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Application of three-dimensional model in the management of irreducible atlanto-axial dislocation

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Objective: The aim of this study was to describe the application of the rapid prototyping (RP) life-size 3-dimensional model used to improve accuracy of screw insertion in irreducible atlanto-axial dislocation (IAD).

Methods: The study included 10 patients with IAD. All patients were assessed using the Japanese Orthopedic Association (JOA) score. Radiographs, MRI and CT were conducted during the preoperative and postoperative procedure. A 3D RP model was created for each patient. The model was used to obtain detailed information of each pedicle and used as an intraoperative reference. Assisted by the model, transoral atlanto-axial reduction plate fixation was performed in each case.

Results: The average operation time was 145 (range: 90 to 180) minutes and average blood loss was 120 (range: 60 to 250) ml. JOA scores improved after surgery. All 40 transoral pedicle/lateral mass screws were placed without serious complications or internal fixation failure. Postoperative radiographs and CT scan showed 38 transoral pedicle/lateral mass screws located in the pedicle tracts. Satisfactory reduction was achieved in 95% of screws. Two screws perforated the lateral wall of the C2 pedicles in an extremely narrow pedicle case. No neurologic sequelae or vertebral artery injury were detected.

Conclusion: The RP technique is effective and reliable in achieving an accurate and safe screw insertion during IAD surgery, especially in anatomically abnormal cases.

Key words: Anatomic model; atlanto-axial instability; atlanto-axial joint; rapid prototyping.

Irreducible atlanto-axial dislocation (IAD) is result of the development of ossifications or scarring in the synovial pannus between the odontoid and the axis and includes basilar invagination, malunion of a fracture of the upper spine and rheumatoid arthritis. Decompression of the spinal cord and stabilization of the atlanto-axial joint is needed. However, due to its special and complex anatomic structures, IAD presents a notoriously difficult surgical challenge. At present, traditional radiographs, CT scan or MRI are used in diagnosis, preoperative planning and postoperative assessment. However, these 2-dimensional images provide limited morphometric information about the abnormality of the spine.[1]

The new advanced technology of rapid prototyping (RP) creates a life-size 3-dimensional model based on CT digital imaging.[2] The 3-dimensional anatomy structure can improve the diagnosis, preoperative planning and accuracy of screw placement during surgery.

To our knowledge, the literature is limited on the use of RP technique in the management of IAD.[3] In this

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study, we aimed to describe the application of life-size 3-dimensional models prior to surgery for patients with IAD.

Patients and methods

The study included 10 patients (4 male, 6 female; average age: 38 years, range: 13 to 54 years) with IAD treated between January 2011 and July 2012. All patients were assessed using the Japanese Orthopedic Association (JOA) scores. Pre- and postoperative radiographs, MRI and CT were conducted.

A Siemens dual-source 64-slice spiral CT (SOMATOM Definition; Radiology Department, Guangzhou General Hospital of Guangzhou Military Command, Guangzhou, China) was used for continuous axial tomography of the atlanto-axial joint with 1-mm slice thickness and 1-mm interval. Scanning parameters were set at 120 kV and 205.50 mA and scanning matrix at 512×512. The CT images were processed into data files in the Digital Imaging and Communications in Medicine (DICOM) format using an Online Workstation and saved onto an optical disc. DICOM format data were used for three-dimensional reconstructions using Simpleware 4.2 software (Laboratory of Orthopaedic Technology and Implant Materials, Guangzhou, China). A computer-assisted design (CAD) model was generated using threshold segmentation and region growing technology. The model was output as a surface triangularization technique and saved in a triangularized file format (STL). An STL apparatus (AFS-450.i Beijing, China) used selective laser sintering (SLS) technology to build an RP life-size model layer by layer.

Assisted by the 3-dimensional model, the abnormal anatomy of the atlanto-axial joint was clearly observed from any perspective and detailed information obtained. Direction, diameter and pedicle length was measured before the operation in order to determine the size and placement direction of the screws. The diameter of the canal and severity of the compression was observed, allowing for accurate identification of the site and decompression range. The model was taken into the operation as a reference after sterilization.

Transoral atlanto-axial reduction plate (TARP) was applied in each case, using the technique detailed in our previous reports.[4,5] A nasal trachea cannula was inserted after the induction of general anesthesia. The patient was placed in the supine position with the neck in hyperextension and cranial tong traction at a weight of 6-8 kg. After strict sterilization of the oral cavity and pharyngeal portion, the operating field was exposed. The RP model was used as a reference to determine the resection margin. According to the preoperative simulative procedure, the anterior part of both the C1-C2 articular capsules and cartilaginous surfaces were removed using a high-speed burr. The osteophytes, scar or the synovial pannus between the odontoid and the axis were dissected to allow a reduction of the atlanto-axial joint.

Fluoroscopy was used to secure a safe and optimal reduction. Somatosensory-evoked potential and motion-evoked potential were applied to prevent iatrogenic spinal cord injury. Ideal entry points were determined prior to surgery. According to the evaluation and simulation in the model before surgery, the proper depth and diameter of the pedicle screws were placed in the TARP in a safe direction. A granulated iliac crest autograft was packed into the lateral joints and the atlanto-dens interval. After removal of the devitalized tissue, the midline wound was closed in two layers.

The nasal trachea cannula was dwelled for 24 hours. Nasogastric feeding was continued until the 7th postoperative day. Oral ultrasonic atomizing inhalation was used 3 times a day until the incision was healed. Cervical collar was applied for 2 to 3 months. Prophylactic antibiotics were used for 5 to 7 days. Postoperative radiographs and CT scan were taken to assess the efficacy of the decompression and safety of the screw placement at 7th to 10th postoperative day and patients were evaluated using the JOA assessment.

Illustrative case

A 42-year-old woman experienced headache, dizziness, numbness of the limbs and unsteady gait 6 years previously. She was diagnosed with Chiari malformation and basilar invagination and underwent posterior fossa decompression surgery in 2006 in a different hospital. The symptoms of dizziness and numbness of limbs alleviated after surgery. However, symptoms returned in 2009. The patient presented to our hospital with complaints of an unsteady gait requiring an assistive device to walk and lack of fine-motor coordination in the hands and legs. Physical examination revealed limited cervical spine flexion and extension. The patient's gait was unsteady and sensory deficits in the extremities were observed. Upper and lower extremity muscle weakness of Grade 4 of 5 was determined. She had symmetrical hyperreflexia and positive Hoffmann's and Babinski's signs bilaterally. The RP model was created using the CT data. Preoperative radiographs of the patient revealed atlanto-axial dislocation (Fig. 1a and b). The sagittal (Fig. 1c) and axial plane (Fig. 1d) of the CT showed Chiari malformation, basilar invagination and dislocation of the atlanto-axial joint. Three-dimensional digital reconstruction of the C0-C5 revealed different directions of view (Fig. 2). After op-

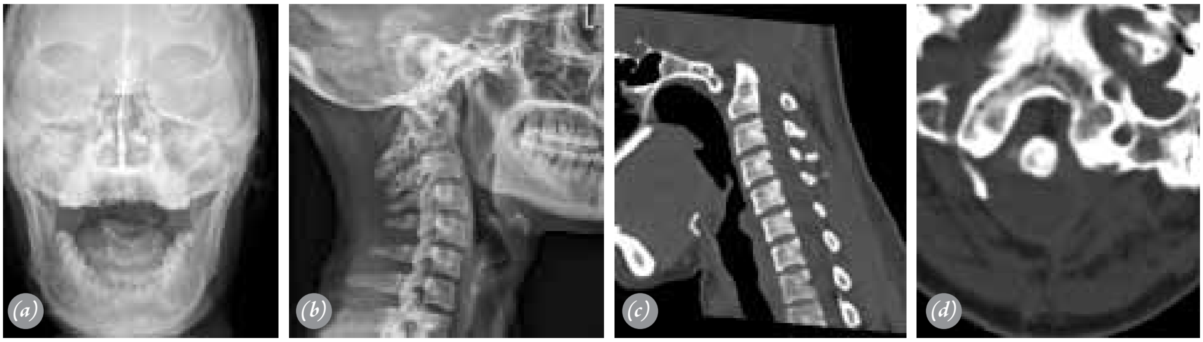

Fig. 1. **(a, b)** Preoperative radiographs of the patient revealed atlanto-axial dislocation. **(c)** Sagittal plane and **(d)** axial plane of the CT showed the Chiari malformation, basilar invagination and dislocation of the atlanto-axial joint.

eration, CT showed satisfactory screw trajectory on the atlas (Fig. 3a), axis (Fig. 3b) and coronal (Fig. 3c) views without breaching the medial of the lateral cortex of the pedicles. Postoperative CT (Fig. 3d) and radiograph (Fig. 3e) showed a thoroughly decompression and satisfactory reduction with bone graft to achieve bone fusion. The patient was able to ambulate using a walker and was discharged from the hospital at Day 7. A soft neck collar was applied for 3 months.

Posterior CT of another patient, a 20-year-old female, revealed that the screw perforated into the lateral wall of the C2 pedicle (Fig. 4). There were no complications in this case.

Results

Forty reverse transpedicle/lateral mass screws were inserted. Detailed information of each pedicle was obtained and the ideal entry point and plate size were determined using the 3-dimensional RP models. Mean operation time was 145 (range: 90 to 180) minutes and average blood loss 120 (range: 60 to 250) ml. JOA scores improved after surgery. All 40 transoral transpedicle/lateral mass screws were placed without serious complications or internal fixation failure. Postoperative radiographs and CT scan showed 38 transoral pedicle screws were positioned in the pedicle tracts and satisfactory reduction was acquired in 95% of the screws. Two screws perforated into the lateral wall of the C2 pedicles in one extremely narrow pedicle case. No neurologic sequelae or vertebral artery injury (VAI) were detected.

Discussion

The RP technique creates life-size models that help the surgeon observe the anatomy from any direction. This technique has been successfully applied in many fields, including cranial construction, maxillofacial fracture, tissue engineering, thoracic deformities, complex spinal surgery, and trauma.[6-12] We aimed to use RP in the upper cervical spine and achieve optimal clinical results.

Screw insertion in the C1-C2 poses a tremendous challenge to the surgeon due to the variable courses of vertebral artery and the small pedicles of the atlas and axis. Common complications in IAD surgery include neural deficit, pedicle fracture with pedicle screw insertion and VAI.[13-14] The risk of VAI and neurological deficit from VAI have been reported to be 4.1% and 0.2%, repectively.[15] Inexperienced surgeons have been shown to have a higher risk of causing VAI.[14] A careful

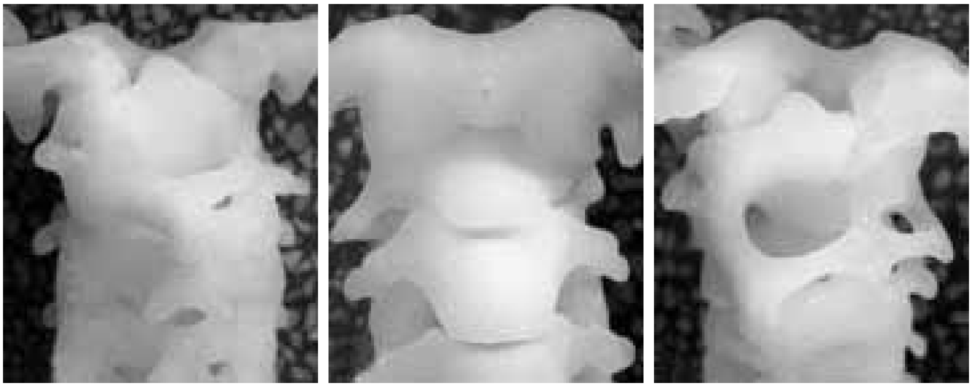

Fig. 2. Three-dimensional digital reconstruction of C0-C5 demonstrated different directions of view.

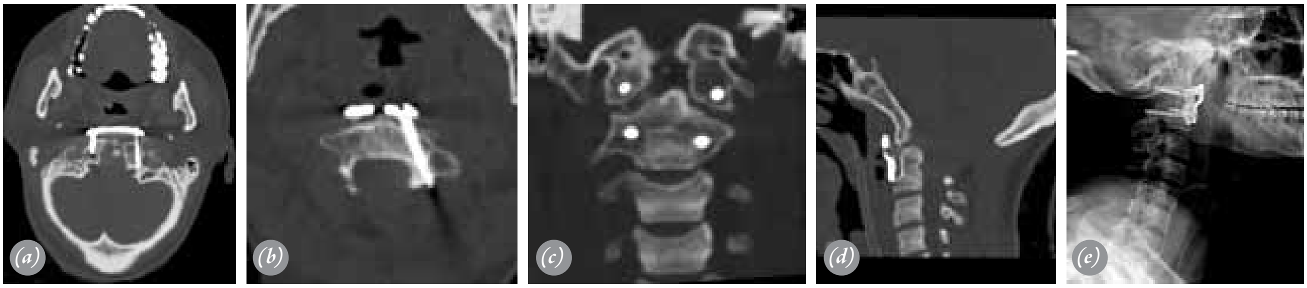

Fig. 3. Postoperative examination CT showed satisfactory screw trajectory of the **(a)** atlas, **(b)** axis, and **(c)** coronal view without breaching the medial of lateral cortex of the pedicles. **(d)** Postoperative CT and **(e)** radiograph showed a thoroughly decompression, satisfactory reduction with bone graft to achieve bone fusion.

preoperative evaluation is the most important factor in preventing VAI and avoiding postoperative neurologic deficit.

According to our experience, 3-dimensional models are helpful in preoperative assessment and planning and intraoperative accuracy, especially in anatomically abnormal or complex cases (basilar invagination, upper spine fracture malunion, and revision of atlanto-axial joint surgery). Using the 3-dimensional model, the atlanto-axial joint could be observed from any direction and the dissection margin and relationship of the cervical foramen and the orientation of pedicles could be determined. After measuring the length and width of the vertebral pedicles, a suitable sized screw and plate could be selected and inserted in the life-size models to obtain valuable experience. Models were taken into the operating theatre after sterilization to act as a reference to better understand the anatomy during the surgery. Therefore, 3D models help the surgeon achieve accurate and complete decompression, save precious intraoperative time and reduce the exposure of radiographs during screw insertion.[3]

Fig. 4. Another case of posterior CT showed the screw perforation into the lateral wall of the C2 pedicle.

Three-dimensional models are also useful for teaching surgical procedures and in helping the student gain a better understanding of the pathology of upper cervical spine disease. Rapid prototyping has been utilized in training young doctors in the field of cranial reconstruction.[16] Upper cervical spine surgery poses a big challenge for surgeons, partly due to their rare performance. Three-dimensional models may serve as important learning tools for young doctors to practice this difficult operation and acquire valuable experience. Furthermore, the models can help patients understand the procedure and build a more trusting relationship between the surgeon and patient.[17]

Surgeons should be aware of possible errors during application. Currently available technology image-processing software remains based on 2-dimensional images to manufacture the RP model. The thickness of the CT slice should be less than 1 mm to produce a more accurate model. Moreover, as past experience is mainly accumulated based on 2D images, clinical evaluation still relies heavily on them. In current clinical practice, 3D models cannot completely replace CT-scan and MRI. However, they can serve as an important complementary tool to obtain a better understanding of the anatomy in a life-size model, especially in complex and intractable cases. In this study, the small sample size and lack of control group may contribute to deviation in the results.

In conclusion, the RP technique is beneficial in the preoperative assessment and planning and intraoperative accuracy of IAD surgery, especially in complex cases with anatomical abnormalities. The life-size model assists in obtaining complete decompression, secures screw insertion and minimizes the potential risk of iatrogenic VAI and pedicle perforation. The use of the RP models is promising in the field of upper cervical spine surgery.

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Conflicts of Interest: No conflicts declared.

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