Screw fixation via diploic bone paralleling to occiput table: anatomical analysis of a new technique and report of 11 cases

Tan Mingsheng · Wang Huimin · Jiang Xin ·
Yi Ping · Wei Hongyu · Yang Feng ·
Wang Wu · Zhang Guangbo

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Abstract Several types of posterior approaches have been adopted for occipitocervical fusion. Prior to this study, Foerster et al. in 1927 used a fibular strut graft in the site between the occiput and the lower cervical spine to achieve fusion. Since then, various techniques including wrings, Hartshill loop, AO reconstructive plate, and AXIS occipital plate were described and used widely. As far as we know, all these techniques involve the screw placement vertical to the diploic bone; however none has ever addressed the feasibility of screw placement in occiput paralleling to the diploic bone. In our study, 30 dry specimens of human occiputs were measured manually using vernier calipers and protractors. The intradiploic screw was first supposed to be inserted inferiorly to the superior nuchal line (SNL) prominence. The entry point located at the superior edge of the SNL prominence. Afterward, the measurements of extracranial occiput in SNL area on midline and bilateral 15 mm to the midline sagittal-cutting planes of the occiput were conducted. The thickness of the occipital bone at the location of SNL prominence, the entry point, the exit point and the screw orientation were measured, respectively. Afterward, 11 patients with craniocervical malformation were treated surgically using this alternative and their X-ray radiographs and CT scans were evaluated postoperatively. The data

showed that the occipital at the site of SNL prominence was the thickest. The thickest point was external occipital protuberance (EOP), which was up to 14 mm. The thickness decreased gradually from the site of SNL to the superior border of surgical decompressed area. The actual length of screw channel was about 26 mm. The mean thickness for safe screw insertion ranged from 5.73 to 14.14 mm. A total of 22 intraocciput screws parallel to diploic bone were placed precisely, without injury to the cerebral and inner occipital venous sinus. The results confirm that occiput is available for holding intraocciput screw paralleling to diploic bone.

Keywords Antomy · Occiput · Diploic bone · Occipitocervical instability · Screw fixation

Introduction

Craniocervical fusion may be indicated for the instability of the craniocervical junction caused by rheumatoid disease, tumor, trauma, congenital malformations or iatrogenic disorders to the upper cervical spine [15]. In order to reach instant stability and avoid using postoperative rigid external support, the internal fixation was recommended by many surgeons in recent years. The use of wires, screws, rods, and plates was well described [3, 7, 8, 16, 18]. However, the biomechanical study showed that the plate–screw construct could provide better occipitocervical stability under cyclic loading conditions [4]. Because the thickness of the occipital bone in the lateral region was only 2–6 mm, the instrument complications such as screw loosening, stability deficiency and inner occipital table penetration, were frequently encountered in clinical practice [3, 9]. The anatomic studies suggested that the external occipital protuberance

T. Mingsheng · J. Xin · Y. Ping · W. Hongyu · Y. Feng ·
W. Wu · Z. Guangbo
China-Japan Friendship Hospital, Department of Orthopedic
Surgery, Beijing, China

W. Huimin (✉)
Guangdong Provincial Hospital of TCM,
Department of Orthopedic Surgery, Num 111,
Da De Road, Guangzhou 510000, China
e-mail: whuimpeter@yahoo.com

(EOP) and the site adjacent to the superior nuchal line and external crest were composed of dense cortical bone and the occipital bone in these sites were relatively thicker [5]. So some surgeons advocated the use of unicortical screw at occipital protuberance, and the screws should be directed toward the EOP to minimize the risk of penetration of the inner occipital table [5, 11].

The superior biomechanical features of transpedicular screw in cervical spine, as well as in lumbar and thoracic spine, are achieved and generally accepted [2]. Our report describes a new technique, which is defined as intradiploic screw paralleling to occiput. The feasibility was explored on the basis of the anatomic study of 30 isolated human skulls. The entry point and the screw trajectory were analyzed. In addition, 11 patients indicated with craniocervical instability were successfully treated by this technique.

Materials and methods

Anatomic study

Thirty adult dry skulls were obtained commercially. All anatomic parameters were measured by vernier calipers (precision, 0.02 mm) and goniometers (precision, 1°). The screw used in this study was supposed to be inserted downwardly through the region of SNL prominence. The entry point located at the superior edge of the SNL prominence. Measurement on occiput related to this technique contained two parts:

1. Extracranial occiput termed as SNL zone (Fig. 1)
2. Fifteen millimeter lateral to the midline of the occiput on the saggital plane (Fig. 2).

Patients and techniques

A total of 11 patients with upper cervical disorders necessitating reoperation from June 2002 to March 2006, were reviewed retrospectively. All cases underwent the surgical protocol of combining screws via diploic parallelly and cervical spine pedicle screws instruments. Of these patients, there were 7 cases with type Chiari I malformation, 4 cases with recurrent cervical tumor, prior to this surgery, they all underwent the first operation due to the original disease. The JOA scoring system was used to evaluate each patient's neurological status, and the radiological files were collected to demonstrate the fusion status. The thickness of the occipital bone in the midline and 15 mm lateral to the midline positions were measured in the lateral radiograph and CT scans of occiput, and all

Fig. 1 Measurements on the extracranial occiput in the SNL area. *A*, entry point which locate at the superior edge of SNL prominence and the parallel line 15 mm lateral to the midline of the occiput. *B*, the exit point lies 15 mm lateral to the midline and 15 mm below the EOP center. *AB*, the distance between point *A* and *B*, that was the projection of screw path on the occipital surface

Fig. 2 Measurements on the saggital-cutting plane 15 mm lateral to the midline of the occiput. *B'*, 2 mm beneath point *B* at the external surface of bone. *T_A*, *T_B*, the thickness of the occipital bone at the location of point *A* or *B*. *AB'*, the actual length of the screw path

these data were used intraoperatively. The patients' data were seen in Table 1.

Surgical technique

A posterior midline incision extending from the site 2 cm above the EOP to the C3 spinal process was made. The paraspinal muscle was dissected to expose the occiput and C1–C2 laminae. Based on the anatomic studies of dry occipital bones and the measurements before the surgery, entry point was determined as 15 mm lateral to the posterior to the midline at the level of superior edge of SNL. And the screw path and its length were determined during the operation. A hole with 10 mm in diameter at the position of the exit point were burred. With the help of a special guide (Fig. 3), the exit point was determined with the line connecting the entry point and exit point paralleling to the midline. If patient need decompression of the foramen magnum, the exiting point of the screw was regarded as the site located at the superior edge of the decompression zone. Screw placement in C2 in our report was conducted according to Ebraheim method [6] and other transpedicular screw fixation in lower cervical spine was inserted referencing to Abumi method [1]. Prebending the rod and securing the procedure with the help of a special slotted connector (Fig. 4) which had a Z-shape structure with two parallel holes holding the screw and the rod simultaneously. The spine lamina and the occiput table were spurred to perform autogenous iliac crest bone graft.

The statistical differences between two sides were analyzed by Student's *t* test. The confidence for significance was defined as $P \leq 0.05$ (Figs. 5, 6).

Results

Based on 30 specimens, each parameter on the left and right side was shown as follows (Table 2).

The mean distance of the screw trajectory was 26 mm. The mean thickness in this site ranged from 5.73 to 14.14 mm. The thickness of the occipital table inferior and superior to the SNL decreased gradually, with the narrowest site still higher than 5.7 mm. The actual length of screw path was about 26 mm.

Although all paired parameters on the atlas were measured individually on the left and right side, no statistical difference was found.

The results of anatomic measurement of 11 patients in radiology before and after the operation were consistent with the data obtained from dry bone anatomic study. Satisfactory screw placement was achieved in all patients. The screw used in the surgery was 26 mm in length and

3.5 mm in diameter. The mean operation time was 3.45 h (2.5–5.5 h) and the mean blood loss was 450 ml (250–1,600 ml). Patients' neurological function improved significantly at the final follow-up. The mean JOA score of the patient improved from 10.15 preoperatively to 14.64 postoperatively. No case of neurovascular injury and implant failure was noted. No penetration into the inner occipital table was found on the postoperative radiographs and CT scans. At the final follow-up, all patients demonstrated radiographic evidence of solid bony fusion.

Discussion

Feasibility of instrumentation with screw paralleling to the occiput table

Internal fixation with plates and screws has been recommended for craniocervical fusion by most of the surgeons recently. The anatomic study of the occipital bone is the key for safe screw placement in the occiput. EOP is situated at the center of the external surface of the squamous portion of the occiput. The cortex of the occipital bone above the EOP and the superior nuchal line, which extends laterally from the protuberance, is much thicker and occupies much cortical bone. The thickness inferior to the EOP and SNL is decreased and has much variance. The regions surrounded by the SNL and the midline through the EOP are the best sites for rigid screw fixation in occiput [5, 10, 14, 19].

Olivier [13] noted that the mean thickness of the protuberance in dry skulls was 15.6 mm in males and 13.9 mm in females. Sasso et al. [17] reported the mean thickness of the occipital bone at the SNL was 14 mm in the median zone, 6.6 mm in the right paramedian zone, and 5.7 mm in the left zone. The results of the anatomic study of occipital bone by Ebraheim were closed to the above measurements. Because the venous sinuses situated below the EOP prominence, he suggested that the screws with the length of 8–12 mm should be used around the EOP. The screw should be directed toward the EOP to minimize the risk of screw penetration out the inner occipital table [5].

The anatomic data in the current study indicate that the mean thickness of the occipital bone 15 mm below the EOP center is 10.6 mm and the thickness of the bone 15 mm lateral to EOP center is about 6 mm. The thickness of the bone increased gradually above EOP center, and then decreased at the superior edge of the SNL, where the thickness is still above 6 mm. It can be confirmed that the thickness of occipital bone in this area is larger than 6 mm, which can hold a screw with 26 mm in length and 3–4 mm in width.

Table 1 Patient demographic and clinical data

Case no.	Age (years), Gender	Symptoms or signs	Diagnosis	Previous operation (type and result)	Duration of follow-up (months)	Outcome (JOA score)		Complication
						Before operation	At final follow-up	
1	48, Female	Pain in occipitocervical region, progressive unsteady walk, both upper limbs numbness and weakness for 12 years	Chiari I Malformation	Decompression of foramen magnum, C0–C3 internal fixation and fusion, C1–C2 dislocation with internal fixation failure	58	8	14	None
2	39, Male	Pain in neck and shoulder, upper and lower limbs numbness and weakness for 6 years	Chiari I Malformation	Only decompression of foramen magnum region with no internal fixation and fusion, C1–C2 dislocation	22	11	15	None
3	37, Male	Pain in occipitocervical region, neck stiffness, and limbs numbness for 5 ys	Chiari I Malformation	Decompression of foramen magnum, C0–C5 internal fixation and fusion, internal fixation failure	12	13	16	None
4	38, Female	Pain in occipitocervical region, dizziness, unsteady walk, both upper limbs numbness for 16 years	Chiari I Malformation	Decompression of foramen magnum, C0–C4 internal fixation and fusion, internal fixation failure	46	8	13	None
5	39, Male	Pain in neck and shoulder, limited motion of neck and limbs numbness and weakness for 8 ys	Chiari I Malformation	Decompression of foramen magnum, with no internal fixation and fusion, C1–C2 dislocation aggravation	26	11	16	None
6	62, Male	Pain in occipitocervical region, limited motion of neck limbs numbness and claudication for 15 years	Chiari I Malformation	Decompression of foramen magnum region with no internal fixation and fusion, C1–C2 dislocation aggravation	42	10	15	None
7	41, Male	Pain in occipitocervical region, unsteady walk, both upper limbs numbness and weakness for 20 years	Chiari I Malformation	Decompression of foramen magnum region, C0–C7 internal fixation and fusion, internal fixation failure	18	6	11	None
8	45, Female	Pain in neck and shoulder, limbs numbness and claudication for 15 years (the forth operation)	C2–C5 Neurilemoma	Resection of C2–C5 laminae and tumor three times without internal fixation C1–C2 dislocation	42	8	13	None
9	29, Male	Pain in occipitocervical region, limited motion of neck and upper and lower limbs numbness for 6 years	Giant cell tumor of bone in C1 lateral mass	Resection of the tumor and occipitocervical internal fixation and fusion internal fixation failure and C1–C2 dislocation	24	11	15	None
10	50, Female	Pain in neck and shoulder, upper and lower limbs numbness	C1–C2 Neurilemoma	Resection of C1–C2 laminae, spinous process and tumor without internal fixation C1–2 dislocation	18	12	16	None
11	44, Male	Pain in occipitocervical region, limited motion of neck, and limbs numbness for 5 years	C1–C2 Neurilemoma	Resection of C1–C2 laminae, spinous process with internal fixation and fusion internal fixation failure and C1–C2 dislocation	10	14	17	None

Fig. 3 Special guide

There are two reasons for lateral border of SNL prominence not suitable to be selected as entry point. First, much variance exists at this region. Second, exposure of this region needs extensive dissection of the scalp and subcutaneous tissues. Current study indicates that the external table of the occiput is vault-shape, which is extinctive at the EOP where the thickness is up to 14 mm. The thickness above and below the SNL prominence becomes less with the least thickness of 6 mm. The midline of the occipital and the superior border of the SNL can be selected as bony symbols. Another reason for this is that there is more manipulating place for screw insertion in the surgery. The entry point locates 15 mm lateral to the midline at the level of the superior border of the SNL prominence. The exiting point lies 15 mm lateral to the midline and 15 mm below the EOP center. Because the superior nuchal line and the ridges are adjacent to the transverse dural venous sinuses, the occipital screw should be inserted accurately. So the screw is placed parallel to the occipital table with screw tunnel locating between the outer and inner occiput, and exit from the superior rim of the occipital decompressional area. The postoperative radiograph indicated that the 22 occipital screws were placed accurately.

The features of this novel instrumentation

Since Foerster's first description of occipitocervical reconstruction using a fibular strut graft in 1927, many stabilizing procedures with and without internal fixation have been reported for craniocervical reconstruction. Most conventional techniques using posterior wiring require long fusions and/or postoperative rigid external support due to insufficient initial stability [12]. Recently, short-segmental fixation using plate and screws had been reported. This technique can provide better spine stability under cyclic loading. For some patients, sufficient decompression of the occiput may be accomplished to guarantee the long-term effect. The preliminary studies show that the thickness of the occipital bone in the median plane is about two times than that in the paramedian plane. The screw pullout strength is correlative to the screw length biomechanically [5, 10, 14, 19]. The screws of previous noted techniques are placed vertically to the occipital tables. Because the thickness in the lateral zone of the occiput is only 2–6 mm, screw loosening and penetration out of the inner occipital table cannot be avoided if screws are placed vertically to the occipital tables. Based on these considerations, we performed the anatomic studies on the EOP and SNL prominence of the occipital bone. The screw we used is parallel to the inner and outer occipital tables and is just passing through the diploic bone of the occipital bone.

The properties of this technique are as follows. First, it has longer screw path. The outer, middle and inner table contributes 45, 45 and 10%, respectively to total occipital thickness. The outer and inner tables are almost cortical bones while the middle portion is cancellous bone [19]. The diploic screws come into the posterior surface of the outer table at the location of superior border of SNL prominence, pass through the diploic bone, and exist between the outer and inner tables. The screw trajectory in

Fig. 4 Illustrations of instrumentations. **a** Secure the screw and the rod with the help of a slotted connector. **b** Posterior view of instrument

Fig. 5 A case of 48-year-old female with basilar invagination who underwent decompression and reconstruction using this implant. **a** Intraoperative photograph. **b** A-P and lateral view of photograph taken three months after the surgery; **c, b** A-P and lateral view of photograph taken 3 years after the operation, showing obviously bony fusion

Fig. 6 A CT slice of the screws

this method is about 4–6 times longer than that in conventional techniques. The screws occupy larger cortical bone and are relative longer, which result in the greater contact area between screws and bone. Second, this technique is safer than conventional method, according to the anatomic studies on occiput, the thickness of the occipital bone at whole screw trajectory is more than 6 mm, and the screw can be inserted accurately. The possibility of

Table 2 Measurements on the occiput (mm)

	Left	Right	Mean
AB	26.85 ± 3.32	25.62 ± 3.54	26.25
T_A	6.04 ± 1.44	6.42 ± 1.74	6.24
T_B	5.81 ± 1.63	5.65 ± 1.71	5.73
AB'	26.54 ± 2.12	25.86 ± 2.43	26.21

Data are defined as mean $\pm$ standard deviation. No significant difference was found between left and right sides of specimens in all parameters

AB the projection of screw path on the occipital surface, AB' the actual length of the screw path, T_A , T_B the thickness of the occipital bone at the location of point A, B

penetration out of inner occipital table is relatively lower. Finally, it uses less number of screws to perform the craniocervical fusion. For conventional method, at least six screws are needed to fix the occiput, which bring about the result of decreasing the area of occipital bone graft bed for occipitocervical fusion. Furthermore, so much screws placing in the variable occiput will increase risk of damaging the cerebral tissue and occipital venous sinuses. However, in our method, only two screws are needed to fix the occiput which can provide much area for the bone struts fusion. The long-term fusion effect has proved this;

however its actual biomechanical features are expected to be explored.

In summary, the anatomic study shows that occiput is capable for this kind of instrumentation. This technique is easier to be manipulated and can minimize the risk of injury to the cerebral tissue and inner occipital venous sinuses. The shortcomings of this study exist on the not enough patients and short time follow-up period. Biomechanical tests, operative indications, and further anatomic and clinical studies associated with the technique are being explored now.

References

1. Abumi K, Ito H, Taneichi H, Kaneda K (1994) Transpedicular screw fixation for traumatic lesions of the middle and lower cervical spine: description of the techniques and preliminary report. *Spinal Disord* 7:19–28
2. Abumi K, Kaneda K (1997) Pedicle screw fixation for nontraumatic lesions of the cervical spine. *Spine* 22:1853–1863
3. Bridwell KH, DeWald RL (1997) *The textbook of spinal surgery*. Lippincott-Raven, Philadelphia, pp 986–990
4. Doherty BJ, Esses SI, Heggeness MH (1991) A biomechanical study of occipital–cervical fixation. Presented at the Cervical Spine Research Society, Philadelphia, Pennsylvania
5. Ebraheim NA, Lu J, Biyani A, Brown JA, Yeasting RA (1996) An anatomic study of the thickness of the occipital bone: implications for occipitocervical instrumentation. *Spine* 21:1725–1730
6. Ebraheim N, Rollins JR Jr, Xu R, Jackson WT (1996) Anatomic consideration of C2 pedicle screw placement. *Spine* 21:691–695
7. Flint GA, Hockley AD, McMillan JJ, Thompson AG (1987) A new method of occipitocervical fusion using internal fixation. *Neurosurgery* 21:947–950
8. Grob D, Dvorak J, Panjabi M, Froehlich M, Havek J (1991) Posterior occipitocervical fusion—a preliminary report of a new technique. *Spine* 16:S17–S24
9. Grob D, Dvorak J, Panjabi MM, Antinnes JA (1994) The role of plate and screw fixation in occipitocervical fusion in rheumatoid arthritis. *Spine* 19:2545–2551
10. Maher TR, Yeung AW, Caruso SA, Merola AA, Shin T, Zipnick RI, Group JM, Bono C (1999) Occipital screw pullout strength: a biomechanical investigation of occipital morphology. *Spine* 24:5–9
11. Heywood AW, Learmonth ID, Thomas M (1988) Internal fixation for occipitocervical fusion. *J Bone Joint Surg Br* 70:708–711
12. Oda I, Abumi K, Sell LC, Cunningham BW, McAfee PC (1999) Biomechanical evaluation of five different occipito-atlanto-axial fixation techniques. *Spine* 24:2377–2382
13. Olivier G (1975) Biometry of the human occipital bone. *J Anat* 120:507–518
14. Roberts DA, Doherty BJ, Heggeness MH (1998) Quantitative anatomy of the occiput and the biomechanics of occipital screw fixation. *Spine* 23:1100–1108
15. Robertson SC, Menezes AH (1998) Occipital calvarial bone graft in posterior occipitocervical fusion. *Spine* 23:249–253
16. Sandhu FA, Pait TG, Benzel E, Henderson FC (2003) Occipitocervical fusion for rheumatoid arthritis using the inside–outside stabilization technique. *Spine* 28:414–419
17. Sasso RC, Jeanneret B, Fischer K, Magerl F (1994) Occipitocervical fusion with posterior plate and screw instrumentation. A long-term follow-up study. *Spine* 19:2364–2368
18. Smith MD, Anderson P, Grady MS (1993) Occipitocervical arthrodesis using contoured plate fixation. An early report on a versatile fixation technique. *Spine* 18:1984–1990
19. Zipnick RI, Merola AA, Gorup J, Kunkle K, Shin T, Caruso SA, Maher TR (1996) Occipital morphology: an anatomic guide to internal fixation. *Spine* 21:1729–1730