Check for updates

Full Length Article

JHS(E)

Journal of Hand Surgery
(European Volume)
0(0) 1–6
© The Author(s) 2024
Article reuse guidelines:
sagepub.com/journals-permissions
DOI: 10.1177/17531934241276375
journals.sagepub.com/home/jhs
Sage

Titanium patient-specific scaphoid replacement for unreconstructable nonunions: a case series study

Willem Geuskens[1,2], Andreas Verstreken[2,3], Eline Stroobants[1] and Frederik Verstreken[2,3]

Abstract

Although reconstruction is the preferred treatment option for symptomatic scaphoid nonunions, this may not be an option due to inadequate bone quality or degenerative changes. Existing salvage procedures tend to compromise function. This study introduces an alternative approach through the utilisation of a 3-D-printed titanium patient-specific scaphoid implant. In this retrospective case series, the outcomes of 12 patients treated for an unreconstructable scaphoid nonunion with a 3-D-printed prosthesis were evaluated. Patient-reported outcomes, range of motion, grip strength and plain radiographs were assessed pre- and postoperatively. The mean follow-up was 2 years and 8 months. Range of movement and patient-reported outcome scores improved postoperatively, although improvement in movement was not significant. Except for one, all implants showed satisfactory alignment on radiographs without any further degenerative changes. 3-D-printed titanium scaphoid replacement may be an alternative to salvage procedures for unreconstructable scaphoid nonunion.

Level of evidence: IV

Keywords

Scaphoid, nonunion, arthroplasty, 3-D printing, innovation

Date received: 11th March 2024; revised: 1st August 2024; accepted: 2nd August 2024

Introduction

Due to its retrograde blood supply, the scaphoid is susceptible to loss of vascularity after a fracture, contributing to a relatively high incidence of nonunion and avascular necrosis (Handley and Pooley, 1991; Zura et al., 2016).

The primary goal of scaphoid nonunion treatment is to restore the anatomy of the bone and congruency of the wrist joint. Unfortunately, reconstruction of the scaphoid is not always successful because of its complex osseus and ligamentous anatomy (Marai et al., 2006; Yeo and Kim, 2018). Failure to achieve union can lead to a predictable pattern of scaphoid nonunion advanced collapse (SNAC) (Mack et al., 1984).

In cases of scaphoid nonunion, where reconstruction is no longer an option, the remaining treatment options are limited to so-called 'salvage procedures', such as four-corner arthrodesis (FCA), proximal row carpectomy (PRC) and total wrist arthrodesis. Although satisfactory outcomes have been reported, each of these procedures compromise wrist motion and strength (Wyrick et al., 1995). Biomechanically, the loss of carpal height in PRC results in decreased strength whereas the change in radiocarpal joint motion in FCA leads to a decreased range of motion (ROM) (Debottis et al., 2013).

[1]UZ Leuven, Department of Orthopaedic Surgery and Traumatology, Leuven, Belgium
[2]AZ Monica Hospital, Department of Orthopaedic Surgery and Traumatology, Deurne, Belgium
[3]University of Antwerp, Department of Orthopedic Surgery and Traumatology, Edegem, Belgium

Corresponding Author:
Willem Geuskens, Florent Pauwelslei 1, 2100 Deurne, Belgium.
Email: willem.geuskens@hotmail.com

An alternative treatment option is scaphoid implant arthroplasty, with the potential to avoid or at least delay the need to perform salvage procedures. Historic attempts to develop a functional scaphoid implant have not been successful. During the 1940s, 1950s and 1960s, vitallium, acrylic and silicone implants were used, respectively (Haussman, 2002; Legge, 1951; Pequignot et al., 2000). Unfortunately, these implants were compromised by complications, such as silicone synovitis, dislocations, non-physiological movements and foreign body reactions.

Better results were reported by Spingardi and Rossello (2011) using a titanium implant. Nevertheless, restoring the complex and variable anatomy of the scaphoid bone remains a challenge. Recent progress in 3-D-printing technology offers the potential to replicate the scaphoid bone more precisely to restore anatomy and joint congruency.

The aim of this study was to present a case-series of 3-D-printed, patient-specific titanium scaphoid prosthesis as a treatment option for unreconstructable scaphoid nonunions.

Methods

Patient selection and characteristics

In this retrospective case series, 12 patients diagnosed with an unreconstructable scaphoid nonunion were treated with a patient-specific, 3-D-printed titanium scaphoid implant between 2017 and 2022. The diagnosis was confirmed through clinical evaluation and further imaging with radiographs and computed tomography (CT) scans.

Previous infection and end-stage SNAC wrists were considered contraindications for scaphoid replacement surgery. Patient outcomes were obtained from postoperative standard of care data and the study was approved by the local Institutional Review Board.

The 3-D-printed scaphoid

A CT scan of the contralateral scaphoid was used as a template for the titanium implant with the design modified based on the anatomy of the affected wrist. The prosthesis included eyelets for ligament reinsertion, trabecular areas for ligament ongrowth and a central tunnel for ligament reconstruction with a tendon graft (Figure 1). The implant was then manufactured through a process of selective laser melting (SLM® 125 printer; Nikon SLM Solutions AG, Germany) of progressive 30-μ layers of titanium powder (Ti-6Al-4V-ELI), followed by a heat cycle to reduce internal stresses and a polishing process to minimize the friction coefficient.

Surgical technique (ligament suspension technique)

The patient is placed supine on the operating table with the arm extended on an arm table. The procedure is performed under tourniquet control. An oblique volar incision is made over the scaphoid tubercle followed by a second incision 8 cm more proximal over the flexor carpi radialis (FCR) tendon. A split in the FCR is made distally, isolating one-third of the width. A metal wire is used to divide the tendon proximally, allowing the harvest of an 8 cm partial FCR graft, distally based on the second metacarpal. Through the same palmar incision, the scaphoid tubercle is identified and attached ligamentous structures are divided from the bone.

A 4 cm longitudinal dorsal incision over the radiocarpal joint is made. The extensor pollicis longus (EPL) tendon is identified and released from its compartment, then retracted radially. The wrist capsule is exposed and a modified Berger capsulotomy is performed. The capsular incision is modified to preserve the insertion of the dorsal intercarpal (DIC) and dorsal radio-carpal (DRC) ligament insertions on the lunate. The scaphoid is identified, soft tissue

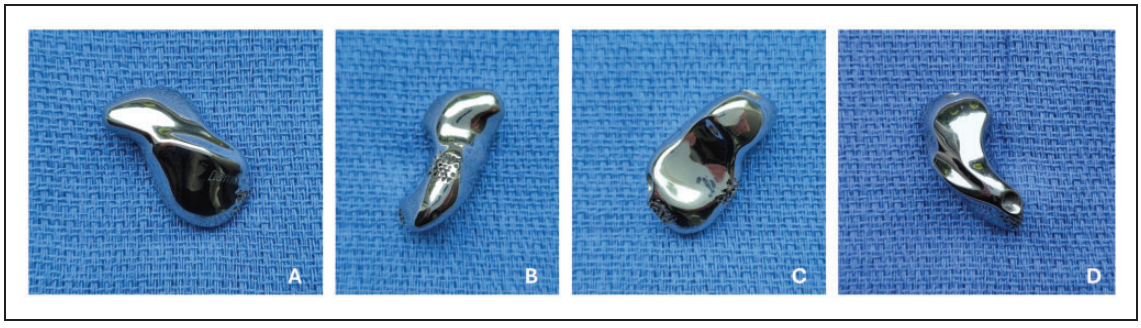

Figure 1. The 3-D-printed scaphoid implant: (a) radial, (b) palmar, (c) ulnar and (d) dorsal views.

attachments are divided and the scaphoid completely removed. The dorsal and palmar scapholunate ligament attachments to the lunate are preserved. The FCR tendon graft is passed through the central tunnel of the prosthesis and the prosthesis is inserted in the appropriate position. The tendon graft is fixed onto the dorsal lunate under appropriate tension with a suture anchor. Care is taken not to overtighten the tendon graft, as this impedes scaphoid flexion with radial deviation of the wrist. The dorsal scapholunate ligament is reinserted on the prosthesis eyelets. A trabecular surface is printed in this area for ligament ongrowth. Correct implant position and stability is confirmed by direct visualization and testing under fluoroscopy.

After closure, a bulky dressing with a wrist splint is applied. The wrist is immobilized for 6 weeks postoperatively, followed by 4 weeks of intermittent splinting.

Physiotherapy is started at 6 weeks postoperatively and the program consists of progressive passive and active ROM and strengthening exercises of the wrist, all within pain limits for the first 3 months.

Outcomes

A visual analogue scale (VAS) score, Patient-Rated Wrist Evaluation (PRWE) score and Quick Disabilities of the Arm, Shoulder and Hand (QuickDASH) score were used to assess pain, patient-reported outcomes and satisfaction. Functional outcome measurements included ROM and grip strength (Jamar dynamometer). Standard posteroanterior and lateral radiographs were assessed pre- and postoperatively.

Statistics

Because of the small sample size of the cohort, nonparametric statistical analyses were performed, despite the continuous data having a normal distribution (Skaik, 2015). The continuous data are presented as median (range). Comparisons of pain and function between preoperative and postoperative data were based on the Wilcoxon signed-rank test for paired samples. Outcomes were considered significantly different if the calculated p-value was <0.05.

Results

Patient characteristics

A total of 12 patients with an unreconstructable scaphoid nonunion were treated with a 3-D-printed titanium scaphoid implant.

The median age of the patients at the time surgery was 48 years (range 31–70 years). Eight patients were treated for a right-sided and four patients for a left-sided scaphoid nonunion with avascular necrosis. Five patients experienced a SNAC grade 1 wrist preoperatively, with degenerative changes between the distal part of the scaphoid and the radius.

Two patients were lost to follow-up: one patient underwent revision surgery with resection of the implant due to symptomatic anterior subluxation of the prosthesis and the other patient died from an unrelated cause. Consequently, the outcomes of 10 patients are reported in this study. The median follow-up period was 2 years and 8 months (range 13–61 months)

Range of motion

Both flexion and extension improved postoperatively. The median ROM preoperatively was 38° of flexion (range 5°–80°) and 23° of extension (range 0°–80°) compared with 40° of flexion (range 30°–80°) and 35° of extension (range 15°–80°) postoperatively. The total ROM arc improved significantly from 63° (range 15°–160°) to 75° (range 45°–160°) (Figure 2).

Strength

A Jamar hand dynamometer was used to evaluate isometric grip strength. Postoperative grip strength levels were compared with the unaffected side (%). Weighted mean grip strength was 30.1 kg (range 14–57 kg), which represented 74% of the contralateral side (range 50–105 kg).

Pain and patient satisfaction

Both PRWE and QuickDASH scores, as well as VAS scores for pain, did improve significantly postoperatively ($p < 0.01$). The median preoperative VAS score of the patients was 7 (range 4–9) versus 0 (range 0–4) postoperatively. The median QuickDASH score decreased from 48 (range 14–82) to 9 (range 0–32) and PRWE score from 63 (range 18–93) to 13 (range 0–51) (Figure 3).

Radiographic outcomes

One implant had to be removed because of failure to maintain the prosthesis position. All other implants showed satisfactory joint congruency with no radiographic complications, such as radiocarpal osteoarthritis, bone cysts or signs of loosening. Additional flexion-extension and ulnar-radial deviation views showed no signs of instability (Figure 4).

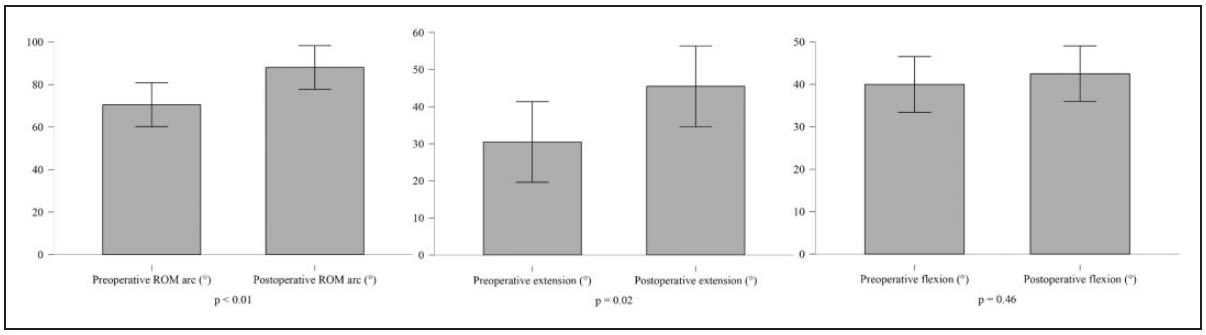

Figure 2. Range of motion.

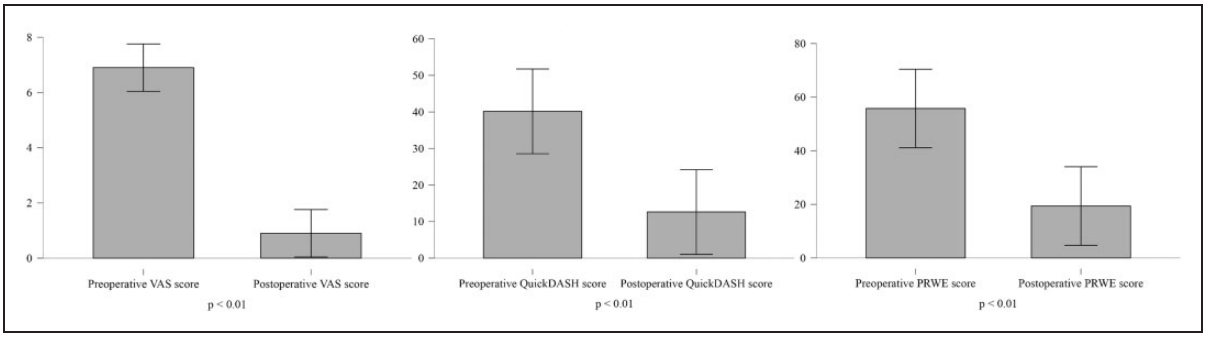

Figure 3. Patient satisfaction.

Discussion

Treatment options for unreconstructable nonunions of the scaphoid bone are limited and may compromise wrist motion and function (Maris et al., 2024). Encouraged by the results of a titanium implant arthroplasty of the scaphoid reported by Spingardi and Rossello (2011), we further investigated scaphoid replacement as a potential treatment option.

Our study implemented a bespoke 3-D-printed titanium implant and modified the surgical technique. Using 3-D-printing technology, we were able to design a matching scaphoid replacement to precisely restore anatomy and joint congruency. Therefore, we expected a lower failure rate and greater durability of the implant. This theory was supported by the findings of Honigmann et al., (2018) who tested 3-D-printed patient-specific scaphoid replacements combined with a tendon suspension in a cadaveric setting, observing normal kinematic behaviour and a stable scapholunate interval during physiologic ROM. Very recently, Cioffi et al. (2023) reported on the outcomes of nine partial and 10 total 3-D-printed titanium scaphoid implants. The design and surgical technique for their total scaphoid implants differ from ours. Their implant has a stem at the distal end that fits into a predrilled hole in the trapezium and is further stabilized to the lunate with artificial tape. At the 1-year follow-up, their reported results were very similar to our results, with a mean improvement in VAS for pain of 5.7 points, improvement in grip strength of 12 kg and reduction in PRWE score of 16.2.

Contrary to the surgical technique described by both Spingardi and Cioffi, we used a ligament suspension technique to optimize the biomechanical properties of the implant, therefore negating the need for a stem inserting in the trapezium to provide extra stability.

A recently published meta-analysis included a total of over 3800 patients experiencing a SLAC or SNAC wrist deformity who underwent salvage surgery (Reyniers et al., 2023). They analysed the outcomes of 1066 PRCs and 2771 FCAs. The most striking advantage of our preliminary results is the preservation of ROM. We have demonstrated a flexion-extension arc of 75°, which is similar to the flexion-extension arc for FCAs (77°) and considerably better than the arc for PRCs (63°). In our series, pain and patient satisfaction outcomes appear to be slightly better than either FCA or PRC, whereas postoperative grip strength is situated within the same range as FCA, which is better than after PRC.

Another advantage of 3-D-printed scaphoid reconstruction is that it does not preclude future salvage procedures. This could potentially delay or prevent

Figure 4. Radiographs in (a) ulnar deviation, (b) radial deviation, (c) flexion and (d) extension 6 years postoperatively.

the need for conversion to a more functionally compromising salvage procedure, although longer follow-up is needed to examine this question.

There are several limitations to this study, most of them related to the innovative nature of the procedure. First, the small sample size of the cohort is likely to diminish the strength of our conclusions. Second, our study lacks a control group for comparison. Third, long-term results must be monitored to determine the durability of the implant. Lastly, we believe there is still room for improvement in fine tuning the implant and the surgical technique. Further adaptations of the implant may enhance wear characteristics, promote ligament ongrowth and improve biomechanical behaviour. A minimally invasive surgical technique may enhance the stability of the implant. If signs of implant instability appear during longer follow-up, more complex ligament reconstructions may be necessary.

This study emphasizes the potential of a 3-D-printed patient-specific scaphoid prosthesis as a treatment option for nonunions of the scaphoid that cannot be reconstructed. After short-term follow-up of at least 1 year, there is a significant improvement of pain and PROM scores, and the procedure can preserve better wrist ROM and strength than other salvage procedures. We propose that the 3-D-printed titanium scaphoid implant may be a treatment option for selected and well-informed patients diagnosed with unreconstructable nonunions of the scaphoid, but long-term outcomes are not available yet.

Declaration of conflicting interests The authors disclosed the following potential conflicts of interest with respect to the research, authorship, and/or publication of this article: FV is a consultant for Cadskills.

Funding The authors received no financial support for the research, authorship, and/or publication of this article.

Ethical approval Ethical approval to report this case series was obtained from the AZ Monica Institutional Review Board (No. 508).

Informed consent Written informed consent was obtained from the patients for their anonymized information to be published in this article.

References

Cioffi A, Rovere G, Bosco F et al. Treatment of scaphoid nonunions with custom-made 3D-printed titanium partial and total scaphoid prostheses and scaphoid interosseous ligament reconstruction. Healthcare (Basel). 2023, 11: 3123.

Debottis DP, Werner FW, Sutton LG, Harley BJ. 4-corner arthrodesis and proximal row carpectomy: A biomechanical comparison of wrist motion and tendon forces. J Hand Surg Am. 2013, 38: 893–8.

Handley RC, Pooley J. The venous anatomy of the scaphoid. J Anat. 1991, 178: 115–8.

Haussman P. Long-term results after silicone prosthesis replacement of the proximal pole of the scaphoid bone in advanced scaphoid nonunion. J Hand Surg Br. 2002, 27: 417–23.

Honigmann P, Schumacher R, Marek R, Büttner F, Thieringer F, Haefeli M. A three-dimensional printed patient-specific scaphoid replacement: a cadaveric study. J Hand Surg Eur Vol. 2018, 43: 407–12.

Legge RF. Vitallium prosthesis in the treatment of the carpal navicular fracture. West J Surg Obstet Gynecol. 1951, 59: 468–71.

Mack GR, Bosse MJ, Gelberman RH, Yu E. The natural history of scaphoid non-union. J Bone Joint Surg Am. 1984, 66: 504–9.

Marai GE, Crisco JJ, Laidlaw DH. A kinematics-based method for generating cartilage maps and deformations in the multi-articulating wrist joint from ct images. Conf Proc IEEE Eng Med Biol Soc. 2006, 2006: 2079–82.

Maris S, Apergis E, Apostolopoulos A et al. Scapholunate advanced collapse (SLAC) and scaphoid nonunion advanced collapse (SNAC): A review of treatment options for stage ii. Cureus. 2024, 16: e59014.

Pequignot JP, Lussiez B, Allieu Y. [A adaptive proximal scaphoid implant]. Chir Main. 2000, 19: 276–85.

Reyniers P, van Beek N, De Schrijver F, Goeminne S. Proximal row carpectomy versus four-corner arthrodesis in the treatment of SLAC and SNAC wrist: meta-analysis and literature review. Hand Surg Rehabil. 2023, 42: 194–202.

Skaik Y. The bread and butter of statistical analysis "t-test": uses and misuses. Pak J Med Sci. 2015, 31: 1558–9.

Spingardi O, Rossello MI. The total scaphoid titanium arthroplasty: a 15-year experience. Hand (N Y). 2011, 6: 179–84.

Wyrick JD, Stern PJ, Kiefhaber TR. Motion-preserving procedures in the treatment of scapholunate advanced collapse wrist: proximal row carpectomy versus four-corner arthrodesis. J Hand Surg Am. 1995, 20: 965–70.

Yeo JH, Kim JY. Surgical strategy for scaphoid nonunion treatment. J Hand Surg Asian Pac Vol. 2018, 23: 450–62.

Zura R, Xiong Z, Einhorn T et al. Epidemiology of fracture nonunion in 18 human bones. JAMA Surg. 2016, 151: e162775.