The indications of upper cervical fusion include inflammatory disorders, trauma, neoplasms, degenerative arthritis, and congenital conditions. Various methods of posterior short-segment fixation and fusion have been described in the treatment of patients with upper cervical instability, including sublaminar wires, hooks, clamps, and Magerl's screws. Over the past several years, C1 lateral mass screws have become a popular option for achieving stable fixation of posterior atlantoaxial instability. However, the posterior arch at the position of the vertebral artery groove can be regarded as another vertebral pedicle, and lateral mass be regarded as another vertebral body. Therefore, the screw fixation via posterior arch and lateral mass in atlas resembling pedicle screws fixation can be achieved. The technique is different from C1 lateral mass screw fixation and the screw is inserted through the posterior arch and lateral mass in C1. In this report, we present our experience with this technique during the course of 36 months from Oct. 2004 to Oct. 2007.

METHODS

Clinical profile

Twenty-three patients with upper cervical disorders requiring stabilization were treated by posterior fixation and fusion using the atlas pedicle screw system at our department between Oct. 2004 and Oct. 2007. There were 16 males and 7 females, ranging in age from 19 to 52 years, with a mean age of 38 years. Based on the pathogenetic mechanisms, atlantoaxial dislocation was
in 19 patients, including 4 congenital odontoid disconnections, 6 old odontoid fractures, 4 fresh odontoid fractures (Aderson II C), 3 rupture of the C₁ transverse ligaments, and 2 fracture of C₁; C₂ tumor was in 2 patients (1 metastatic carcinoma, 1 chordoma); giant neurilemoma of C₂-C₃ was in 2 patients with instability after the resection of the tumors. All patients had neck pain and limitation of cervical motion. Twenty-one patients had sensory and motor disturbance of limbs.

Operative technique

After the patients were treated by skull traction and underwent general anesthesia, they were put in a prone position (C₂ tumor was resected through transoral approach first). The lateral masses of C₁-C₄ vertebrae were exposed through an approximately 6 cm longitudinal midline skin incision from occipital tuberosity to spinous process of C₄. Lateral masses of C₂-C₄ were exposed widely and the posteriors arches of C₁ were dissected subperiosteally to 2 mm lateral to the midline of C₂-C₄ lateral masses. The giant neurilemoma of C₂-C₃ was dissected. The Summit screw-rod system (Depuy, USA) or PCF screw-rod system (Weigo, China) was used to all patients with 3.5 mm in diameter of universal screws, 26-30 mm in length (mean 28 mm) of C₁ screws and 24-28 mm length (mean 26 mm) of C₂ screws. The entrance site of C₁ screw was approximately 1-2 mm lateral to the midline of the lateral masses C₂-C₃ and 1-2 mm superior to inferior border of C₁ posterior arch. The outer cortex was tapped. Holes, 2.0 mm in size, were drilled. The screws were angled medially less than 10° and cephalad approximately 5°. Entrance point in C₂ was chosen to locate in the medial-superior quadrant of lateral mass (2 mm medial-superior to the central point of lateral mass). The screws were placed medially 25° and cephalad 25°, penetrating the anterior cortex or not. Lateral mass or pedicle screws fixation was performed in C₃ or lower. The screws were determined by the C-arm. Rods were then connected to the multiaxial screws. Cancellous bone granules of iliac crest or iliac crest bone flaps were placed between the laminas after decortication.

Fig. 1. Neutral, flexion and extension lateral x-ray films (A-C) and 3-D computed tomographic reconstruction (D, E) obtained from a 32 years old male patient with congenital odontoid disconnection and atlantoaxial dislocation preoperatively. Lateral x-ray film (F) of the cervical spine obtained 2 weeks postoperatively demonstrating a good reduction and fixation. Lateral x-ray films (G, H) of the cervical spine obtained 3 months and 10 months and computed tomographic reconstruction (I) obtained 6 month postoperatively demonstrating rigid bony fusion.
Postoperative evaluation and follow-up

Operative time, bleeding volume, and complications were recorded. All patients were immobilized without external fixation or with a collar for 1-3 months. All patients were followed up and evaluated at 1, 3, 6, 12 and 18 months by radiographs. The patients were also evaluated by CT at 3 or 6 months to verify arthrodesis.

RESULTS

Among the 23 patients, 46 C1 pedicle screws, 42 C2 pedicle screws and 6 lower cervical lateral mass screws and 2 pedicle screws were placed. Postoperative X-rays demonstrated good alignment of the spine and satisfactory screw position. The mean operative time and bleeding volume was 2.7 hours and 490 ml respectively. No intraoperative complications were directly related to surgical technique. No neurological, vascular or infective complications were encountered. All the 23 patients in our series showed signs of clinical and neurological recovery of varying degrees.

All patients were followed up for 3-36 months (average 15 months). Firm bony fusion was documented in all patients after 3-6 months. One patient with atlas fracture showed anterior occipitocervical fusion, resulting from heterotopic ossification due to anterior atlantooccipital membrane injury. There was no implant failure. Two typical cases were exhibited in Figs. 1 and 2.

DISCUSSION

C1 pedicle screw placement is technically demanding. Practice in the cadaver lab, intimate knowledge of the patient’s peculiar anatomy and clinical experience are reported by Resnick, Tan, Ma, et al.2,4,6,7 In this study, we evaluated the feasibility, safety and efficacy of atlas pedicle screws system fixation and fusion for the treatment of upper cervical diseases.

Feasibility of the placement of atlas pedicle screws

The posterior arch of C1 at the position of the vertebral artery groove can be regarded as other vertebral pedicle, and lateral mass be regarded as other vertebral body. Therefore, the screw fixation via posterior arch and lateral mass in atlas resembles pedicle screws fixation. The technique is different from the Harms technique, which is C1 lateral mass screw fixation. The quantitative anatomy of the atlas has been reported. Ma et al.8 reported the feasibility of posterior pedicle screws placement on atlas. They measured the mean width of the mid-portion of the C1 lateral mass and it was 12.78 mm ± 1.14 mm, and that of the C1 pedicle was 8.57 mm ± 0.65 mm, respectively. The mean width of C1 posterior arch under the vertebral artery groove was 8.46 mm ± 0.57 mm, and the height of this portion, 3.88 mm ± 0.52 mm for medial one-third and 4.25 mm ± 0.51 mm for lateral one-third. This dimension represents the working area for a screw placed below the...
vertebral artery groove in the posterior arch. It is possible to place a 3.5-mm diameter screw in the lateral part of C1 posterior arch by proper surgical technique.\(^6\)\(^8\) Some authors advocate lateral mass fixation and believe it is safer than C1 pedicle screws if the height of C1 posterior arch under vertebral artery groove is less than 4.0 mm.\(^6\)\(^8\) Whichever a part of the cortex in inferior border of posterior arch might be penetrated because of the height of posterior arch less than 3.5-4.0 mm at entrance point or iatrogenic reasons, the notching technique is possible in these patients.\(^9\) We recommend inserting the C1 pedicle screws if only posterior arch and pedicle are present at entrance point even if the height of posterior arch less than 3.5-4.0 mm because the increase of height in the connection portion of pedicle and lateral mass ensure the large part of the screw being in the pedicle, in which biomechanical strength is better or at least equal to the lateral mass screw theoretically. He et al\(^10\) reported if the height of the pedicle under the groove for vertebral artery at the entry path was 1.75-3.5 mm, the pedicle screws fixation could be achieved by the entrance point at posterior arch and partly drilling through or passing the posterior arch. When it was less than 1.75 mm, the entrance point should be at the connection of atlas lateral mass and pedicle. In the present study, the height of the pedicle under the groove for vertebral artery at the entry path was more than 3.5 mm. To our knowledge, though the width of pedicle and lateral mass is enough to hold a 3.5-mm screw, figure characteristics and anatomic variation of lateral mass should be considered. When performing the technique, we generally regulate the angle of medial and cephalad inclination to avoid penetrating the medial-superior cortex of lateral mass into atlantooccipital joint.

Placement of atlas pedicle screws

A variety of options have been described for entrance point and trajectory of C1 pedicle screws fixation. Resnick et al\(^2\) reported that the entrance points in C1 were chosen to be directly rostral to the C2 screws in the rostrocaudal midportion of the lamina of C1 and the screws were angled medially approximately 10° to avoid the vertebral foramen. Tan et al\(^4\) advocate that the entry point is 18-20 mm lateral to the midline and 2 mm superior to the inferior border of posterior arch. The direction of screw placement is perpendicular to the coronal plane and about 5° cephalad to the transverse plane, which is similar to that of Resnick et al. Ma et al\(^7\) placed the screw 3 mm inferior to the superior border of posterior arch and in the midline between C1 inferior articular process and C2 C2 lateral mass, medially 10°, cephalad 5°. In this method, the entry point is more laterally than the two methods mentioned above.

According to Ma’s method, we performed the screw fixation via posterior arch and lateral mass in atlas by individual surgical scheme. The height of the pedicle under the groove for vertebral artery was ascertained by preoperative 3D CT reconstruction. If it was more than 4 mm, the entry point was 2 mm superior to inferior border of posterior arch; if it was less than 4 mm, the entry point was 1-1.5 mm superior to inferior border of posterior arch. The lateral mass of C1 is characterized as lateral higher than medial, posterior higher than anterior, inferior wider than superior. We advocate that the entrance point and trajectory of screw placement are more lateral, inferior, perpendicular (avoiding beyond medial inclination) and regulate the cephalad angle. To enhance the accuracy of the surgical procedure, the local anatomy of the upper cervical region and individual variations of posterior arch and lateral mass structures should clearly be understood before surgery. Preoperative planning with lateral radiographs and CT scans of atlas is helpful in locating the entry point and regulating the screw direction. In our clinical practice, the screw direction has to be controlled properly during the operation and individual insertion of the screw should be taken into consideration. The internal carotid artery is at risk during bicortical screw fixation of the atlas.\(^11\) Surgical technique must be precise to ensure that the screw does not extend beyond the bone membrane of anterior cortex of C1.

Advantages of C1 pedicle screws-rod fixation

C1 wiring and clamps fixation techniques contribute a lot to the treatment of atlantoaxial instability. Though these procedures are easily accomplished, stability remains a problem. They are stable in flexion-extension but not in rotation and lateral bending. Magerl’s screw fixation technique displays a better fixation and immediate postoperative stability than wiring and clamps techniques.\(^1\)\(^9\) However, this type of screw fixation is only adapt to the lanky cases with a good flexibility of lower cervicle\(^12\) and is associated with the risk of vertebral artery injury\(^2\) in some patients because of the position of the vertebral artery. The presence of a high-riding vertebral artery, which may occur in up to 23% of
patients, is a contraindication to placement of Magerl’s screws. In others, the technique is difficult because of body habitus, such as obesity, swan neck deformity or humpback. Pedicle screw system and lateral mass screw system have proved to be rigid and safe. The screws can be inserted before the reduction is accomplished, and they can be used to achieve better reduction. However, the lateral mass screw placement needs to expose and dissect C₂ nerve root and vertebral venous plexus, which is difficult to operate and may cause refractory bleeding. Refractory bleeding of venous plexus would compel screw fixation only in one side or other fixation technique.\textsuperscript{13-15} Naked screw threads may be potentially dangerous to C₂ nerve root and veinplexus\textsuperscript{16} and bicortical fixation may be required because the depth of screw in bone is obviously less than pedicle screws. Some studies showed the biomechanical intensity of lateral mass screw-rod system was similar to Margerl screw system, and unicortical fixation of pedicle was similar to bicortical fixation of lateral mass.\textsuperscript{16,17} Universal screw-rod system is easier to perform than screw-plate system, and has higher intensity because of its connecting and locking patterns. It could be taken off and refixed for adjusting its curvature degree if the reduction is not satisfactory after fixation. Occipitocervical fixation will enormously restrict the cervical and cephalic motions, which is only applied to the patients who were not suitable to C₁ fixation or occipitocervical instability; or used as temporary fixation before bone fusion.

**Indications of C₁ pedicle screws-rod system**

C₁ pedicle screw system can be used as a successful anchor for correction and fusion of a variety of atlantoaxial, and occipitocervical problems, including some of the most difficult pathologies in this area such as fresh Aderson II C odontoid fracture, old odontoid fracture, rupture of the transverse ligament, odontoid deformity, atlantoaxial dislocation caused by rheumatoid, and metastatic disease. The optimum method for C₁ fractures remains a point of debate. Some authors advocate nonoperative management by semi-rigid or rigid external immobilization for C₁ fracture. Some authors propose that C₁ fracture may be considered for surgical fixation and fusion by first-stage operation if there is a definite atlantoaxial instability.\textsuperscript{16} Gallie wiring, Brooks wiring, Halifax clamp, Apofix clamp fixation are all performed via C₁ posterior arch approach, which is not suitable for fresh C₁ fracture, and must be applied after the fusion of posterior arch and lateral mass. Magerl screws do not rely on posterior arch approach, so they can be used for C₁ fractures when the C₁ arch is deficient.

The technique of C₁ pedicle screws provides immediate rigid fixation,\textsuperscript{13} allows for screw bicortical placement, and appears to be widely applicable in selected C₁ fractured patients. Theoretically, C₁ pedicle screw fixation and fusion are only contraindicated when bilateral or one side screw trajectory is obviously destroyed by serious burst fracture, tumor of lateral mass or tuberculosis, which may obviously affect the atlas fixation stability. At that condition, other short-segment fixations such as wiring system, clamps system, Margerl’s screws are also contraindicated, and occipitocervical fixation may be the alternatively surgical method. Therefore, C₁ pedicle screw system fixation and fusion are applicable to all C₁ fractured patients, except those in whom occipitocervical fixation is required.

Posterior fixation and fusion with the atlas pedicle screw system as an alternatively technique provides immediate rigid fixation, has superior biomechanical properties. This procedure is technically demanding and careful preoperative planning and meticulous surgical technique are necessary to place the screws safely. It may be applicable to a larger number of patients.

**REFERENCES**


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