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Technical Strategies and Surgical Results of C1 Lateral Mass-C2 Pedicular Screw Fixation in Atlantoaxial Disorders

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Objective: There are various posterior fusion techniques in managing C1-2 instability. The aim of this study is to evaluate surgical techniques and clinical results including complications of the C1 lateral mass and C2 pedicle screw fixation (C1-2 LMPSF) in atlantoaxial disorders.

Methods: From February 1997 to July 2008, 24 patients were performed C1-2 LMPSF due to C1-2 instability. Pathway of vertebral artery was classified into three groups by 3D-angiogram. Diameter of C1 lateral mass and C2 isthmus on the plain X-ray and CT was measured before operation. Surgical method was divided into four groups according to fixation site (bilateral or unilateral) and bone graft (with or without graft). Stability of C1-2 fixation was postoperatively evaluated by flexion and extension cervical lateral films. We reviewed clinical data, imaging studies and old chart retrospectively as sources for analysis.

Results: Among 24 patients, os odontoideum was the most common cause (16 out of 24). Four patients had anomalous vertebral artery. Mean diameters of C1 lateral mass was 9.9(range 4.2~16.4) mm at right side, 10.3 (range 3.4~14.2) mm at left side. Mean diameter of C2 isthmus was 5.8 (range 1.0~10.1) mm at right side and 5.8(range 2.1~8.2) mm at left side. Two patients showed very narrow C2 isthmus. As a result, unilateral C1-2 LMPSF was performed on 6 patients (4 for anomalous vertebral arteries and 2 for narrow C2 isthmus). 12 of 18 patients were with C1-2 interlaminar bone graft and 6 patients without bone graft. All patients showed stable C1-2 fixation by flexion and extension cervical lateral X-ray films taken at least 6 months after surgery. Five out of 8 patients who had preoperative radiculopathy only showed improved symptoms. However, Seven out of 8 patients who had myelopathy showed little neurological improvement .

Conclusion: For C1-2 LMPSF, preoperative 3D CT-angiogram study is mandatory to identify abnormal vertebral artery and narrow C2 isthmus. Bilateral C1-2 LMPSF without bone graft is enough to obtain stable C1-2 fixation. If there is an abnormal vertebral artery or narrow C2 isthmus, unilateral C1-2 LMPSF with bone graft and wiring is alternative successful method.

Key Words: Atlantoaxial instability • Atlantoaxial fixation • Lateral mass of atlas • Isthmus of axis

INTRODUCTION

There are various techniques for atlantoaxial (C1-2) fusion; wiring, metallic clamp fixation(Halifax) and C1-2 transarticular screw fixation[2,3,7].

Among the various techniques, C1-2 transarticular screw fixation combined with wiring and bone graft has been widely accepted because of its excellent fusion rate and biomechanical stability[10,18]. However problems such as unfavorable bony anatomy, aberrant position of the vertebral artery, obesity with short neck and sagittal malalignment of the cervical spine are the issuing in C1-2 transarticular method, and up to 26% of patients are unfeasible for this method[11,19,20].

C1 lateral mass and C2 pedicle screw fixation(C1-2 LMPSF) method for C1-2 instability or dislocation was proposed as an alternative method for transarticular screw

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by Goel and coworkers at 1998[5]. Harms modified that C1-2 LMPSF procedure in 2001, and Harms and Melcher described it using C1 lateral mass-C2 pedicle screw with rod system and reported good clinical results[8].

C1-2 LMPSF has numerous advantages; excellent fixation force than other methods, possible C1 posterior decompression, easy feasibility of elongation to occiput and/or lower vertebrae. However, there are many variations in vertebral artery tract, C1 lateral mass and C2 isthmus, and surgeons must be fully aware of the anatomy of atlantoaxial complex. Strict preoperative evaluations and prompt modifications are mandatory studies for the safe surgery. Yet, there are few reports about clinical experiences and results about C1-2 LMPSF for various atlantoaxial abnormalities.

In this study, we reports the clinical results of C1-2 LMPSF operated on 24 patients with various atlantoaxial diseases and describe the technical pitfalls.

PATIENTS AND METHODS

1. Patients

This study is based on a retrospective review of patients who had undergone C1-2 LMPSF between February 1997 and July 2008. Twenty four patients (male:female=14:10) with mean age of 45.4 years (range 7-68) underwent C1-2 LMPSF. Preoperative diagnoses were 16 for os odontoideum, 5 for rheumatoid arthritis, and 3 for trauma. The average follow-up duration was 9.4 months (range 3-35) (Table 1). Three out of 16 os odontoideums were combined with Down synd rome, and one of 5 rheumatoid arthritis patient had cerebral palsy.

2. Preoperative Study for the Surgery

We evaluated patients with not only plain X-rays and magnetic resonance image (MRI) study but also 3D-reconstructive computed tomography including angiogram (3D-CT angiogram) preoperatively. We could know three dimensional atlantoaxial complex, trajectory of vertebral artery, size and correlations with vertebral foramen of C1 lateral mass, size of isthmus and correlations with vertebral artery, and venous anatomy adjacent to atlantoaxial complex.

Table 1. Demographic data of the patients

Patients (n=24)		Data
Age		45.4years (range 7~68)
Sex		14:10
Mean follow-up duration		9.4 months (range 3~35)
Disease	Os odontoideum	16(3 with Down syndrome)
	Rheumatoid arthritis	5(1 with cerebral palsy)
	C1-2 instability by trauma	3

3. Surgical Procedures

Under general anesthesia, the patient is placed in the prone position with the head held by Mayfield 3-pin fixation system. It is very difficult to approach C1 lateral mass due to narrow C1-2 interlaminar space if the neck is too much extended, so flexion of head is helpful if neurologically possible. Cervical spine is exposed subperiosteally from the occiput to the C3-4. C1-2 complex is exposed to the lateral border of the C1-2 articulation. Surrounding veins can be coagulated for shrinkage by bipolar coagulator and venous bleeding can be managed by compression with gelfoam. Intersection of inferior border of C1 arch, and midpoint of C1 lateral mass, 3~4 mm lateral to the medial wall was entry point of C1 lateral mass screw, and the end point was anterior wall of C1 lateral mass (Fig. 1A, B, C and D). Unlike Harms' described junction between lamina and lateral mass as the entry point in his original article, by the way, it is rather difficult to find it because C2 nerve root is very closely attached to C1 lateral mass and the junction is somewhat deep from the operative field. The authors undercut the inferior margin of C1 lamina using Kerrison punch or drill, it is very helpful to find the junction between C1 lamina and lateral mass and prepare the hole to insert guiding drill 8) (Fig. 1C and D). Trajectory of screw insertion is 10~15°medially, direct to anterior tubercle of atlas. The entry point of C2 pedicle is lateral to the superior margin of the C2 lamina, cranial and medial quadrant of the isthmus surface and the trajectory is 15~25° medially, 20°upward direction. It is very important to expose the medial border of C2 isthmus for identifying the direction of screws and 3 dimensional imagination of screw trajectory just under the medial cortical bone during the procedure of guiding drill along the isthmus. In mostly adults, the screws 3.5 or 4.0 mm of diameter with 26~28 mm length was enough for C1-2 LMPSF.

For several surgical cases, interlaminar autologous bone graft was performed with Gallie wiring technique. Recently, interlaminar bone fusion was performed only for unilateral C1-2 LMPSF.

After inserting the screws, the head fixation system was released and neck was readjusted to neutral or rather extended position. Then after applying the rods, we finally fixed the screws and rods (Fig. 2A and B).

4. Radiological Evaluation

We analyzed preoperatively plain X-ray films, 3D-CT angiogram and MRI. We classified vertebral artery variation by Hong's classification[9]. From transverse foramen to the medial wall of vertebral canal of atlas (diameter of C1) and axis (diameter of isthmus) was estimated. Because 3.5 or 4.0 mm of screw diameter was used, diameter of C1 lateral mass and C2 isthmus was should be larger than 4.0 mm. We divided the diameter (D) of lateral mass of C1 and isthmus of C2 into 3 groups as <4, $4 \leq D < 7$ and ≥ 7 mm in C1 and <4, $4 \leq D < 5$ and ≥ 5 mm in C2 (Fig. 3A and B). We divided C1-2 LMPSF as bilateral or unilateral fixation by screw inserting site. It was also divided into with or without bone graft.

Stable C1-2 fixation was confirmed by flexion-extension lateral cervical X-ray film at 1, 6, 12 months after operation. Criteria of stable C1-2 fixation was no interval change of antlantodental interval (ADI) compared to immediate postoperative flexion-extension lateral films taken at least 6 months after surgery.

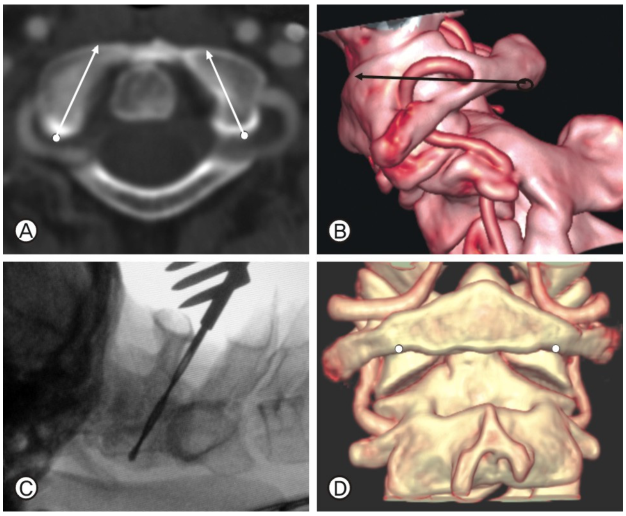

Fig. 1. A, D: Entry point: intersection of Inferior border of C1 arch and midpoint of C1 lateral mass, End point: Anterior wall of C1, B: undercutting the inferior margin of C1 lamina (circle) to find entry point easily, C: intraoperative image.

5. Clinical Evaluation

We divided the patients preoperatively into four groups along neurological symptoms; neck pain (Grade I), radiculopathy (Grade II), mild myelopathy (Grade III), severe myelopathy (Grade IV). According to Modified Odom's criteria, postoperative symptom relief was evaluated as excellent, good, fair and poor grade[17].

RESULTS

1. Abnormal Pathway of Vertebral Artery

For 20 out of 24 patients, 3D-reconstructive CT angiogram was carried out. In four patients, operation was performed without 3D-reconstructive CT angiogram. 16 out

Table 2: Variations of vertebral artery at C1-2 complex by Hongs classification

Classification of vertebral artery pathway	No. of cases (%)
Normal	16 (80%)
Unilateral/bilateral persistent 1st intersegmental artery	2/1 (15%)
Unilateral fenestrated vertebral artery	1 (5%)

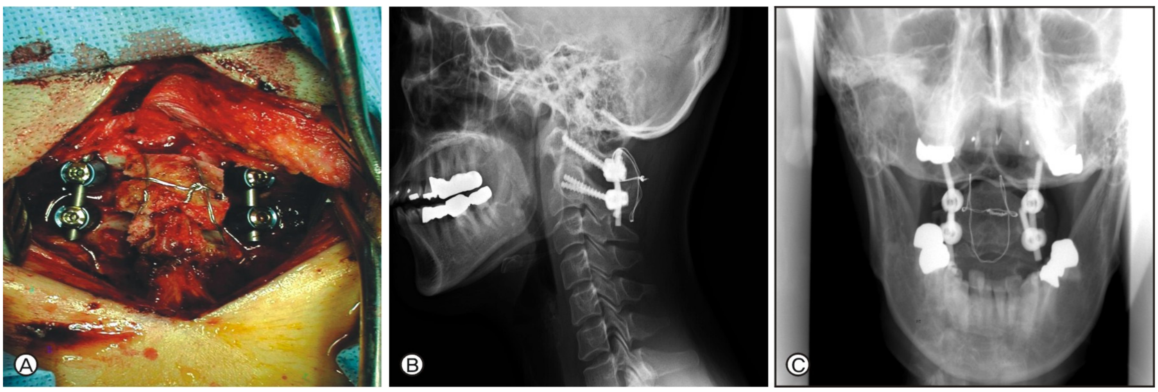

Fig. 2. A: Intraoperative photographs of C1-2 LMPSF with bone graft. B, C: Postoperative cervical lateral X-ray.

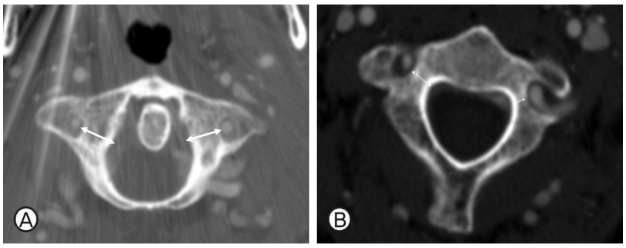

Fig. 3. A: Diameter of C1 lateral mass. B: Diameter of C2 isthmus. From transverse foramen to medial wall of vertebral canal of atlas and axis was calculated.

Table 3. Diameters of C1 lateral mass and C2 isthmus

		Mean at right(mm)		Mean at left(mm)
Lateral Mass of C1		9.9(4.2~16.4)		10.3 (4.0~14.2)
Isthmus of C2		5.8(1.0~10.1)		5.8 (2.1~8.2)
Grades of diameter		Diameter of C2 isthmus(mm)		
		I(<4)	II(4 ≤D<5)	III(≥6)
Diameters of C1 lateral mass (mm)	I(<4)	0/0	0/0	0/0
	II(4≤D<7)	1/0	8/8	1/1
	III(≥7)	1/0	11/11	2/4

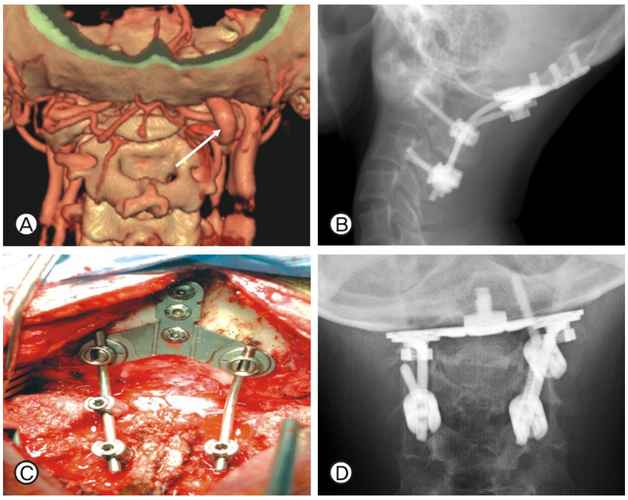

Fig. 4. A: Images of unilateral C1-2 LMPSF with bone graft. Due to narrow C1 lateral mass and high riding vertebral artery (arrow), to insert the screw at right side was risky, C: intraoperative photograph, B, D: Postoperative plain X-ray

of 20 patients had normal anatomical vertebral artery. Persistent 1st intersegmental artery was observed in two patients bilaterally and one patient unilaterally. One patient showed unilateral fenestrated vertebral artery(Table 2). If there was variation in vertebral artery, we did not insert the screw to avoid vessel injury. As a result, unilateral C1-2 LMPSF was performed for 4 of 24 patients (16.7%) because of abnormal pathway of vertebral arteries(Fig. 4A, B, C and D).

2. Diameter of Lateral Mass of C1 and C2 isthmus

Mean diameter of C1 lateral mass was 9.9(range 4.2-16.4) mm at right side, 10.3(range 3.4~14.2) mm at left side. Mean diameter of C2 isthmus was 5.8(range 1.0-10.1) mm at right side and 5.8(range 2.1~8.2) mm at left side (Table 3). If diameter of C2 isthmus was in group I (< 4), we did not insert the screw and unilateral C1-2 LMPSF was performed in two cases (8.3%) (Fig. 5A, B and C). Because diameters of C1 lateral mass were all over grade II, there was not a case that cannot be performed bilaterally due to narrow C1 lateral mass.

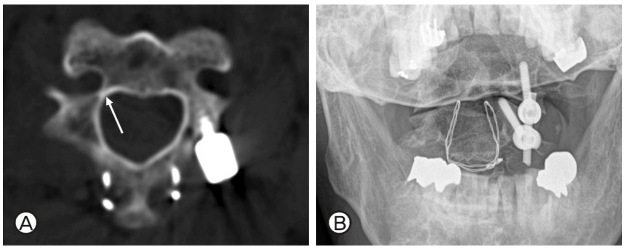

Fig. 5. Image of unilateral C1-2 LMPSF due to narrow C2 isthmus. A: CT axial image shows narrow C2 isthmus(arrow) and prominent vertebral artery B: sagittal view of C2 isthmus. C: Postoperative plain AP X-ray.

Table 4. Methods of screw fixation and wiring

Operation method	No. of cases (bilateral/ unilateral)
Bilateral C1-2 LMPSF without bone graft	6
Bilateral C1-2 LMPSF with bone graft	12
Unilateral C1-2 LMPSF without bone graft	1
Unilateral C1-2 LMPSF with bone graft	5

3. Methods of Screw Fixation and Wiring

Bilateral C1-2 LMPSF was performed on 18 patients. 12 of 18 patients were with C1-2 interlaminar bone graft and 6 patients without bone graft. Autologus rib or iliac bone was the source of graft. For six patients of unilateral C1-2 LMPSF, bone graft was performed in 5 patients and 1 patient without bone graft (Table 4). Unilateral fixation was because of vertebral artery abnormality or small diameter of C2 isthmus.

4. Surgical Complications

There was no specific complications except one patient

Table 5. Preoperative neurological symptoms and postoperative outcomes

Preoperative neurological status	Postoperative modified Odom's criteria			
	Excellent	Good	Fair	Poor
Neck pain (Grade I)	5	2	1	0
Radiculopathy (Grade II)	4	1	3	0
Mild myelopathy (Grade III)		1	5	0
Severe myelopathy (Grade IV)			2	0

with focal operative wound infection. After using intravenous antibiotics for several days, the wound was healed. In one patient, severe occipital headache continued for long time after operation, we think it might be due to trauma of C2 nerve root when coagulate the venous bleeding.

5. Stable C1-2 Fixation

All patients showed stable C1-2 fixation by flexion and extension cervical lateral X-ray films taken at least 6 months after surgery.

6. Clinical Improvement

16 patients showed neurological deficit (Grade II-IV) preoperatively, and among them 8 patients were grade III or IV. Eight patients were neurologically normal. Five out of 8 patients who had preoperative radiculopathy only (Grade II) showed improved symptoms (excellent or good grades). However, Seven out of 8 patients who had myelopathy (Grade III or IV) showed little neurological improvement (fair grade) (Table 5).

DISCUSSION

C1-2 instability can be caused by numerous conditions such as trauma, os odontoideum, rheumatoid arthritis, and other various congenital malformations. Among them, fracture of odontoid process or rupture of transverse ligament by trauma is the most common cause[1]. However, in our series, the most common etiologies (15 out of 24) were congenital anomaly like os odontoideum.

C1-2 transarticular screw fixation, which was introduced in 1987 by Magerl, has been widely selected operation method for C1-2 fusion and has very high fusion rate of 95~100%[6]. Instrument failure by rotatory movement after prior C1-2 fusion method such as wiring which was the most vulnerable point of wire method, can be prevented by transarticular fusion methods. Firm stabilization is acquired immediately after operation and do not need external fixation device in most cases[4].

Although transarticular C1-2 fixation has many advantages, it needs long skin incision, long trajectory and excessive neck flexion. The close proximity of the vertebral artery to the C1-C2 transarticular screw trajectory makes this procedure technically demanding and potentially hazardous, and it is known that narrow pars of C2 is not rare[14]. In our cases, mean diameter of C2 isthmus is only 5.8 mm. This technique must be performed with great care by experienced surgeon due to critical vertebral artery injury and misdirection of screws to pass the center of atlantoaxial facet joint[4,13,16].

C1-2 LMPSF as a way to immobilize the C1-C2 complex was introduced at 2001 by Harms[8]. The advantage of this technique in achieving high fusion rates and good outcomes was clearly demonstrated[8,21]. C1-2 LMPSF was designed for reduce disadvantages of transarticular fixation method C1-2 LMPSF has some advantages than transarticular method as follows; less stress of vertebral artery injury, little flexed cervical spine, small skin incision, direct reduction of atlantoaxial dislocation while operation, biomechanically stable, feasible fixation procedure with occiput and lower cervical spine, direct fixation into dislocated and fractured atlas[12]. As Kim;s report at 2004, the C1-2 LMPSF method was found to have the highest biomechanical stiffness followed by C1-2 transarticular screw method[12]. For C1-2 transarticular fixation, the entry angle of screw must be lie-down, and it is very hard to predict solid geometry because of long trajectory of screws through C1-2 facet joint. In comparison, C1-2 LMPSF does not need excess flexion, and surgeon can predict the screw trajectory more easily than C1-2 transarticular fixation. For easy prediction of the pathway of the screw in C2, the medial wall of C2 isthmus should be exposed completely lateral to the dura mater.

C1-2 LMPSF has the risk of vertebral arterial injury during screw insertion as well, however it has short trajectory of screws with direct view for C1 and C2. Direct vision with short screw trajectory gives the surgeons more confidence about three dimensional imaging of where the screws are passing inside cervical structures.

Otherwise, problems like huge venous bleeding, deep surgical field And possible risk of C2 nerve root injury are the vulnerable points of C1-2 LMPSF. To overcome this difficult procedure, partial removal of inferior part of C1 lateral mass by drill or Kerrison punch can be helpful to prevent nerve damage and make wider surgical field to identify the junction of C1 lateral mass and lamina.

In six patients, unilateral C1-2 screw fixation was done because of ipsilateral persistent intersegmental vertebral artery or too narrow C2 isthmus. Vertebral artery has some variations and it is the limitation of C1-2 LMPSF[9]. We surveyed the variations of third segment of vertebral artery, where the C1 transverse foramen passes, 20% had variations such as persistent intersegmental artery or fenestrated artery. This rate of abnormal pathway of vertebral artery is not low. To prevent the disaster of vertebral artery injury, obsessive study using the 3D CT angiogram is mandatory before the surgery. Too small diameter of C2 isthmus with high arch of vertebral artery to insert screw has been already reported. According to Mandel' s report, among 205 cadavers, five specimens (2.4%) had an isthmus width less than 5 mm[15]. On contrary of the problem in inserting the screw into C2 isthmus, diameter of most C1 lateral masses was enough for screw insertion. We could not find the C1 diameter below 4 mm that is the least size of the lateral mass for passing the screw.

We followed plain lateral X-ray at 6months after surgery, the firm stabilization was obtained successfully in all cases. For initial cases of our series, bone graft and wiring was performed with C1-2 LMPSF. However the other cases without bone graft also showed good stability. We think that bone graft is not needed for bilateral C1-2 LMPSF. Yet, stability associated with unilateral C1 lateral mass C2 pedicle screw fixation is not reported. We think if it is dangerous to insert screw due to anomalous vertebral artery or narrow C2 pedicle, unilateral fixation combined with bone graft can also provide successful fusion.

CONCLUSION

Twenty four patients with various atlantoaxial diseases could be treated by C1-2 LMPSF to obtain stable C1-2 fixation. For C1-2 LMPSF, preoperative 3D CT-angiogram study is mandatory to identify abnormal vertebral artery and narrow C2 isthmus. Bilateral C1-2 LMPSF without bone graft is enough to obtain stable C1-2 fixation. If there is an abnormal vertebral artery or narrow C2 isthmus, unilateral C1-2 LMPSF with bone graft and wiring is alternative successful method.

REFERENCES

1. Coyne TJ, Fehlings MG, Wallace MC, Bernstein M, Tator CH: C1-C2 posterior cervical fusion: Long-term evaluation of results and efficacy. **Neurosurgery 37:** 688-692; discussion 92-93, 1995
2. Cybulski GR, Stone JL, Crowell RM, Rifai MH, Gandhi Y, Glick R: Use of halifax interlaminar clamps for posterior c1-c2 arthrodesis. **Neurosurgery 22:**429-431, 1988
3. Dickman CA, Sonntag VK, Papadopoulos SM, Hadley MN: The interspinous method of posterior atlantoaxial arthrodesis. **J Neurosurg 74:**190-198, 1991
4. Gluf WM, Schmidt MH, Apfelbaum RI: Atlantoaxial transarticular screw fixation: A review of surgical indications, fusion rate, complications, and lessons learned in 191 adult patients. **J Neurosurg Spine 2:**155-163, 2005
5. Goel A, Laheri V: Re: Harms J, melcher P. Posterior c1-c2 fusion with polyaxial screw and rod fixation (spine 2001;26: 2467-71). **Spine 27:**1589-1590, 2002
6. Grob D, Magerl F: Surgical stabilization of c1 and c2 fractures. **Orthopade 16:**46-54, 1987
7. Grob D, Jeanneret B, Aebi M, Markwalder TM: Atlanto-axial fusion with transarticular screw fixation. **J Bone Joint Surg Br 73:**972-976, 1991
8. Harms J, Melcher RP: Posterior c1-c2 fusion with polyaxial screw and rod fixation. **Spine 26:**2467-2471, 2001
9. Hong JT, Lee SW, Son BC, Sung JH, Yang SH, Kim IS, et al: Analysis of anatomical variations of bone and vascular structures around the posterior atlantal arch using three-dimensional computed tomography angiography. **J Neurosurg Spine 8:**230-236, 2008
10. Jeanneret B, Magerl F: Primary posterior fusion c1/2 in odontoid fractures: Indications, technique, and results of transarticular screw fixation. **J Spinal Disord 5:**464-75, 1992
11. Jun BY: Anatomic study for ideal and safe posterior c1-c2 transarticular screw fixation. **Spine 23:**1703-1707, 1998
12. Kim SM, Lim TJ, Paterno J, Hwang TJ, Lee KW, Balabhadra RS, et al: Biomechanical comparison of anterior and posterior stabilization methods in atlantoaxial instability. **J Neurosurg 100:**277-283, 2004
13. Liang ML, Huang MC, Cheng H, Huang WC, Yen YS, Shao KN, et al: Posterior transarticular screw fixation for chronic atlanto-axial instability. **J Clin Neurosci 11:** 368-372, 2004
14. Ma XY, Yin QS, Wu ZH, Xia H, Liu JF, Zhong SZ:

Anatomic considerations for the pedicle screw placement in the first cervical vertebra. **Spine 30:**1519-1523, 2005

15. Mandel IM, Kambach BJ, Petersilge CA, Johnstone B, Yoo JU: Morphologic considerations of c2 isthmus dimensions for the placement of transarticular screws. **Spine 25:**1542-1547, 2000
16. Menendez JA, Wright NM: Techniques of posterior C1-C2 stabilization. **Neurosurgery 60:**S103-11, 2007
17. Odom GL, Finney W, Woodhall B: Cervical disk lesions. **J Am Med Assoc 166:**23-28, 1958
18. Richter M, Schmidt R, Claes L, Puhl W, Wilke HJ: Posterior atlantoaxial fixation: Biomechanical in vitro comparison of six different techniques. **Spine 27:**1724-1732, 2002
19. Solanki GA, Crockard HA: Peroperative determination of safe superior transarticular screw trajectory through the lateral mass. **Spine 24:**1477-1482, 1999
20. Spangenberg P, Coenen V, Gilsbach JM, Rohde V: Virtual placement of posterior C1-C2 transarticular screw fixation. **Neurosurg Rev 29:**114-117, 2006
21. Stulik J, Vyskocil T, Sebesta P, Kryl J: Harms technique of c1-c2 fixation with polyaxial screws and rods. **Acta Chir Orthop Traumatol Cech 72:**22-27, 2005