The Radiological Feature of Anterior Occiput-to-Axis Screw Fixation as it Guides the Screw Trajectory on 3D Printed Models: A Feasibility Study on 3D Images and 3D Printed Models

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Abstract: Anterior occiput-to-axis screw fixation is more suitable than a posterior approach for some patients with a history of posterior surgery. The complex osseous anatomy between the occiput and the axis causes a high risk of injury to neurological and vascular structures, and it is important to have an accurate screw trajectory to guide anterior occiput-to-axis screw fixation.

Thirty computed tomography (CT) scans of upper cervical spines were obtained for three-dimensional (3D) reconstruction. Cylinders (1.75 mm radius) were drawn to simulate the trajectory of an anterior occiput-to-axis screw. The imitation screw was adjusted to 4 different angles and measured, as were the values of the maximized anteroposterior width and the left-right width of the occiput (C0) to the C1 and C1 to C2 joints. Then, the 3D models were printed, and an angle guide device was used to introduce the screws into the 3D models referring to the angles calculated from the 3D images.

We found the screw angle ranged from $\alpha_1$ (left: 4.99 ± 4.59°; right: 4.28 ± 5.45°) to $\alpha_2$ (left: 20.22 ± 3.61°; right: 19.63 ± 4.94°); on the lateral view, the screw angle ranged from $\beta_1$ (left: 13.13 ± 4.93°; right: 11.82 ± 5.64°) to $\beta_2$ (left: 34.86 ± 6.00°; right: 35.01 ± 5.77°). No statistically significant difference was found between the data of the left and right sides. On the 3D printed models, all of the anterior occiput-to-axis screws were successfully introduced, and none of them penetrated outside of the cortex; the mean $\alpha_4$ was 12.00 ± 4.11° (left) and 12.25 ± 4.05° (right), and the mean $\beta_4$ was 23.44 ± 4.21° (left) and 22.75 ± 4.41° (right). No significant difference was found between $\alpha_4$ and $\beta_4$ on the 3D printed models and $\alpha_3$ and $\beta_3$ calculated from the 3D digital images of the left and right sides.

INTRODUCTION

Various posterior occipitocervical fusion techniques have been reported,1–3 which are based on posterior wires, rods, plates, and screws,4–6 and these techniques achieve good osseous fusion and have been widely used by spine surgeons.

In a number of clinical situations, such as in the case described by Dvorak et al7 patients with a history of posterior surgery leading to disruption of osseous anatomy and significant posterior scar tissue, there are not sufficient landmarks to achieve safe and effective posterior stabilization; Dvorak et al7 performed anterior occiput-to-axis screw fixation on the patient in their case study. Simultaneously, a biomechanical study showed that anterior occiput-to-axis screw fixation could achieve biomechanical stability comparable to that of posterior approaches.8

Compared to posterior surgery, which causes considerable damage to the extensor muscles as well as bleeding, anterior occiput-to-axis screw fixation could be performed by a percutaneous approach,9 which has the advantages of being minimally invasive, causing less blood loss, and resulting in shorter hospital stays.

The following additional advantages of occiput-to-axis screw fixation are reported: the anterior approach could be performed more conveniently than the posterior approach; the supine position is better for reduction and stable recovery and prevents having to change the position after anesthesia; and the anterior approach might be more suitable for patients with pressure from anterospinal compression.

The complex osseous anatomy between the occiput and the axis causes a high risk of injury to the neurological and vascular structure; to avoid these complications, it is important to have an accurate screw trajectory to guide the anterior occiput-to-axis screw fixation.

METHODS AND MATERIALS

The research was performed following the Declaration of Helsinki principles and was approved by the Institutional Review Board of The Second Affiliated Hospital of Wenzhou Medical University, Zhejiang Spinal Research Center, 109# XueYuan Western Road, Wenzhou, Zhejiang 325000, People’s Republic of China (e-mail: spinechi@163.com; wangthomas2002@163.com).

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Medical University. Informed consent was obtained from the participants.

Thirty computed tomography (CT) scans of upper cervical spines were obtained from the Star PACS system (INFINITT, Seoul, South Korea) of our hospital; the participants were without spinal diseases, and had CT scans for health testing or had presented with oral diseases; patients with any spinal abnormality such as a fracture or tumor were excluded.

The data from the CT scans (in DICOM format) were imported into Mimics software v10.01 (Materialise, Leuven, Belgium) for the three-dimensional (3D) reconstruction. We drew a cylinder (1.75 mm radius) to simulate the trajectory of the anterior occiput-to-axis screw.

The screw entry point was identified at the concavity on the anterior cortex of the C2 arch referred to by Lu et al.10 and the angle of the imitation screw was adjusted to 4 different angles with the following measurements: maximized interior angle ($\alpha_1$) and maximized lateral angle ($\alpha_2$) on the anteroposterior (AP) view, minimized dorsal angle ($\beta_1$), and maximized dorsal angle ($\beta_2$) to the referential line on the lateral view (Figure 1). The values of the maximized anteroposterior width and the left-right width of the occiput (C0) to the C1 joint (APW1 and LRW1) and C1 to C2 joints (APW2 and LRW2) were measured as well (Figure 1).

The average of $\alpha_1$ and $\alpha_2$ was calculated and is referred to $\alpha_3$, and the average of $\beta_1$ and $\beta_2$ was calculated and named $\beta_3$. Simultaneously, the 3D images data were saved in .STL format and imported to Cura software. After a 3D digital model was created in Cura, we save it in G code format and imported it to a 3D Printer (3D ORTHO Waston Med, Inc., Changzhou, Jiangsu, China) to print the 3D model.

After the 3D model was printed, it was fixed in a holding device, and an angle guide device was used (Figure 2, Designed by YLC and SW); the K-wire angle was referred to $\alpha_3$ and $\beta_3$, as previously calculated. After the K-wire was inserted with the assistance of the angle guide device, the AP and lateral X-ray films were obtained, the angle of the screw on the AP and lateral films were measured and referred to as $\alpha_4$ and $\beta_4$, respectively.
TABLE 1. The Parameters Measured From 3D Digital Images

|                | Left            | Right           | T    | P-Value |
|----------------|-----------------|-----------------|------|---------|
| AP view        |                 |                 |      |         |
| α1 angle       | 4.99 ± 4.59     | 4.28 ± 5.45     | 0.858| 0.398   |
| α2 angle       | 20.22 ± 3.61    | 19.63 ± 4.94    | 0.636| 0.530   |
| α3 (averaged)  | 12.60 ± 3.73    | 11.95 ± 4.15    | 0.918| 0.366   |
| Lateral view   |                 |                 |      |         |
| β1 angle       | 13.13 ± 4.93    | 11.82 ± 5.64    | 1.610| 0.118   |
| β2 angle       | 34.86 ± 6.00    | 35.01 ± 5.77    | -0.388| 0.701  |
| β3 (averaged)  | 23.86 ± 4.81    | 23.42 ± 4.89    | 0.530| 0.600   |
| C0–C1 facet    |                 |                 |      |         |
| LRW1           | 12.43 ± 1.93    | 12.04 ± 2.17    | 1.721| 0.096   |
| APW1           | 16.87 ± 1.34    | 16.88 ± 1.38    | -0.075| 0.940  |
| C1–C2 facet    |                 |                 |      |         |
| LRW2           | 15.92 ± 2.26    | 16.18 ± 2.00    | -0.836| 0.410  |
| APW2           | 15.76 ± 1.53    | 15.94 ± 1.56    | -0.933| 0.358   |

α1: Maximize interior angle on AP view; α2: maximize lateral angle on AP view; α3: the average of α1 and α2; β1: minimize dorsal angle on lateral view; β2: maximize dorsal angle on lateral view; β3: the average of β1 and β2; APW1 and LRW1: maximize anteroposterior width left-right width of occiput to C1 joint; APW2 and LRW2: maximize anteroposterior width and left-right width of occiput to C1 to C2 joint.

Then, the α4 and β4 measured in the 3D models were compared to α3 and β3.

STATISTICAL ANALYSIS

The statistical analysis was conducted using SPSS software v17.0 (SPSS, Inc., Chicago, IL). A paired t-test was used to compare the measurements of the left and right side and the measurements between the 3D digital images and the 3D printed models. The level of significance was set at P < 0.05.

RESULTS

On the AP view, the screw angle ranged from α1 (left: 4.99 ± 4.59°; right: 4.28 ± 5.45°) to α2 (left: 20.22 ± 3.61°; right: 19.63 ± 4.94°); on the lateral view, the screw angle ranged from β1 (left: 13.13 ± 4.93°; right: 11.82 ± 5.64°) to β2 (left: 34.86 ± 6.00°; right: 35.01 ± 5.77°). The anteroposterior width of the C0 to C1 facet was 16.87 ± 1.34 (left) and 16.88 ± 1.38 (right), slightly larger than that at the C1 to C2 facet (left: 15.76 ± 1.53 and 15.94 ± 1.56 (right), the left-right width of the C0 to C1 facet was 12.43 ± 1.93 (left) and 12.04 ± 2.17 (right), shorter than that at the C1 to C2 facet (left: 15.92 ± 2.26 and 16.18 ± 2.00 (right); they were all wide enough for 3.5 mm or 4.0 mm diameter anterior occiput-to-axis screw fixation. No statistically significant difference was found between the data of the left side and right side (Table 1).

Guided by the angles of α3 and β3 calculated from the 3D digital images and assisted with the angle guide device, all of the anterior occiput-to-axis screws were successful introduced and none of them penetrated outside of the cortex (Figure 3); the mean α4 was 12.00 ± 4.11 (left) and 12.25 ± 4.05 (right) and the mean β4 was 23.44 ± 4.21 (left) and 22.75 ± 4.41 (right). No significant difference was found between the α4 and β4 from the 3D printed models and the α3 and β3 calculated from the 3D digital images on the left and right sides (Table 2).

DISCUSSION

Occipitocervical fixation has been challenging for spinal surgeons because of the complex anatomical structures and the high risk of neural and vascular injury at the occipitocervical junction. Most previous reports focused on posterior techniques based on rods, plates, and screws to achieve occipitocervical fusion.5,6

Posterior stabilization is not suitable in a number of unique situations, such as that of patients with a history of posterior surgery leading to disruption of the osseous anatomy and significant posterior scar tissue, described by Dvorak et al7 and that of patients with a history of posterior cranial fossa decompression surgery or dysplastic C2 pedicles, described by Wu et al8. Anterior occiput-to-axis screw fixation could be performed via the Smith–Robinson approach or percutaneously; compared to the posterior approach, which causes considerable damage to the extensor muscles and bleeding, the anterior approach is less invasive and results in less blood loss. Cai et al9 reported a novel anterior occiput-to-axis locking plate system, which might have a better biomechanical property than simply 2 anterior occiput-to-axis screws; however, their

FIGURE 3. The photo of the 3D printed models after the anterior occiput-to-axis screws were introduced (A and B), the AP (C) and lateral (D) X-ray films of the 3D printed models after the anterior occiput-to-axis screws were introduced.
TABLE 2. The Comparison of Angles Between 3D Digital Images and 3D Printed Models

|          | α3 or β3       | α4 or β4       | T     | P-Value |
|----------|----------------|----------------|-------|---------|
| AP view  |                |                |       |         |
| Left     | 12.60 ± 3.73   | 12.00 ± 4.11   | -1.565| 0.128   |
| Right    | 11.95 ± 4.15   | 12.25 ± 4.05   | 1.013 | 0.320   |
| Lateral  |                |                |       |         |
| Left     | 23.86 ± 4.81   | 23.44 ± 4.21   | -0.960| 0.345   |
| Right    | 23.42 ± 4.89   | 22.75 ± 4.41   | -1.724| 0.095   |

α3: The average of α1 and α2; β3: the average of β1 and β2; α4: the angle of screw in 3D printed models on AP view; β4: the angle of screw in 3D printed models on lateral view.

CONCLUSION

There was enough space for anterior occiput-to-axis screw fixation, and by referring to the parameters of optimal screw trajectory and with the aid of the angle guide device, we could achieve an optimal screw trajectory on a 3D printed C0 to C2 model.

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