditions like rheumatoid arthritis. Transarticular screw fixation between the atlas and the axis provides superior stability and reduces the nonunion rate. Screw placement requires a careful anatomic study, in particular of the C2 isthmi, through CAT or NMR slices. The surgical technique is laborious but results in few complications if the surgeon follows the instructions and known well the anatomy of the region. The screw must be placed closet o the medial border of the C2 isthmus, following a sagittal orientation. The screw's inclination is controlled on the image intensifier. Correct incorporation of the iliac crest graft depends on the technique used, which involves appropriate graft decortication and placement.

The 4-screw fixation technique, 2 in the lateral masses of the atlas and 2 in the C2 isthmi represents, in our experience, a "second choice" technique for patients with pseudoarthrosis or who require reoperation.

REFERENCES

1. Crawford NR, Hurlbert RJ, Choi WG, Dickman CA. Differential biomechanical effect of injury and wiring at C1-C2. Spine. 1999;24:1894-902.
2. Crisco JJ, Parijabi MM, Oda T, Grob D, Dvorar J. Bone graft translation of four upper cervical spine fixation techniques in a cadaveric model. J Orthop Res. 1991;9:835-46.
3. Grob D, Crisco JJ 3rd, Panjabi MM, Wang P, Dvorak J. Biomechanical Evaluation of four different posterior atlantoaxial fixation techniques. Spine. 1992;17:480-90.
4. Dvorak J, Wälchli B. Kopfschmerzen beim Zervikalsyndrom. Ther Umsch. 1997;54(2):94-7.
5. Grob D. Atlantoaxial immobilization in rheumatoid arthritis: a prophylactic procedure? Eur Spine J. 2000;9:404-9.
6. Grob D, Dvorak J, Panjabi M, Froehlich M, Hayek J.. Posterior occipito-cervical fusion. Spine. 1991;16 Suppl 3:S17-24.
7. Dvorak J, Grob D, Baumgartner H, Gschwend N, Grauer W, Larsson S. Functional evaluation of the spinal cord by magnetic resonance imaging in patients with rheumatoid arthritis and instability of upper cervical spine. Spine. 1989;14:1057-64.
8. Floyd T, Grob D. Translaminar screws in the atlas. Spine. 2000;25:2913-5.
9. Magerl F, Seemann P. Stabile posterior fusion of the atlas and axis by transarticular screw fixation. En: Kehr P, Weidner A, editors Cervical Spine. Strassbourg, Wien, New York: Springer Verlag; 1986. p. 322-7.
10. Jeanneret B, Magerl F. Primary posterior fusion C1/C2 in odontoid fractures: indications, technique and results of transarticular screw fixation. J Spine Disord. 1992;5:464-75.
11. Subach BR, McLaughlin MR, Albright AL, Pollack IF. Current management of pedicatric atlantoaxial rotatory subluxation. Spine. 1998;23:2174-9.
12. Grob D. Atlantoaxial instability in odontoid hypoplasia. A long term follow up after atlantoaxial screw fixation. En: 17 Meeting Cervical Spine Research Society, ES. Turin, Italy; 2001.
13. Yonenobu K, Ono K. Laminoplasty, in cervical spondylosis and similar disorders. En: Ono K, Dvorak J, Dunn E, editors. Singapore, New Jersey, London, Hong Kong: World scientific; 1998. p. 501-22.
14. Dickman C, Sonntag V. Posterior C1-C2 transarticular screw fixation for atlantoaxial arthrodesis. Neurosurgery. 1998;43: 275-80.
15. Wigfield C, Bolger C. A technique for frameless stereotaxy and placement of transarticular screws for atlantoaxial instability in rheumatoid arthritis. Eur Spine J. 2001;10:264-8.
16. Goffin J, Van Brussel K, Martens K, Vander Sloten J, Van Audekercke R, Smet MH. Three-dimensional computed tomography-based, personalized drill guide for posterior cervical stabilization at C1-C2. Spine. 2001;15:1343-7.
17. Gallie WE. Fractures and dislocations of the cervical spine. Am J Surg. 1939;46:495-9.
18. Grob D, Jeanneret B, Aebi M, Markwalder T. Complications of atlanto-axial fusion with transarticular screw-fexation. J Bone Joint Surg Br. 1993;75B Suppl II:178.

Conflict of interests

The author has declared to have no conflict of interests.