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ORIGINAL ARTICLE / *ORJİNAL MAKALE*

TRANSPEDICULAR FIXATION IN FRACTURE-DISLOCATIONS OF THE CERVICAL SPINE: TWO YEARS' EXPERIENCE

SERVİKAL FRAKTÜR DİSLOKASYONDA TRANSPEDİKÜLER VİDA FİKSASYONU: İKİ YILLIK DENEYİM

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SUMMARY:

Object: Transpedicular fixation technique, by means of anterior or posterior approaches, is known to be a biomechanically stronger method in cervical fracture-dislocation. Pedicle axis views are obtained using fluoroscopy to match the screw entry point with pedicle orientation and to report the clinical results and safety of cervical pedicle screw fixation (CPSF) in patients treated for unstable cervical fracture -dislocation.

Methods: Post-operative malposition of the transpedicular screws of the 52 pedicles of the 12 patients who have been operated due to trauma were investigated. Fixation was performed between C3 and C7, and iliac wing and lamina were used as autograft for fusion.

Results: Eight of the cases were male, while four were female. The average age of the patients was 40.9 (34-65). 12 of the cases had trauma; 4 had unilateral, 8 had bilateral fracture dislocation. Five of these were at the C5-C6 segment, four in C6-7 segment, while the other three were at the C6-C7 segment. In the postoperative computed tomography (CT) scans, the applied screw was observed to have directly penetrated into the vertebral foramen in only one (1.9 %) pedicle during the fixation process; however, the blood circulation appeared normal in angiography. In terms of screw-pedicle relations, the screws were at their correct places in 45 pedicles (86.5 %), while non-critical pedicular lateral orientation was detected in 3 (5.7 %), and medial orientation in another 4 pedicles (7.6 %). The cases were followed up for a total of 14 to 31 months (24.7). Solid posterior bone fusion was achieved in all, there is no morbidity or mortality in this series.

Conclusion: Use of the CPSF provides a very strong three column stabilization but also carries a high risk of vascular injury without nerve damage. Postoperative CT scanning showed major breach in one pedicle (1.9 %) and minor breach in 7 pedicles (13.2 %) of 52 screws that had perforated the pedicle. CPSF can be performed in a one stage posterior procedure without the need of anterior surgery in trauma patients.

Key Words: *Cervical fracture-dislocation, surgical treatment, transpedicular screw fixation.*

Level of Evidence: *Retrospective clinical study, Level III.*

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ÖZET:

Amaç: Anterior ya da posterior yaklaşımla transpediküler fiksasyon tekniği servikal kırıklı-çıkıkta biyomekanik olarak kuvvetli bir metot olarak bilinmektedir. Bu çalışmada pedikül aksları, vida giriş noktalarının pedikül oryantasyonu ile eşleştirilmesi amacıyla, floroskopi ile belirlenmiş, instabil servikal kırıklı-çıkık için pedikül vidası ile fiksasyon (PVF) yapılan hastalarda tekniğin klinik sonuçları ve güvenilirliği tartışılmıştır.

Metot: Travma nedeniyle opere edilen 12 hastanın 52 pedikülüne takılan transpediküler vidaların postoperatif malpozisyonu araştırılmıştır. C3 ve C7 arası fiksasyon yapılmış ve iliak kanat ve laminalar füzyon için otogreft olarak kullanılmıştır.

Sonuçlar: Hastaların sekizi erkek, dördü kadındı. Hastaların ortalama yaşı 40.9 idi (34-65). Vakaların 12'sinde neden travma idi; 4'ünde unilateral, 8'inde bilateral kırıklı-çıkık mevcuttu. Bunların beşi C5-C6 segmentinde, dördü C4-C5 segmentinde ve kalan üçü ise C6-C7 segmentindeydi. Postoperatif bilgisayarlı tomografi (BT) incelemelerinde, takılan vidanın direk olarak vertebral foramene penetrasyonu sadece bir vakada (% 1,9) görüldü; ancak anjiyografide kan akımı normaldi. Vida-pedikül ilişkisine bakıldığında, 45 pedikülde (% 86,5) vidalar doğru yerleşimde iken 3'ünde (% 5,7) kritik olmayan pediküler lateral oryantasyon ve 4'ünde (% 7,6) medial oryantasyon saptandı. Vakalar 14 ile 31 ay boyunca (ortalama 24.7 ay) takip edildi. Tümünde posterior kemik füzyon oluşurken, mortalite ya da morbidite oluşmadı.

Sonuç: PVF kullanımı çok güçlü üç kolon stabilizasyonu sağlamakla beraber sinir hasarı olmaksızın vasküler hasar riski taşır. Postoperatif BT görüntülemelerinde yerleştirilen 52 vidanın bulunduğu bir pedikülde (%1,9) majör hasar ve yedi pedikülde (%13,2) minör hasar tespit edildi. PVF travma hastalarında anterior cerrahiye ihtiyaç duyulmaksızın tek seanslık bir posterior cerrahi girişim olarak uygulanabilir.

Anahtar Kelimeler: *Servikal kırıklı çıkık, cerrahi tedavi, transpediküler vida fiksasyonu.*

Kanıt Düzeyi: *Retrospektif Klinik Çalışma, Düzey III*

INTRODUCTION:

A number of internal fixation procedures have been used for instability of the cervical spine. Recently developed posterior fixation procedures have been performed in the cervical spine by using lateral mass screws or a pedicle screws. Both of these procedures, which do not require the lamina be used for stabilization, are useful in patients undergoing one stage posterior decompression and stabilization of the cervical spine. There is superior biomechanical stability with cervical pedicle screw fixation (CPSF) compared to the use of lateral mass screws [11,13]. In pedicle screw fixation procedures of the cervical spine, direct screw fixation of C2 pedicles in C2 fracture has been performed by a few surgeons [6]. During the last decade, CPSF has been used in the treatment of degenerative disorders [2], as well as in trauma surgery [4,5]. Since 1994, several attempts have been made to enhance the safety and accuracy of CPSF. Based on current experimental and clinical studies [4,5,10,15,17] computer-assisted surgery systems are suggested to be the safest procedures for CPSF [18,20,25,26]. Appealing clinical results were achieved with CPSF [4,28]. However, in laboratory studies, pedicle perforation could not be completely prevented with any technique [10,15,21,22]. Some authors have been more critical of this technique being used to stereotactic[19] or computed topographic (CT) guidance.

The purpose of this study is to evaluate the feasibility and accuracy of fluoroscopy use during CPSF as a standardized clinical protocol for patients with cervical fracture dislocation.

CLINICAL MATERIAL AND METHODS

We performed a total of 52 posterior CPSFs in 12 cases in a prospective clinical study held in our clinic between March 2007 and December 2009. Ten pedicle screw procedures were held in cadaver specimens. Eight of the cases were male, while four were female. The average age of the patients was 40.9 [34-65]. 12 of the cases had trauma; 4 had unilateral, 8 had bilateral fracture dislocation. Five of these were at the C5-C6 segment, four in C6-7 segment, while the other three were at the C6-C7 segment. These two cases also received CPSF application following mini-laminotomy technique.

Detailed pedicle length and diameter measurements; and calculations of frontal, sagittal, and longitudinal angles of all pedicles were done prior to the operations. Posterior transpedicular fixation was applied to all cases utilizing monoplanar imaging using fluoroscopy. The cases were followed up for a total of 14 to 31 months (24.7 months). Solid posterior bone fusion was achieved in all, there is no morbidity or mortality in this series.

Grading of the pedicle screw position:

Grade I; Screw centered in the pedicle causing only minor plastic deformation of the pedicle cortex at most.

Grade IIa; Screw threads or less than one-fourth of the screw cross-section penetrating the cortex; no contact of the screw with the spinal cord, nerve root or vertebral artery.

Grade IIb; More than one-fourth of the screw cross-section penetrating the cortex but no contact with neurovascular structures.

Grade III; Screw position according to grade II, however, in contact with neurovascular structures.

Illustrative Cases:

Case 1 - The first case was a 44-year- old male who had paraplegia due to traffic accident (Frankel A), and we observed fracture dislocation at the level of C6-7 (Figure-1.a). He was operated using transpedicular cervical fixation and fusion technique with the graft being obtained from the iliac wing (Figure-1.b). The case has a VAS score of 4, complains from neck pain, and is at the 22 months of follow up. The fusion is perfect (Figure-1.c)

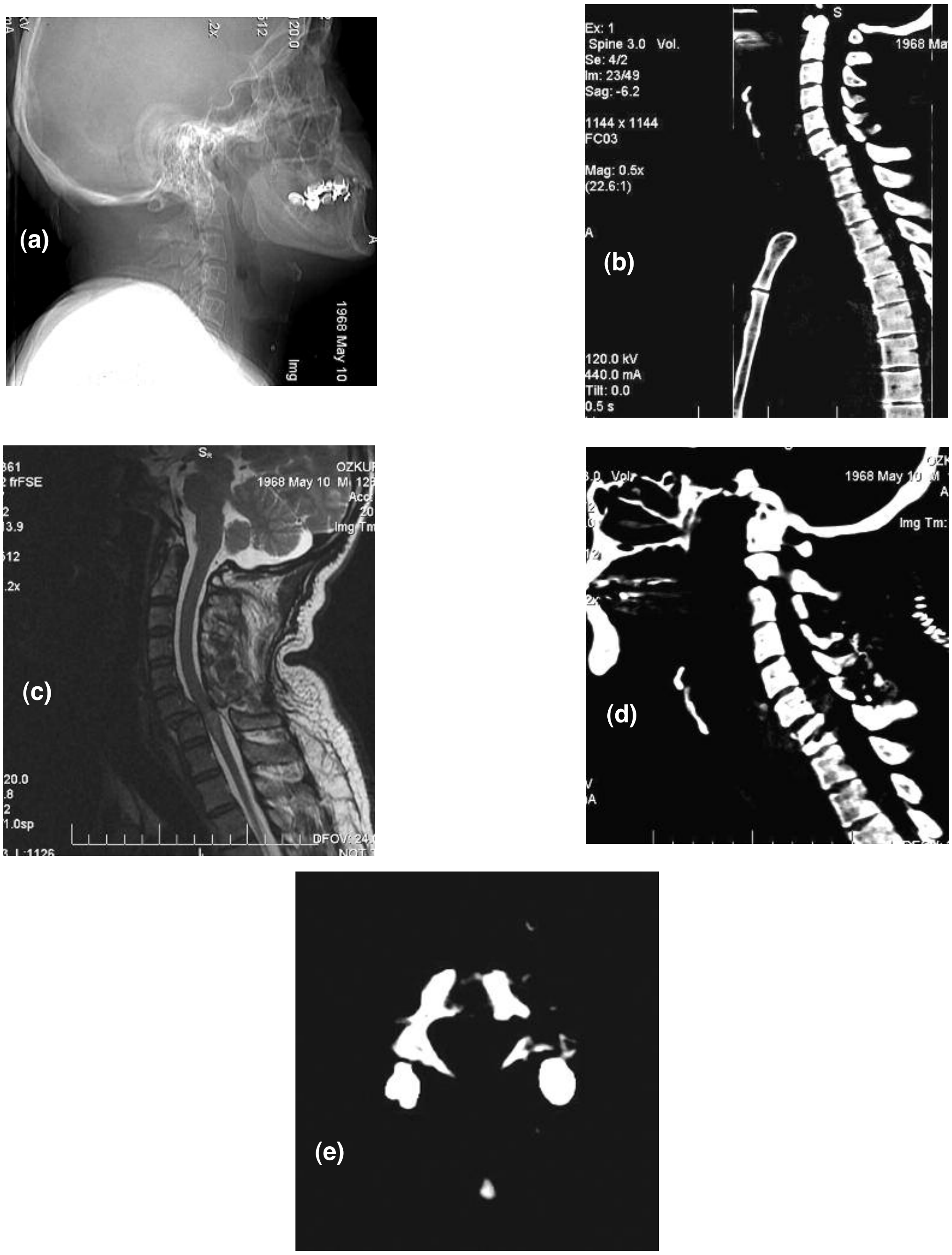

Figure-1. Case 1. Imaging studies obtained in a 44-year-old man with a fracture-dislocation at the level of C6-7. Preoperative direct X- ray **(a)** and sagittal CT scan **(b)** showing fracture-dislocation in C5-C6 level **(c)** Sagittal T2-weighted MR image demonstrating hyperintense signal due to edema and traumatic pseudoherniation. **(d)** Postoperative lateral CT scan showing posterior fixation with transpedicular screw/rod system. **(e)** Postoperative CT scan demonstrating accurate pedicle screw placement in C7 bilaterally.

Case 2 - The second case was a 45-year-old male patient, who was evaluated in our emergency clinic due to traffic accident inside vehicle. The patient displayed a C5-C6 fracture-dislocation in CT scan imaging (Figure-2.a). As he did not have any additional pathology in the anterior position in MRG, only CPSF by a posterior approach was applied. Facet dislocation developed bilaterally after pedicle screw localization was reduced. The procedure was finished after the placement of the autograft obtained from the iliac wing to the fusion region (Figure-2.b). In the control tomography, a grade 1b malposition was detected in only one screw (Figure-2.c). The case has no complaints at the post-operative stage. He is at the 24th month of follow-up.

CPSF system

The head is fixed in natural sitting position. Paravertebral muscles are stripped with a classical midline incision. Only the facet joint surfaces to be operated are decorticated to thoroughly clean up the capsule. Other facet capsules are maintained. The dominant vertebral arteries of all patients were detected with 3D-Doppler ultrasonography in the pre-

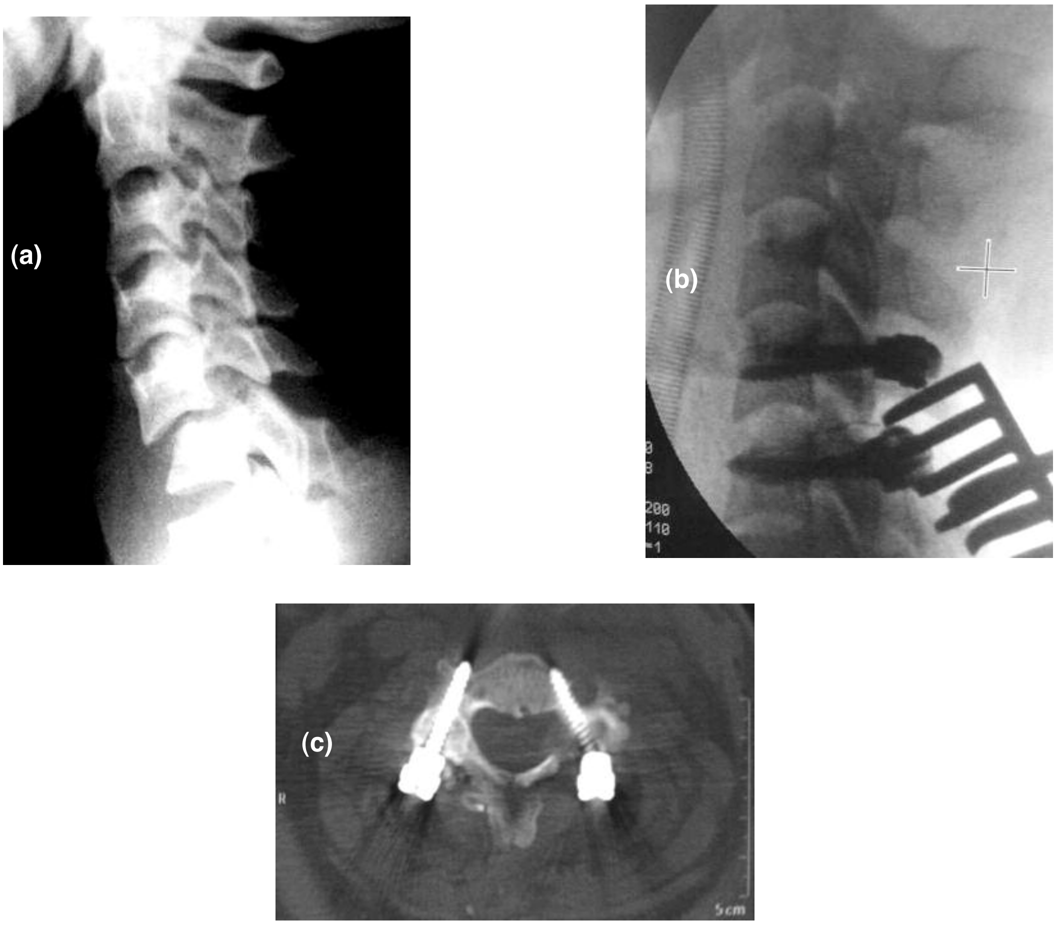

Figure-2. Case 9. **(a)** Preoperative direct x-ray showing fracture-dislocation in C5-C6 level. **(b)** Postoperative sagittal CT scan demonstrating at the final follow-up examination, showing autologous iliac graft, and well maintained cervical alignment. **(c)** Postoperative axial CT demonstrating incorrect screw placement (Grade 3) at the right foramen transversarium.

operative stage, and screw fixation was applied at the non-dominant side of the same level. Following non-problematic insertion of the first screw, in other words after seeing that there is no rupture, the screw of the dominant side is placed.

This process is applied before the screw is placed, in the cases to go through laminectomy or laminoplasty. This way, the position of the screw inside the spinal canal can be observed. The key point for the C2 screw entry site is detected symmetrically. This point is the superior edge of the C2 lamina. A keyhole has to be opened prior to tapping (or drilling) this region, and it is proceeded under control with a high-speed burr oriented at 40° towards the cranial, and 20° towards the medial. The anatomical structure of the C2 vertebra lets us monitor inside the canal from C2 with a hook. This way, penetration inside the canal is prevented while moving the screw forward. If C1 joint will also join the fusion, screw orientation is performed as reaching the lateral mass of the atlas.

The entry point of the pedicles between C3 and C7 is 2 mm lateral to the superior articular process midpoint. In the sagittal plane, it is angled nearly 10° at C3, whereas it is kept neutral or angled 2° at C7. The medial orientation angle of the pedicle, on the other hand, is 45° on average. After biplanar control of the position of the deformity and the screws with scopy image (Figure-3), bone grafts obtained from the iliac wing are placed at the decorticated areas. If the case is a trauma case with dislocation, facet dislocation is reduced after the pedicle screws are placed by a bypass technique and the arrangement of the vertebrae are reprovided.

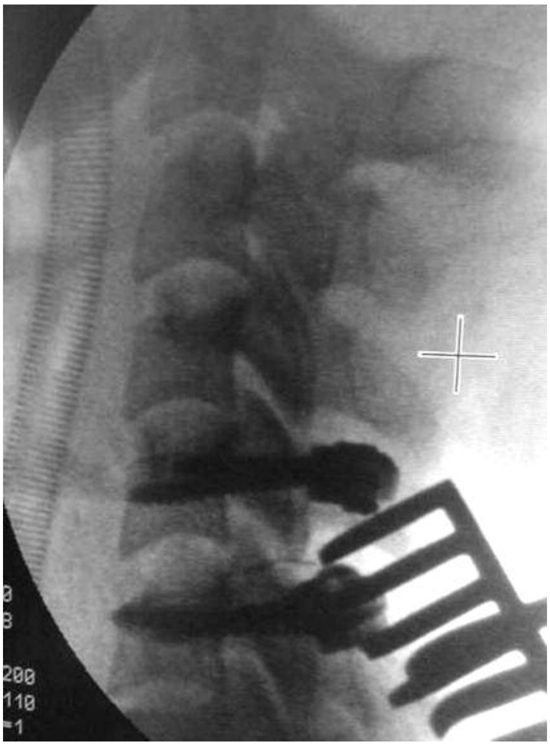

Figure-3. Intraoperative lateral scopy showing transpedicular fixation at the level of C5-C6.

RESULTS

As a result of 52 pedicle applications on a total of 12 patients, the pedicle screws were at their correct positions at 85.5 % of the time (Grade 1; Figures-4.a-c), while at an acceptable position at 13.2 % of the time (Grade 1b; Figure-5). In only one case (1.9 %), the pedicle screw was found unilaterally directly in the vertebral foramen, and it was considered as an inappropriate anatomical position, in other words, Grade 3 (this figure was presented before as a Fig-1.c). Vertebral artery fillings of these cases were complete in angiography (Fig. 6). Single distance CPSF was applied in six cases, whereas double distance was applied in two and triple distance in three patients. All of the patients were mobilized at postoperative day one. The desired posterior one stage reduction and fixation was succeeded in all patients. Pedicle screw diameters and average application angles are provided in Table 1.

The average surgical duration was 105 (90-155) minutes. The average amount of hemorrhage was 140 cc. None of the patients required transfusion. None of the cases suffered hemorrhage due to neurovascular damage.

Neuromaging Evaluation

Preoperatively, we obtained imaging studies in all patients by using plain cervical roentgenography, biplanar computerized tomography (CT) scanning through bone windows, and magnetic resonance imaging (MRI). Bilateral oblique plain x-ray films were routinely obtained to evaluate the condition and size of pedicles of each vertebra. The local kyphosis was determined as the kyphosis angle. The placement of pedicle screws were inspected on postoperative CT scans (in general, 2 mm slices) within the first day of surgery. At later follow-up visits, stability was assessed on flexion-extension radiographs and standard lateral and posterior- anterior views.

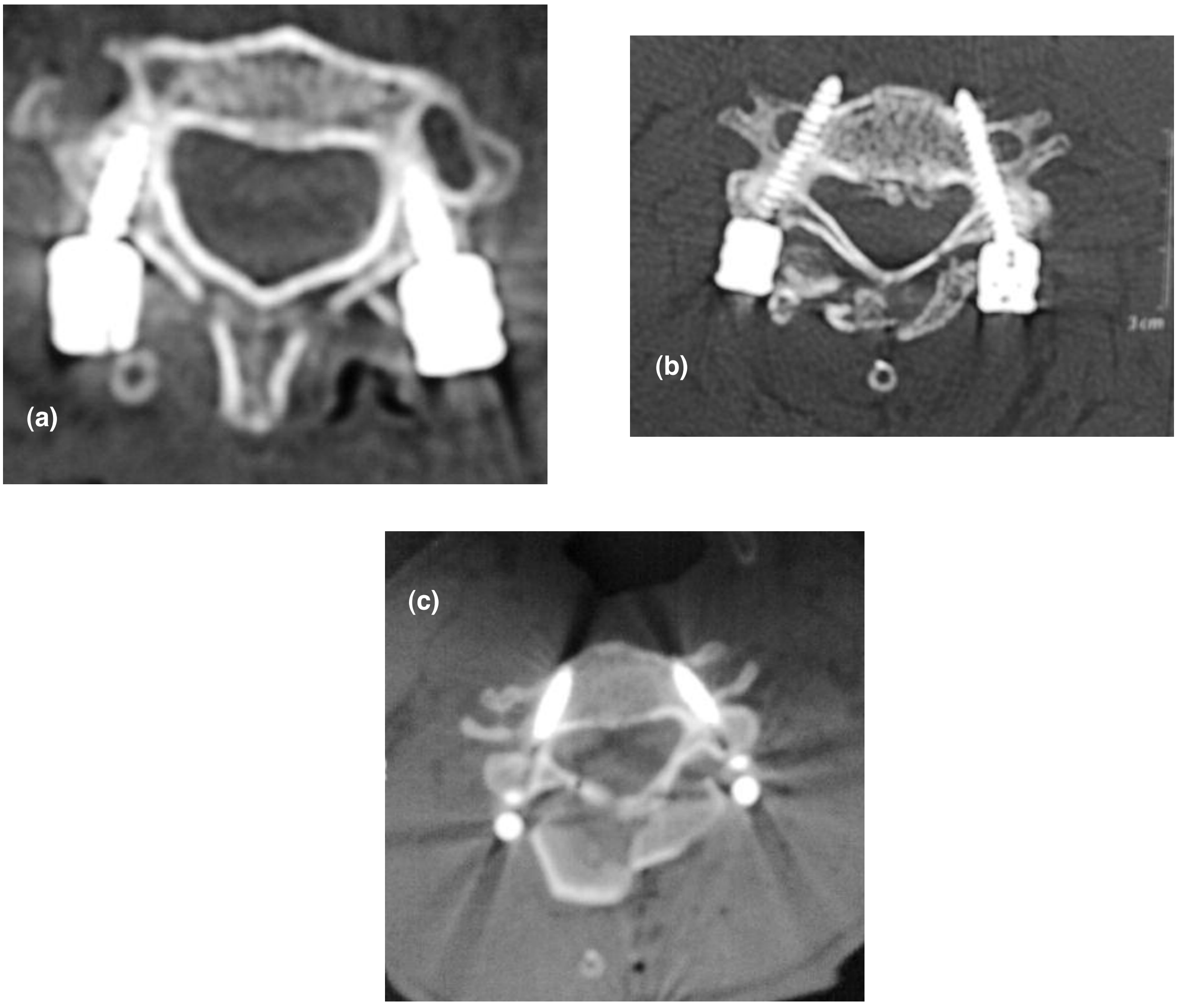

Figure-4. (a-c) Postoperative CT scans demonstrating accurate pedicle screw placement in the pedicles of the different levels.

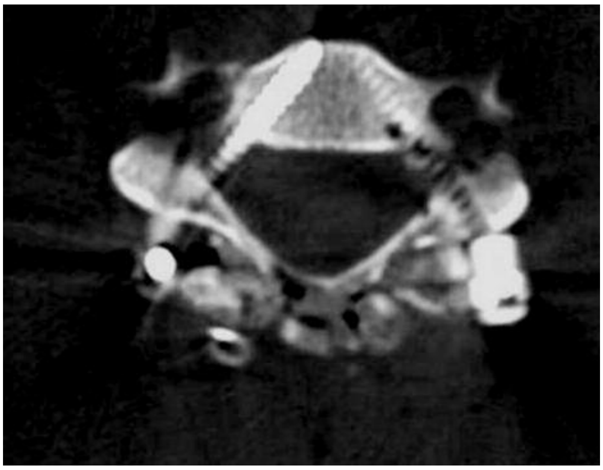

Figure-5. Postoperative CT scan demonstrating accurate pedicle screw placement in the right pedicle of C5, and grade 1B pedicle screw malposition in the left side of C5 pedicle.

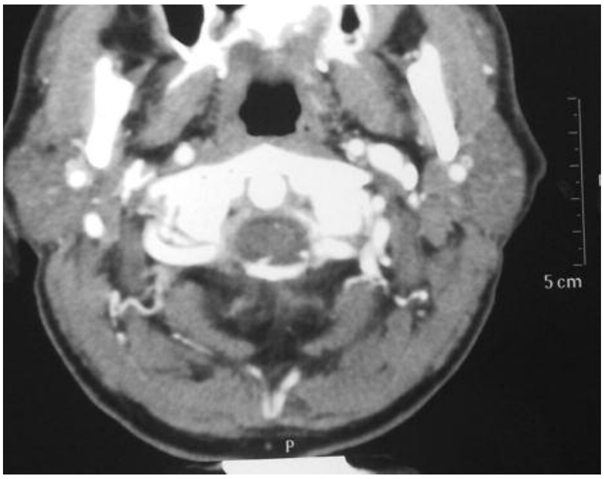

Figure-6. Postoperative CT scan with contrast enhancement showing both vertebral arteries in the foramen magnum.

The follow-up imaging studies were carefully interpreted to identify screw and rod loosening or breakage. We demonstrated that the spinal cord or nerve roots may be injured when the dislocation is reduced because of the marked extrusion of a cervical disc. But, we didn't observe traumatic cervical disc herniation in our cases. Preoperatively and postoperatively, kyphotic deformity at the affected segment (s), which averaged 23° (16-43°) was revealed in nine patients, which was a corrected to 1.2° lordosis after surgery and 0.8° lordosis at the final follow-up examination. Postoperative CT scan was performed in all patients.

Postoperative management

All of the cases were mobilized at postoperative day one. Controls were performed by X-ray imaging as a standard application, and tomography for postoperative pedicle-screw harmony. The cases have been following every six months.

DISCUSSION

Among the various posterior fixation techniques; spinal process wiring, triple-wire technique and sublaminar wiring require use of the lamina as the stabilizing anchor. These techniques allow simultaneous posterior decompression with fixation and stabilization in patients who have undergone previous laminectomy in the cervical spine [20]. However, postoperative rigid external support using a halo vest is required for many patients. Modifications of cervical facet fusion, which is supplemented by rods as longitudinal connectors, may provide some stabilizing effect [11], but stability is not sufficient enough to preclude the need for postoperative external support.

Biomechanical studies have revealed that posterior fixation devices have an advantage over anterior devices for the fixation of posterior instability after laminectomy [4,13]. Anterior surgical approaches did not provide sufficient correction of post laminectomy kyphosis in the cervical spine [13,21]. Kotani et al, have shown that of all the fixation devices only the pedicle screw system provides adequate stability in three column injury model [13]. Joner et al, have provided evidence of greater resistance of pullout of pedicle screws compared with lateral mass screws [8]. In addition, cervical lordosis reconstructed with pedicle screw fixation systems may be provide adequate stability, because lordotic spinal alignment allows the gravity axis to pass through the posterior structures that are reconstructed by rigid instrumentation.

Some of the reports on lateral mass screw procedures have described several cases of screw loosening that had resulted in pseudoarthrosis and loss of kyphosis correction [7,23]. But, our findings suggest that screws inserted into the cervical pedicle provide a more rigid anchor for internal fixation than lateral mass screws, as suggested by in vitro biomechanical studies. We didn't observe any complications such as pseudoarthrosis or loosening of the screw in our cases operated with CPSF.

This system is particularly useful in reduction and stabilization of the cervical spine injuries. Strong fixation to the vertebra by pedicle screw enables application of distraction force to the injured cervical spinal segment. We did not observe any discontinuity of the metallic artifact located posterior to the vertebral body sagittal views on MR images, indicating that ligamentous continuity of the injured disc level was preserved in our series, and we did not observe any patients in whom neurological status deteriorated postoperatively. Therefore, with the CPSF system the cervical spine can be safely stabilized after traumatic injury with one stage surgery, precluding the need for anterior decompression of the spinal canal. Abumi et al. shows that 45 (6.9%) of 669 screws significantly perforated the pedicle [4]. In a comparative study of 3 different techniques for PS placement in human cadaveric cervical spines, Ludwig et al. reported a 65% rate of critical pedicle breaches with insertion based on the morphological data alone, a 40% rate of breaches with supplemental visual and tactile clues provided by mini laminotomy, and an 11% breach rate using a computer-assisted surgical guidance system [15, 24]. In another in-vitro study, an incidence of PS misplacement with a critical breach of 18 % was ebserved using frameless stereotactic guidance, and an 12 % breach was observed using Abumi and colleagues' fluoroscopically assisted technique of probing and tapping the pedicle [4]. Richter et al, reported 92% accuracy using image-guided drilling of 2.5 mm holes in the C-3 and C-4 pedicles in human cadaveric specimens [23]. Our results with the CPSF insertion technique indicate an obvious cortical breach incidence of 13.5 %, including a critical affection rate of 1.9 %, and these are somewhat similar to those of the large series (116 cervical pedicle) of Rath et al [19]. We reported a 1.9 % incidence of complete vertebral foramen penetration in a clinical series of 52 pedicles. The use of intraoperative image-guidance or stereotactic guidance can be considered. They may improve accuracy and significantly reduce the risk of neurovascular injury, especially in the cervical pedicle. However, the current technology is at its limits and we are not able to use these techniques.

A lot of clinical series have been published in the literature about CPSF, but no vascular complications of CPSF have been reported [3,16]. However, including our series, cases with massive encroachment of the transverse foramen by screw misplacement have been described. Abumi et al. included 9 cases with lateral screw perforation in their study, all without vertebral artery (VA) injury [4]. The VA does not occupy the entire transverse foramen, and the risk of injury may not be as high as most authors fear, although devastating sequelae may result from an acute lesion to this vessel [19] Careful drilling and tapping as well as cautious screw insertion seem only to displace the VA without damaging or obliterating it. Within the cervical spinal foramina, the nerve roots are located in the inferior half of the disc . We did not detect any cranial or caudal violations of the pedicle. This can be explained by the fact that cervical pedicles have an oval shape with a significantly greater height than width at all levels [9]

Per-operative neural injury or damage is a rather rare complication of CPSF placement. The incidence of nerve injury is reported to be only 1 % [4,9,12,14,27]. With this technique, by experienced surgeons, the incidence of neural injury was 0% in our series. The incidence of nerve injury of CPSF can be reduced with the mini-laminoforaminotomy. This hole may be explored in the lateral spinal canal at the same side.

CONCLUSION

Use of the CPSF provides a very strong three column stabilization but also carries a high risk of vascular injury without nerve damage. Postoperative CT scanning showed major breach in one pedicle (1.9 %) and minor breach in 7 pedicles(13.2 %) of 52 screws that have perforated the pedicle. CPSF can be performed in a one stage posterior procedure without the need of anterior surgery in trauma patients.

REFERENCES:

1. Anderson PA, Henley MB, Grady MS. Posterior cervical arthrodesis with AO reconstruction plates and bone graft. *Spine* 1991; 16 (3 Suppl): S72-79.
2. Abumi K, Kaneda K. Pedicle screw fixation for nontraumatic lesions of the cervical spine. *Spine* 1997; 22(16): 1853–1863.
3. Abumi K, Kaneda K, Shono Y, Fujiya M. One-stage posterior decompression and reconstruction of the cervical spine by using pedicle screw fixation systems. *J Neurosurg* 1999; 90(1 Suppl): 19-26.
4. Abumi K, Shono Y, Ito M, Taneichi H, Kotani Y, Kaneda K. Complications of pedicle screw fixation in reconstructive surgery of the cervical spine. *Spine* 2000; 25(8): 962–969.
5. Bale RJ, Hoser C, Rosenberger R,.Rieger M, Benedetto KP, Fink C. Osteochondral lesions of the talus: computer-assisted retrograde drilling-feasibility and accuracy in initial experiences. *Radiology* 2001; 218(1): 278–282.
6. Borne GM, Bedeu GL, Pinaudeau M. Treatment of pedicular fractures of the axis. A clinical study and screw fixation technique. *J Neurosurg* 1984; 60(1): 88-93.
7. Fehlings MG, Cooper PR, Errico TJ. Posterior plates in the management of cervical instability: long-term results in 44 patients. *J Neurosurg* 1994; 81(3): 341-349.
8. Garfin SR, Moore MR. Marshall LF. A modified technique for cervical facet fusions. *Clin Orthop Relat Res* 1988; (230): 149-153.
9. Heller JG, Silcox DH 3rd, Sutterlin CE 3rd Complications of posterior cervical plating. *Spine* 1995; 20(22): 2442-2448.
10. Holly LT, Foley KT. Percutaneous placement of posterior cervical screws using three-dimensional fluoroscopy. *Spine* 2006; 31(5): 536–540.

11. Jones EL, Heller JG, Silcox DH, Hutton WC. Cervical pedicle screws versus lateral mass screws. Anatomic feasibility and biomechanical comparison. *Spine* 1997; 22(9): 977-982.
12. Karaikovic EE, Yingsakmongkol W, Gaines RW Jr. Accuracy of cervical pedicle screw placement using the funnel technique. *Spine* 2001; 26(22): 2456-2462.
13. Kotani Y, Cunningham BW, Abumi K, McAfee PC. Biomechanical analysis of cervical stabilization systems. An assessment of transpedicular screw fixation in the cervical spine. *Spine* 1994; 19(22): 2529-2539.
14. Kothe R, Ruther W, Schneider E, Linke B. Biomechanical analysis of transpedicular screw fixation in the subaxial cervical spine. *Spine* 2004; 29(17): 1869–1887.
15. Ludwig SC, Kramer DL, Balderston RA, Vaccaro AR, Foley KF, Albert TJ. Placement of pedicle screws in the human cadaveric cervical spine: comparative accuracy of three techniques. *Spine* 2000; 25(13): 1655–1667.
16. McCullen GM, Garfin SR. Spine update: cervical spine internal fixation using screw and screw-plate constructs. *Spine* 2000; 25(5): 643-652.
17. Neo M, Sakamoto T, Fujibayashi S, Nakamura T. The clinical risk of vertebral artery injury from cervical pedicle screws inserted in degenerative vertebrae. *Spine* 2005; 30(24): 2800–2805
18. Rampersaud YR, Simon DA, Foley KT. Accuracy requirements for image-guided spinal pedicle screw placement. *Spine* 2001; 26(4): 352–359.
19. Rath SA, Moszko S, Schäffner PM, Cantone G, Braun V, Richter HP, Antoniadis G. Accuracy of pedicle screw insertion in the cervical spine for internal fixation using frameless stereotactic guidance. *J Neurosurg Spine* 2008; 8(3): 237-245.
20. Reichle E, Sellenschloh K, Morlock M, Eggers C. Placement of pedicle screws using different navigation systems. A laboratory trial with 12 spinal preparations. *Orthopade* 2002; 31(4): 368–371.
21. Reinhold M, Magerl F, Rieger M,.Blauth M. Cervical pedicle screw placement: feasibility and accuracy of two new insertion techniques based on morphometric data. *Eur Spine J* 2007; 16(1): 47–56.
22. Reinhold M, Bach C, Audigé L, Bale R, Attal R, Blauth M, Magerl F. Comparison of two novel fluoroscopy-based stereotactic methods for cervical pedicle screw placement and review of the literature. *Eur Spine J* 2008; 7(4): 564-575.
23. Richter M, Amiot L, Neller S, Kluger P. Computer-assisted surgery in posterior instrumentation of the cervical spine: an in-vitro feasibility study. *Eur Spine J* 2000; 9 Suppl 1: 65-70.
24. Richter M, Cakir B, Schmidt R. Cervical pedicle screws: conventional versus computer-assisted placement of cannulated screws. *Spine* 2005; 30(20): 2280–2287.
25. Rezcallah AT, Xu R, Ebraheim NA, Jackson T. Axial computed tomography of the pedicle in *the lower cervical spine. Am J Orthop* 2001; 30(1): 59–61.
26. Sakamoto T, Neo M, Nakamura T. Transpedicular screw placement evaluated by axial computed tomography of the cervical pedicle. *Spine* 2004; 29(22): 2510–2514.
27. Ugur HC, Attar A, Uz A. Surgical anatomic evaluation of the cervical pedicle and adjacent neural structures. *Neurosurgery* 2000 ; 47(5): 1162–1168.
28. Yusof MI, Ming LK, Abdullah MS, Yusof AH. Computerized tomographic measurement of the cervical pedicles diameter in a Malaysian population and the feasibility for transpedicular fixation. *Spine* 2006; 31(8): E221–E224.