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ORIGINAL STUDY

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The clinical application of individualized three-dimensional printing guiding template for assisting scaphoid fracture fixation through dorsal approach

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The purpose is to introduce a novel scaphoid screw placement surgery based on a novel three-dimensional (3D) printing guiding template through dorsal approach, and to evaluate the clinical feasibility and accuracy. The diagnose of scaphoid fracture was confirmed by Computed Tomography (CT) scanning, and subsequently the CT scanning data was input into a three-dimension imaging system(Hongsong software, China). An individualized 3D skin surface template with a guiding hole was printed. We put the template to the correct position on patient's wrist. Fluoroscopy was used to confirm the accurate position after drilling of Kirschner wire according to the prefabricated holes of template. Finally, the hollow screw was inserted through the wire. The operations were performed successfully without incision and complications. The operation time was below 20 minutes and the blood loss was below 1ml. The intraoperative fluoroscopy demonstrated good position of the screws. Postoperative imaging showed that the screws were considered to be placed perpendicularly to the fracture plane in the scaphoid. Three months after the operation, the patients acquired good recovery of the motor function of their hands. This present study suggested that the computer-assisted 3D printing guiding template is effective, reliable, and minimally invasive for the treatment of type B scaphoid fracture through dorsal approach.

Keywords: scaphoid fracture; three-dimensional printing; guiding template; dorsal approach.

INTRODUCTION

Fractures of the scaphoid are usually caused by force conduction following the wrist touches the

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ground suddenly during a fall, which is a common type of carpal fracture. It has been reported that the prevalence of scaphoid fracture is relative high. A study by Bond et al. showed that the incidence of this type of fracture was approximately 38/100,000 per year *(1)*.Wolf et al. suggested the incidence of scaphoid fracture at 121 per 100,000 person-years, with a peak occurring in men between the ages of 20 and 24 years *(2)*. The relatively high incidence of scaphoid fracture has been imposing excessive burden on patients' quality of life and social economy. Therefore, timing treatment is recommended. However, due to the special blood supply of scaphoid, those fractures are prone to nonunion and necrosis *(3,4)*.

According to Herbert classification of scaphoid fracture *(5)*, different types of fracture are indicated to different treatment options. Conservative treatment is usually preferred for type A1 fractures. Nevertheless, for those with type A2 and B fractures, internal fixation has been the mainstream treatment comparing with the cast immobilization of long intervals complicated with joint stiffness and muscle atrophy *(6)*. For these subtypes, open surgery is definitely not a good option. Soft tissue damaging in open surgery can easily lead to destruction of scaphoid blood supply, and thus complications such as nonunion, avascular necrosis and arthritis are frequently encountered.

Intramedullary fixation with the Herbert screw for scaphoid fracture is an epoch-making achievement *(7)*, which is the foundation of minimal invasion and solid fixation. Percutaneous scaphoid fixation with Herbert screw has many advantages such as faster duration of healing and earlier return to works *(8)*. Even small displaced scaphoid fractures can be treated through minimally invasive fixation. However, the skills of minimally invasive surgery are not always beneficial, intraoperative repeated puncture is related with high risk of tissue injury. The technique of electromagnetic guided antegrade screw insertion indeed promotes the development of technology *(9)*, and yet the extent of dependent on instrument conditions is too much high.

Three-dimensional(3D) printing technology has been aroused wide public concern since its advent. This technique applied to surgery has the advantages of fast, individualized, intuitive and operable. Thus it is widely used in all aspects of operation such as preoperative planning – intraoperative assisting and postoperative rehabilitation. Some researchers have already reported and verified the accuracy of scaphoid screw fixation using 3D printing guiding template in cadaver *(10)*. Yin et al. ever describes a percutaneous fixation of acute scaphoid fracture with a patient-specific guiding template through volar approach *(11)*. However, Operative approaches for different types of scaphoid fractures are different. Also in theory, the screw should be placed as perpendicular as possible to the fracture plane. Thus some scaphoid fractures with special fracture plane are most suitable with the dorsal approach. However, there is no report on dorsal approach for 3D guiding template assisted fixation surgery of scaphoid fracture.

Therefore, this present study aimed to introduce a novel scaphoid screw placement surgery based on a novel 3D printing guiding template through dorsal approach, and to evaluate the clinical feasibility and accuracy.

MATERIALS AND METHODS

This present study was approved by the ethics institution of our hospital and the informed consent of the patient was obtained.

One 19-year-old patient was admitted to our hospital, presenting with soreness in the right wrist due to injury. The patient was given an X-ray examination but did not show evidence of fracture. Further Computed Tomography (CT) scanning and 3D reconstruction verified the type B2 fracture of his scaphoid (Figure 1).

Based on clinical experience, this type B2 fracture required a surgical treatment. The young patient had a request of short operation time and little scar, considering his swollen tissue and fracture type, the percutaneous fixation with 3D printing guiding template was chosen. We imported related CT data into three-dimension printing processing software(Hongsong software, China) immediately, and determined the approach and entry point of the k-wire by analyzing the fracture plane (Figure 2A). Also the template and direction of internal fixation was determined by software simulation (Figure

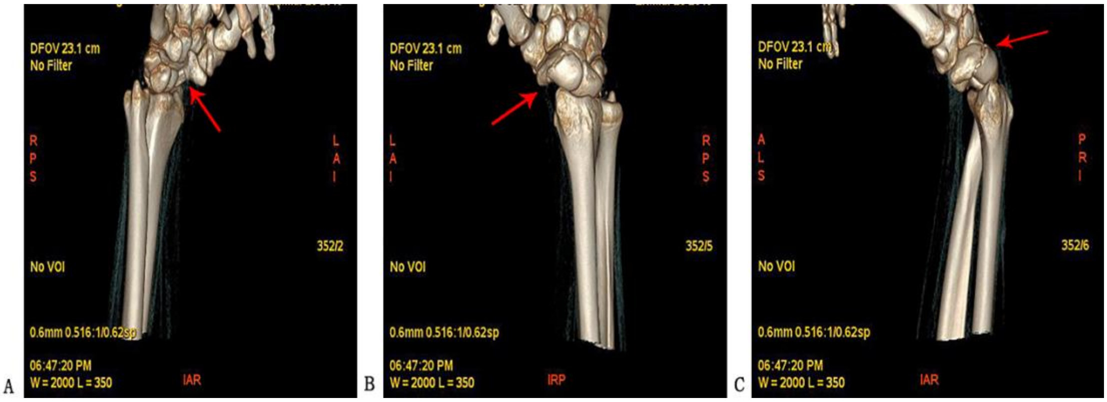

Figure 1. — CT scan of the patient established the fracture of scaphoid (the red arrow indicates the location of fracture). **A.** Palmar view. **B.** Dorsal view. **C** Lateral view.

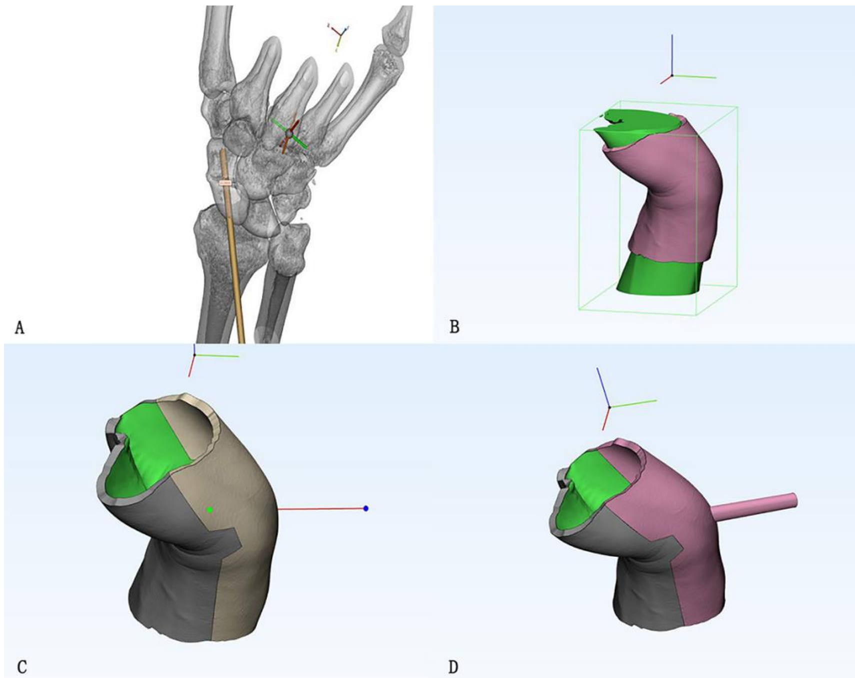

Figure 2. — Designing and preparation of the guiding template. **A.** The guidewire model was designed according to the fracture plane of scaphoid fracture. **B.** The skin interface was used to generate the templates. **C.** The template was designed into two parts. **D.** The guiding hole assembled into the template.

2B, C, D). Based on these data, we printed out the guiding template and sterilized it (Figure 3A). When all this work was done, we operated on the patient immediately.

The entire procedure was relative simple, We put the guiding template to the correct position on the patient's wrist. Following confirming that the template and the skin were closely attached without gaps (Figure 3B, C, D). Fluoroscopy was used to confirm the accurate position after drilling of Kirschner wire according to the prefabricated hole of the template (Figure 4A, B). After measuring the length, the hollow screw was inserted through the wire (Figure 4C, D).

Figure 3. — Representative images of the fixation of template to the wrist. **A.** The template had been sterilized. **B.** The two parts of template. **C.** The template did not deformed. **D.** Make sure no gaps between skin and template.

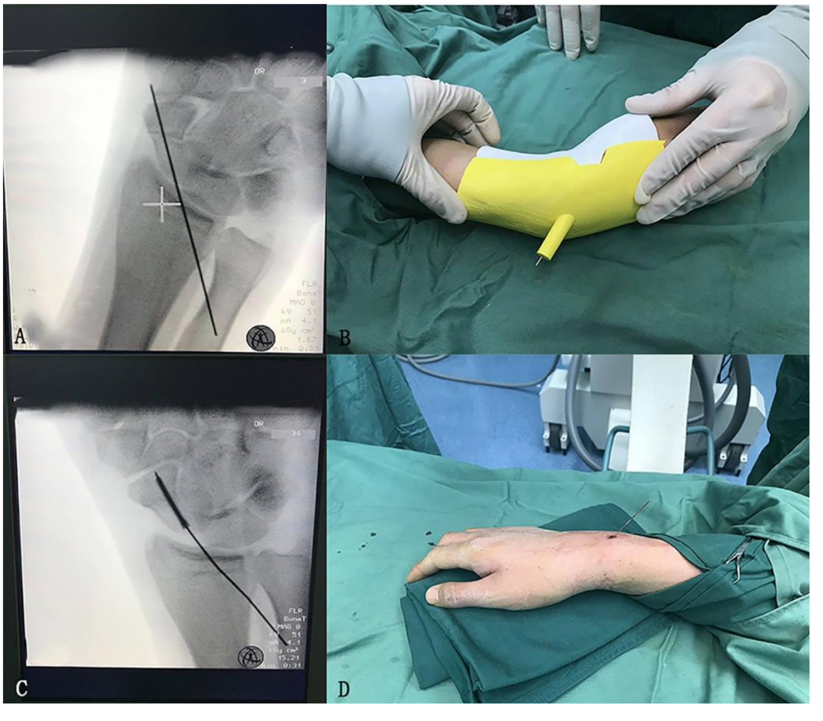

Figure 4. — Intraoperative images of the procedures of the whole operation. **A.** fluoroscopy of the K-wire in the scaphoid. **B.** drilling of K-wire through the guiding hole. **C.** fluoroscopy of the hollow screw in the scaphoid. **D.** The appearance of wrist after drilling the hollow screw.

RESULTS

The operation was performed successfully without incision and complications. The operation time was about 15 minutes and the blood loss was 1ml.

After the surgery, we confirmed the location of the screw by the fluoroscopy (Figure 5A, B).The reduction of scaphoid fracture was pretty satisfactory. The screw was considered to be centrally placed and perpendicular to fracture plane in the scaphoid (Figure 5C). The patients had only mild pain on the second day. Immobilization of the wrist with a short-arm brace were preserved for 3 weeks. After that, patients can do some passive exercises. Heavy manual work and sports activities should be avoided for the first 6 weeks after surgery.

Also we did another similar operation to verify the feasibility of this technology again. The second 48-year-old patient fell down to the floor by accident, also his scaphoid fracture of right hand was identified by CT scanning and 3D reconstruction. Considering his caring about the appearance of hand and also the surgery time, hollow screw fixation with 3D printing guiding template was recommended. The operation was also implemented successfully without incision and complications. The operation time was nearly

Figure 5. — Result of the operation. **A.** Fluoroscopy of the site of hollow screw (positive view). **B.** Fluoroscopy of the site of hollow screw (lateral view). **C.** The appearance of wrist after operation.

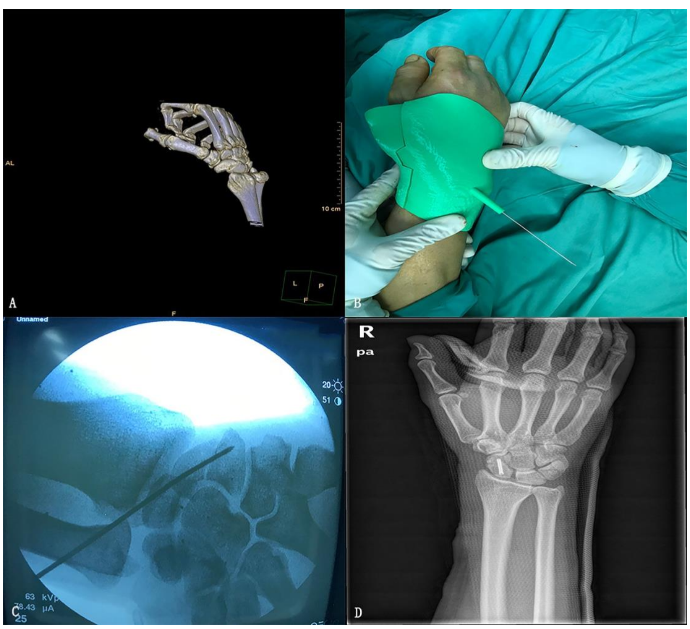

Figure 6. — The whole procedures of another operation. **A.** CT scan of another patient of scaphoid fracture. **B.** Drilling of K-wire through guiding hole of template. **C.** Fluoroscopy of the K-wire in the scaphoid. **D.** Fluoroscopy of the site of hollow screw after operation.

20 minutes and the blood loss was 1ml. the result was also satisfactory (Figure 6).

DISCUSSION

The scaphoid has been the second most commonly fractured bone in the upper extremity, accounting for 60 to 70 percent of all carpal fracture *(12)*.For acute scaphoid fractures, conservative treatment is frequently indicated for incomplete fracture. However, for patients with complete fracture, surgical intervention is often recommended. Several studies have suggested that patients who underwent surgical treatment experienced shorter duration of union, higher union rate of fracture, better grip strength and motion at the final assessment, and faster return to work *(1,13-17)*. For complicated displaced fractures, open surgery is still the priority choice for doctors. Nevertheless, open operation also has some disadvantages. For instance, potential disruption of the blood supply leads to nonunion of scaphoid fracture. In addition, injury of the carpal ligaments possibly cause carpal instability. And thus in order to avoid the complications of open operation, minimally invasive surgery has been suggested for non-displaced and slightly displaced fractures. Percutaneous fixation of acute scaphoid fractures was first described by Streli in 1962 *(18)*. Later a headless hollow screw innovated by Whipple revolutionized the operation of acute scaphoid fracture *(19)*. The subsequent studies have demonstrated satisfactory union rates equal to 100 percent using both volar and dorsal percutaneous or mini-open techniques *(1,20-22)*.

However, minimally invasive surgery is relatively technically demanding for the surgeon. As the location and fixation principle of intramedullary screws are unified *(23)*, it is imperative to decrease the difficulty of surgical technique with tools. Some researchers have tried 3D electromagnetic navigation in scaphoid fracture before[9].But this technique is highly costly, and the accuracy of navigation remained controversial due to difficulties in reference marker positioning in such a small bone of wrist *(24)*.

3D printing technology refers to the layer-by-layer addition of materials by layered processing to create 3D entities. The most obvious advantage is the ability to generate objects of any shape directly from computer graphics data without the need for a mold. This technique is quite mature at present, the economy and rapidity of 3D printing make large-scale applications unhindered. Thus 3D technology has a wide range of applications in modeling, visualization, preoperative surgical simulation, intraoperative assisting, and postoperative rehabilitation in medicine.

In intraoperative assisting field, some doctors have used guiding template technique in radius fracture surgery *(25)*. And some researchers already have a 3D printing study of scaphoid fracture on a cadaver *(10)*. The findings of these researches suggest that 3D technology cannot only simplify the complexity of surgery, but also reduce the tissue destruction. For simple fractures, 3D technology enables true micro-invasiveness. In acute scaphoid fracture, YIN et al. describes a percutaneous fixation with patient-specific guiding templates through volar approach *(11)*. As we known about fixation principles of scaphoid fracture, placing a screw perpendicularly to the fracture plane have biomechanical advantages in terms of fracture healing. Chan et al. find a better central screw placement of scaphoid in the dorsal approach than in the volar approach *(26)*. Soubeyrand et al. also suggest the dorsal approach allowed for the best screw placement perpendicular to the fracture plane in scaphoid *(27)*. Ten Berg et al. confirmed that the dorsal approach was unobstructed for transverse fractures of waist and required deviating slightly from perpendicular screw placement for most horizontal oblique fractures of waist, which was much better than the standard volar approach [28]. Yet ,to the best of our knowledge, there has been no report of individualized guiding template through dorsal approach clinically. So we decided to have performed a surgery for suitable patient with guiding template through dorsal approach.

Actually, there were several details regarding the novel technique need to be cared about during the whole operation. Firstly, prompt diagnosis and communication with patients is significantly important. We need to identify the type of scaphoid fracture prior to operation. Additionally, good communication with patients about the choice of the surgery would make the treatment more immediately and more efficient. Secondly, a comprehensive preoperative plan is definitely required. Factors such as the swelling of patient's wrist after injury, gradually increasing with the passage of time after CT scan, and the difference in the edema between timing of CT scan and timing of surgery could lead to a mismatch between the designed guiding template and the intraoperative wrist, which will adversely disrupt the insertion precision. In this present study, the processing of the CT data took 30 minutes, and another 4 hours was needed to print the template in a three-dimensional printer. It took 40 minutes to sterilize the template using ethylene oxide method. At the same time, we give ice compress to reduce the swelling of wrist. According to our experience, the swelling will not change much if the operation is performed within 8 hours after the CT completed. Thirdly, the surgical approach must be considered carefully. In fact, template was based on CT data. The position of the wrist during CT examination determined the surgical approach. Our experience is that physicians accompanying patients for examinations. After determining the position and type of fracture in neutral position, immediately perform another CT scan of wrist in flexion or dorsal extension position according to surgery approach. Thus the surgeon can design a dorsal approach template or palmar approach template. Lastly, the material of the guiding template we chosen was polylactic acid(PLA), and the physical and chemical properties of which are stable. But the material do not sterilize under high temperature and pressure, otherwise it will be deformed. We sterilized it in ethylene oxide method.

The operations we performed on two patients were successful, There was no incision and complications. The operation time was below 20 minutes and the blood loss was below 1ml. Consequently this 3D printing guiding template technique is considered to be successfully applied in scaphoid fracture surgery, the feasibility and accuracy of the technique is impressive.

Individualized 3D printing guiding template have wide application prospects. We have tried for the scaphoid fracture already. Since the sample of this study was limited, there may be many issues that we have not found. A long-term follow-up of the technique is also needed to explore the validity. Moreover, the effectiveness of this technique need to be validated in multicenter study. however, this study we firmly believe would provide a novel technique for the treatment of scaphoid fracture in the future.

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