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Use of rapid prototyping drill template for the expansive open door laminoplasty: A cadaveric study

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ABSTRACT

Objective: Trough preparation is a technically demanding yet critical procedure for successful expansive open door laminoplasty (EOLP), requiring both proper position and appropriate bone removal. We aimed to use the specific rapid prototyping drill template to achieve such requirement.
Methods: The 3D model of the cadaveric cervical spine was reconstructed using the Mimics 17.0 and Geomagic Studio 12.0 software. The drilling template was designed in the 3-Matic software. The trough position was simulated at the medial margin of the facet joint. Two holders were designed on both sides. On the open side, the holder would just allow the drill penetrate the ventral cortex of the lamina. On the hinge side, the holder was designed to keep the ventral cortex of the lamina intact. One orthopedic resident performed the surgery using the rapid prototyping drill template on four cadavers (template group). A control group of four cadavers were operated upon without the use of the template.
Results: The deviation of the final trough position from the simulated trough position was 0.18 mm ± 0.51 mm in the template group. All the troughs in the template group and 40% of the troughs in the control group were at the medial side of the facet joint. The complete hinge fracture rate was 5% in the template group, significantly lower than that (55%) in the control group ($P = 0.01$).
Conclusion: The rapid prototyping drill template could help the surgeon accomplish proper trough position and appropriate bone removal in EOLP on the cadaveric cervical spine.

1. Introduction

The expansive open-door laminoplasty (EOLP) has proven to be a safe and effective surgical intervention for patients suffered from neurological impairment due to bony cervical stenosis or ossification of the posterior longitudinal ligament (OPLL) [1–3]. The trough preparation is a critical procedure for the success of the EOLP. Proper trough position on both sides and adequate bone removal on the hinge side were the two main aspects of successful trough preparation. Ideally, the trough position should be on the medial side of the facet joint [4]. It was reported that laterally located trough could increase the incidence of postoperative radiculopathy, including the C5 palsy [4,5]. In some rare cases, vertebral artery could be injured due to excessive deep trough if the trough was placed excessively lateral [6]. When preparing the hinge side trough, the ventral cortex should be kept intact, whereas the dorsal cortex and cancellous bone of the lamina should be removed [7]. If the drilling was too deep, a direct ventral bony defect would be created. On the contrary, if the drilling was too shallow, a forcible hinge fracture would be resulted when opening the lamina. In short, trough preparation in the EOLP is technically demanding and requires rich experience.

Here we sought to achieve proper trough position and appropriate amount of bone removal in the EOLP using the computer aided design (CAD) and rapid prototyping (RP) technique. Such CAD-RP technique has already been applied to guide the screw placement in the cervical spine [8–10]. However, to our best knowledge, no study has been conducted to use the CAD/RP technique in the EOLP. In this study, we aim to design and fabricate the specific drill templates for the EOLP to help the orthopedic resident accomplish the EOLP properly in the cadaveric cervical spine.

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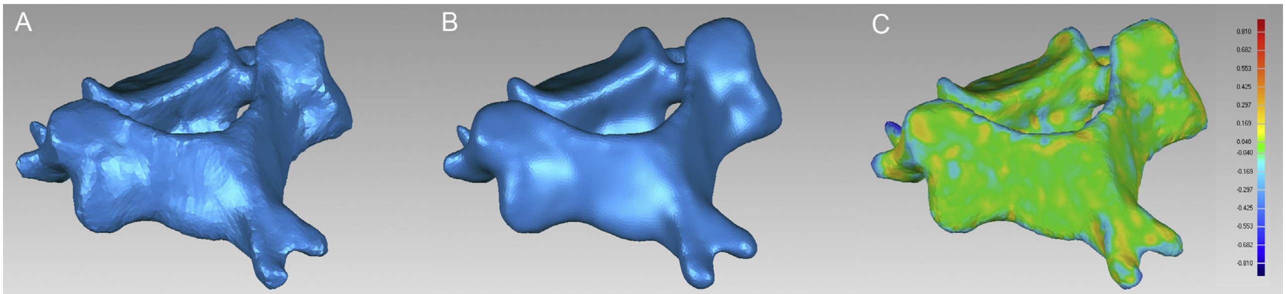

Fig. 1. (A) 3D model of a vertebra (pre-smoothed); (B) Smoothed model; (C) Cloud atlas demonstrates the slight deviation between the pre-smoothed model and smoothed model.

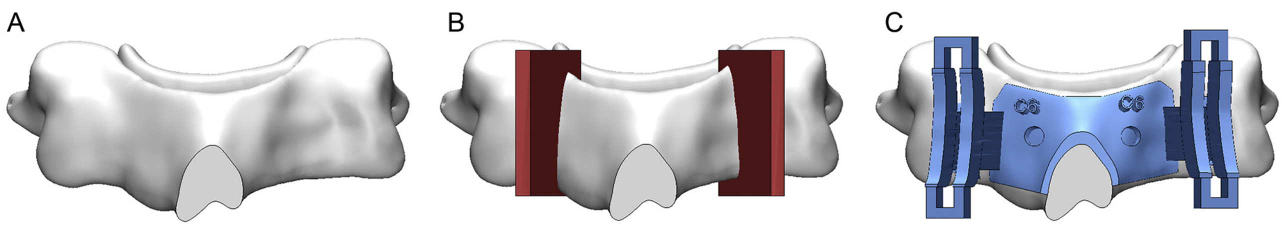

Fig. 2. (A) C6 vertebra with the spinous process amputated; (B) The red boxes indicate the simulated drilling path; (C) The specific drill template. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

2. Materials and methods

2.1. Specimens

A total of eight fresh frozen cadaveric cervical spines were used in the present study by the permission of the Institutional Review Board. All the specimens were first examined by the X-rays to rule out cervical deformity and bony destruction. Then the specimens were imaged with CT scanning (Philips Brilliance 64 CT, Philips Medical System, the Netherland). The slice thickness was 0.75 mm and the slice increment was 0.7 mm. The voltage was 140 kV and the current was 250 mA. The images were stored as DICOM (Digital Imaging and Communications in Medicine) format.

2.2. The template fabrication process

For each specimen, the DICOM files were imported into the Mimics 17.0 software (Materialize, Belgium) to build the 3D model of the cervical spine. Each vertebral model from C3 to C7 was then exported as ".STL" file and processed by the Geomagic Studio 12.0 software (3D Systems, USA) to smooth the model surface. Comparison between the pre-smoothed and smoothed model demonstrated that the mean deviation of these two models was 0.056 mm ± 0.089 mm (Fig. 1). Then the smoothed model was imported into the 3-Matic 9.0 software (Materialize, Belgium) for the template design.

First, the spinous process was amputated (Fig. 2A). Second, two drilling paths were simulated and initially placed at the junction between the lamina and the lateral mass (Fig. 2B). The final locations of the drilling paths were adjusted according to an experienced spine surgeon's suggestion. Third, the back surface of the lamina and lateral mass was extracted and reverse engineered to create the template body. Fourth, two holders were designed at both the open side and hinge side. On the open side, the distance from the top of the holder to the ventral surface of the lamina was set to be equal to the length of the drill, allowing the drill just to penetrate the ventral cortex. On the hinge side, the distance was shorter by the thickness of the ventral cortex of the lamina, aiming to keep the ventral cortex intact during the drilling procedure. Fifth, different parts of the template were assembled to create the complete template (Fig. 2C). Last, the virtual template was exported as ".STL" file and imported into the 3D printer to fabricate the physical template in acrylate resin by stereo-lithography.

2.3. Surgical technique

All the surgeries were performed by an orthopedic resident with less experience in EOLP. The eight specimens were randomly assigned into template group and control group (four specimens in each group). After overnight thawing, the specimens were placed in a prone position. The soft tissue attached to the spinous process, lamina and lateral mass were removed as clear as possible. The spinous process from C3 to C7 was amputated with a rongeur. In the template group, before preparing the troughs, the orthopedic resident marked the location of the troughs on both the open side and hinge side with a black line according to his own choice. Later, a red line was drew using the 3D printed template. The distance between the black line and the red line was measured using an electric digital caliper. Then, the orthopedic resident used one hand to press the 3D printed templates to the lamina while using the other hand to prepare the trough by sliding the high-speed bur in the holder. In the control group, the troughs on both side were prepared without using the 3D printed templates. After the troughs were prepared, the laminae were opened carefully, with the lamina secured to the lateral mass by suture suspension. (Fig. 3, Supplement 1)

2.4. Radiography assessment

After the surgery, the specimens were CT scanned again. In the template group, the deviation of the final position from the simulated position was recorded (Fig. 4): if the final trough position was lateral to the simulated trough position, it was recorded as a negative number; otherwise, it was recorded as a positive number. For both groups, the final trough position was categorized into medial group and lateral group as indicated by Uematsu et al. [4]. The fracture type on the hinge side was recorded according to the published criteria [11]. If the ventral cortex of the lamina on the hinge side was continuous, it was categorized as incomplete fracture. On the