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Research Letter

Augmented reality-assisted rod bending in spinal surgery

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Introduction

In complex deformity cases, surgeons may be confronted with difficulties in shaping and reducing rods into pedicle screw heads, which may result in forceful reduction maneuvers, potential screw loosening or pull-out, and longer surgery time. This study sought to evaluate the benefit of holographic rods as assistive equipment for manual rod bending.

Methods

A custom-written application for an augmented reality (AR) system (HoloLens, Microsoft Cooperation, WA, USA) was designed with the aim of assisting spine surgeons with rod bending. After application startup, the surgeon is asked to place a spatial anchor (SA) near the working area to serve as a local reference coordinate system. Once the SA is in place, the HoloLens camera begins acquiring images at 30 frames/second. A custom-made pointing device (PD, see Fig. 1), equipped with a commercially available fiducial marker (Clear Guide Medical, MD, USA), is then employed to capture the 3D positions of the screw heads. In each incoming frame, possible marker occurrences can be detected and the respective six degrees of freedom pose within the SA coordinate system is estimated using an open-source library [1,2]. Because of the known geometry of the PD, it is then possible to render its 3D triangular surface model as a holographic overlay. This allows the surgeon to visually verify current tracking accuracy. For each pedicle screw, the tip of the PD is moved to the screw head. When the surgeon considers the pose to be correct, a HoloLens clicker is then used to store the current position. Once all screws have been captured, a centripetal Catmull-Rom spline [3] is generated by double clicking. A Catmull-Rom spline is a piecewise function that passes through its defining points, that is, the stored screw head positions. The use of shape parameters was suggested to enable different curves for the same defining points. One well-known parametrization is referred to as centripetal. It guarantees the absence of self-intersections and cusps within curve segments. The resulting hologram can be moved and rotated freely, and employed as a template for bending the implant. The application indicates the precise length of the required rod (Fig. 2).

As a test fixture, we made use of a lumbosacral spine model (Sawbones, WA, USA) with pedicle screws (M.U.S. T.,Medacta, Switzerland) to be inserted bilaterally at six levels (L2−5, S1, iliac). Rod bending (4-mm alloy rod) was performed manually with and without the AR-technology, six times in a randomized fashion on both sides of the spine model by three fellowship-trained spine surgeons. An independent observer recorded the time for bending and inserting the rod, the number of rod-rebending maneuvers, and

Fig. 1. Custom-made pointing device, equipped with a fiducial marker (Clear Guide Medical, Baltimore MD, USA) and HoloLens glasses (Microsoft Cooperation, Redmond WA, USA).

FDA device/drug status: Not applicable.

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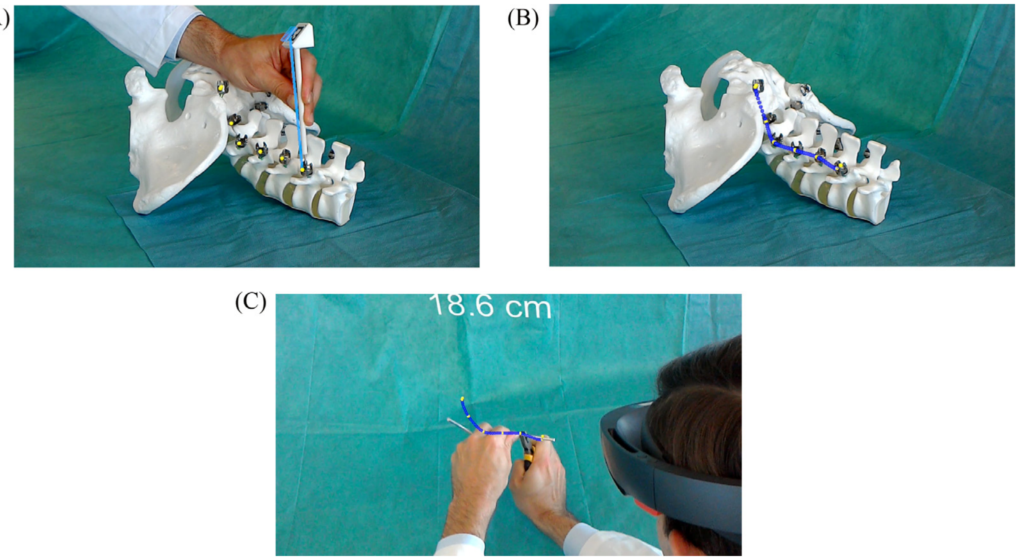

Fig. 2. (A) For each pedicle screw, the tip of the pointing device is moved to the head of the screw. Once the surgeon considers the pose correct, the HoloLens clicker is used to store the current position (yellow dot). (B) Once all screws have been captured, a centripetal Catmull-Rom spline (=rod template) is generated. (C) The resulting hologram can be moved and rotated freely and thus used as a template for bending the implant. In addition, the application indicates the precise length of the required rod.

the accuracy of the rod length. When the AR technology was used for rod bending the time for setup of the AR system and measurement of the screw locations was included in the measured time for bending. The time needed for bending and inserting the rod was averaged and compared using the Welch two-sample *t* test. Statistical significance was defined as $p<.05$. Rod length was stated as correct or incorrect and compared between the two groups using Fisher's Exact Test. The number of rebending maneuvers needed was analyzed using the Pearson's chi-squared test with Yates' continuity correction.

Results

The total time spent on bending and inserting the rod was significantly shorter with AR compared to without (374 ± 79 vs. 465 ± 121 s, $p=.01195$). The rod length was significantly more often correct with AR (15/18 vs. 4/18, $p<.001$). In addition, fewer rebending maneuvers were needed with AR, although, this difference was not significant (7/18 vs. 10/18 $p>.05$).

Discussion

In daily surgical routines, precise rod shaping is required for the appropriate alignment of pedicle screw-rod constructs. Despite the negative biomechanical consequences of rod reduction, it is often used and required if rod bending is not accurate.

With this novel AR application, the time for bending and inserting the rod is decreased by 20% as compared with the conventional method (374 vs. 465 seconds). Furthermore, rod length was significantly more accurate in the AR group compared with the control group. Previously, Solla et al. proposed the concept of patient-specific rods to increase the accuracy of realignment surgery [4]. Prior to that, Tohmeh et al. demonstrated that more precise rod bending could be achieved using a computer-assisted rod bending system, with matched-screw locations and a significant reduction in the peak and residual screw forces [5]. The AR technology could assist the surgeon when in situ fixation of the deformity is not the surgical goal but correction of deformity is. The theoretically wanted 3D-screw positions after deformity correction could be captured as reference points (instead of the in situ position before deformity correction) for generation of the rod hologram. The advantages of the current method are that no complex preoperative planning, manufacturing, or expensive instruments are needed, and that the method is simple and cost effective. The clinical application might still be limited by a suboptimal setup time of the system, but technical evolution toward faster feasibility is expected.

In conclusion, AR-assisted rod bending has the potential to reduce surgery time and increase the accuracy of manual rod bending.

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