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Robot-assisted upper cervical spinal surgery

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Abstract

The fundamental for upper cervical spinal surgery is screws fixation progress, however, anatomical variations of atlantoaxial vertebrae are wide, and the region is adjacent to important organ such as spine cords, oblongata and vertebral artery, all of which make the fixation harder. Robot-assisted navigation can make up for the above shortcomings, and has the potential to more improve the screw placement accuracy.

We recently designed a robot system called TiRobot, which is based on intraoperative three-dimensional images. TiRobot has three components: the planning and navigation system, optical tracking system and robotic arm system. By combining navigation and robot techniques, TiRobot can guide the screw trajectories for orthopedic surgeries.

TiRobot has been used in upper cervical surgeries with the approval from the Ethics Committee. There were 7 screws inserted during the surgeries, 1 screw for posterior C1-2 trans-articular fixation, 1 screw for anterior odontoid fixation and 5 for C1 or C2 pedicel fixation. All surgeries were smoothly performed using TiRobot. According to the post-operation CT image data, all the screw placements were sufficient because there was no perforation of the spinal canal or any unexpected malposition. According to the Gertzbein-Robbins classification, all screws fell into group A. Furthermore, there was a discrepancy between the planned and the actual placements at the entry points and the end points. The average deviation in entry point and end point were 1.21 +/- 0.45mm and 1.19 +/- 0.36mm. These safe and accurate results make TiRobot the first medical robot could be used in upper cervical spinal surgery.

1 Introduction

There are many surgery methods for upper cervical spine including C1-2 trans-articular fixation, odontoid fixation and fracture fixation. And the fundamental for all these surgery is the screws fixation progress, which is considered as one of the most reliable anatomy fixation method. However, anatomical variations of atlantoaxial vertebrae are wide, and the region is adjacent to important organ such as spine cords, oblongata and vertebral artery, all of which make the fixation harder[1]. Computer-assisted navigation has been proved to improve the screw placement accuracy[2], but it may need surgeon repeatedly adjust the placement trajectories, which is non-convenience[3]. Robot-assisted navigation can make up for the above shortcomings, and has the potential to more improve the screw placement accuracy. In recent days, we designed a new robot system combined with navigation, and which we believe is the first robot that can do the upper cervical spinal surgeries.

2 Materials and methods

The recently new designed robot system was called TiRobot, which is based on intraoperative three-dimensional images. TiRobot has three components: the planning and navigation system, optical tracking system and robotic arm system. A set of intraoperative images is initially acquired using a 3-D C-arm (Siemens Medical Solutions, Erlangen, Germany). The robotic arm is identified at the same time by detecting the plate locator on it. After that, the planning and navigation system can perform an automatic registration. Surgeons then plan the entry point and trajectory of the screw on the system and send these to guide the robotic arm. The optical tracking system is made up of an infrared stereo camera and two reference frames, one attached to the spinous process and the other to the robotic arm, thus enabling the optical tracking system to locate the position of the robotic arm relative to the patient and to guide the arm to the planned position. The robotic arm system is built on a mobile platform and has six degree of freedom. It has universal holders on which the reference frame, plate locator, guide holder and surgical instruments can be mounted. The robotic arm spontaneously moves accurately to the required position under the guidance of the planning and navigation and optical tracking systems. By combining navigation and robot techniques, TiRobot can guide the screw trajectories for orthopedic surgeries.

The TiRobot has been used in four upper cervical surgeries with the approval from the Ethics Committee, all the patients involved has been fully informed and signed the informed consent. Mean age for all patients was 52 years old. There were 7 screws inserted during the surgeries, 1 screw for posterior C1-2 transarticular fixation, 1 screw for anterior odontoid fixation and 5 for C1 or C2 pedicel fixation. A postoperative CT scan was performed after operations. The CT image data were reconstructed in sagittal, coronal and axial views by the mimics 15.0 software, and a blind evaluation of the position of the screws was performed by two spine surgeons who were not involved in the surgery. Any penetration of the cortex in the lateral, medial, cranial or caudal directions was measured according to the Gertzbein-Robbins classification[4] (A: no cortical violation; B: cortical breach <2 mm; C: ≥2 mm to <4 mm; D: ≥4 mm to <6 mm; E: ≥6 mm). Also, we measured the discrepancies between the actual path and planned trajectory in entry point and angle deviation[5].

3 Results

All 4 surgeries were smoothly performed using TiRobot. According to the post-operation CT image data, all the screw placements were sufficient because there was no perforation of the spinal canal or any unexpected malposition. According to the Gertzbein-Robbins classification, all screws fell into group A, i.e., good screw positions (Fig. 1).

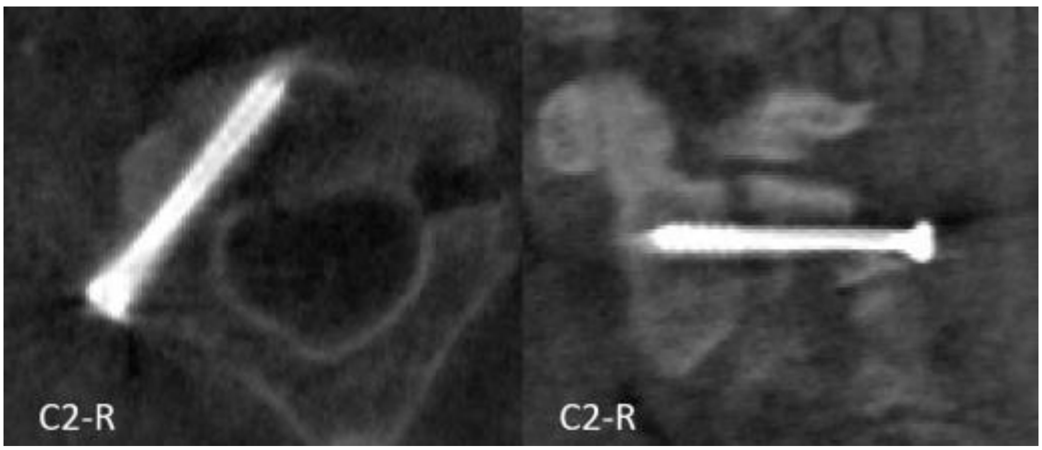

Figure 1: Postoperative computer tomography scans indicating the results of the C2 screw for safety analysis.

Furthermore, as demonstrated in Table 1, there was a discrepancy between the planned and the actual placements at the entry points and the end points. The average deviation in entry point and end point were 1.21 +/- 0.45mm and 1.19 +/- 0.36mm.

Screw serial no.	Patient no.	Level and side	Deviation of entry point (mm)	Deviation of end point (mm)	Total deviation
1	A	Trans-articular C1-2 (L)	0.43	1.32	0.88
2	B	Odontoid (C2)	1.54	0.48	1.01
3	C	C2 (R)	0.80	1.15	0.98
4	D	C1 (L)	1.10	1.28	1.19
5	D	C1 (R)	1.62	0.95	1.29
6	D	C2 (L)	1.17	1.50	1.33
7	D	C2 (R)	1.80	1.67	1.74
Average			1.21	1.19	1.20

SD	0.45	0.36	0.27

Table 1: The accuracy of the inserted screws.

4 Discussions

Screw fixation is the fundamental process in all spinal surgery, however, screws fixation in upper cervical can be technically challenging because of the difficult approach and complex morphology of the upper cervical vertebrae and surrounding vital structures. Surgeons performing this procedure are exposed to high irradiation doses yet have still failed to achieve satisfactory safety and accuracy. Bredow et al [6] reported on their use of navigation with good results. However, for severe deformity, even when surgeons use navigation to identify the perfect trajectory, screw insertion may still be difficult. Bertelsen et al [7] described a robotic system for atlantoaxial fixation, but its accuracy was not sufficient for clinical use (1.94 mm error in a cadaver trial).

In response, we designed the TiRobot which could provide accurate positioning, adequate steadiness and repeatability. We used TiRobot to do four different kinds of upper cervical surgeries, they all demonstrated safe and accurate results, which also makes TiRobot the first medical robot could be used in upper cervical spinal surgery.

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6 Disclosures

The authors have no conflict of interest to disclosure.