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# A Novel Customized 3D Printed Arm Stand Improving Skin Preparation Efficiency in Hand Surgery

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**Summary:** Patient preparation for hand surgery often necessitates skin preparation via the use of an assistant to hold the arm to be operated on in mid-air while disinfectant is applied. This study introduces a three-dimensional printed arm stand that decreases dead time during skin preparation, while also enabling the more efficient use of an assistant. The arm stand devices were customized on the anatomy of the patients and then successfully used on patients having general or regional anesthesia. A practical, reusable, and effective three-dimensional printed arm stand has been developed and applied on both adult and pediatric patients. We have found the bespoke device to be beneficial in terms of reducing theater dead time and overall costs, while increasing the efficiency of an upper limb operating theater list. The rapid prototyping cycle afforded by 3D printing renders this technology a valuable tool for developing medical devices with patient-precise dimensions. *(Plast Reconstr Surg Glob Open 2020;8:e3249; doi: 10.1097/GOX.0000000000003249; Published online 25 November 2020.)*



## INTRODUCTION

The current practice of skin preparation, though effective, tends to be laborious and often necessitates multiple personnel to assist in the process. This is because the limb to be disinfected needs to be kept elevated to ensure sterility is maintained. Naderi et al. in 2012 described a “sterile bag” technique in which the patient’s limb was immersed in a bag filled with povidone iodide. They showed an improved and more effective use of assistants by suggesting that skin preparation could be achieved in as short as 10 seconds. It was however noted that special care was needed, given the top of the bag became unsterile when it came into contact with the patient.[1]

Recent advances in three-dimensional (3D) printing and the multiple applications of this technology in the medical sector have been noted. For instance, Hoang et al. reviewed articles from 1997 until 2016 and provided evidence of overall cost effectiveness of 3D printing in surgical applications. Chen et al. used 3D printing for preoperative preparation in cancer surgery, and Liu et al. used 3D anatomical models in thoracic surgery planning.[2–5] In our study, we aim to introduce a more facile and universal approach to skin preparation with the use of a novel 3D printed arm stand placed at the elbow of the patient that serves to lift the limb off the operating table and therefore assist skin preparation while minimizing the number of personnel required.

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## DEVICE DEVELOPMENT

To design the device, in addition to empirical measurements obtained from our patients, we consulted the “basic biomechanics of the upper limb database” from the NASA anthropometry and biomechanics manual.[6] The first prototype of the device was designed as a simple stand with a central dip in which the olecranon was resting and therefore stabilizing the elbow in a neutral position (Fig. 1). This device was tested on a patient but did not provide enough lift of the hand off the operating table; also, the forearm could easily move laterally while trying to move from pronation to supination to prepare the skin on both sides. The second iteration of the device was designed so as to provide further lifting of the arm as well as lateral stabilization. To achieve that, a cap was 3D printed using a flexible polyurethane filament (YOYI TPU, infill = 20%, $h_{layer}$ = 0.28 mm, v = 40 mm/s) to provide an upward projection to the rested forearm while also being elastomeric, thus minimizing the possibility of any pressure points manifesting (Figs. 1 and 2).

## DEVICE CHARACTERISTICS

A stereolithography file (.stl) of the arm stand device was designed on Blender (Amsterdam, the Netherlands) and

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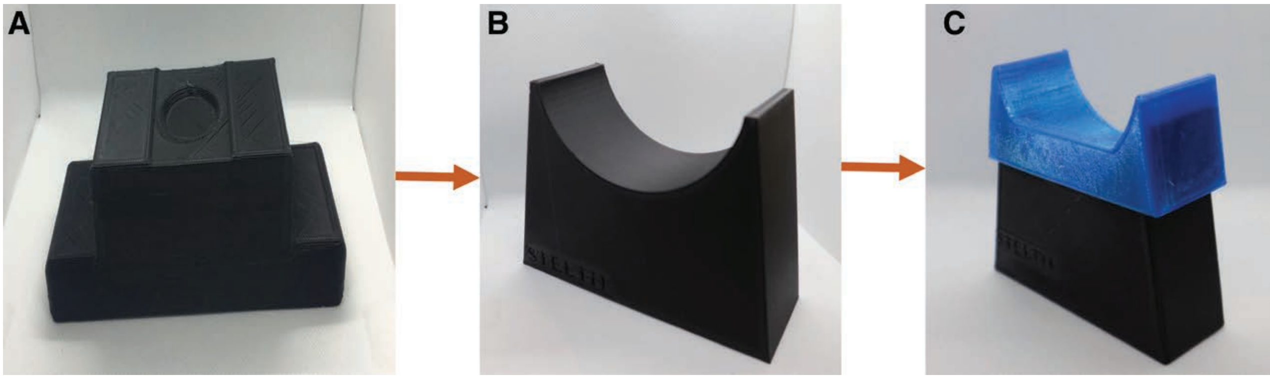


**Fig. 1.** Photographs illustrating the development of the device. A, First prototype with an olecranon dip at the centre. B, Second prototype with a central curve. C, Final prototype with an elastic cap.

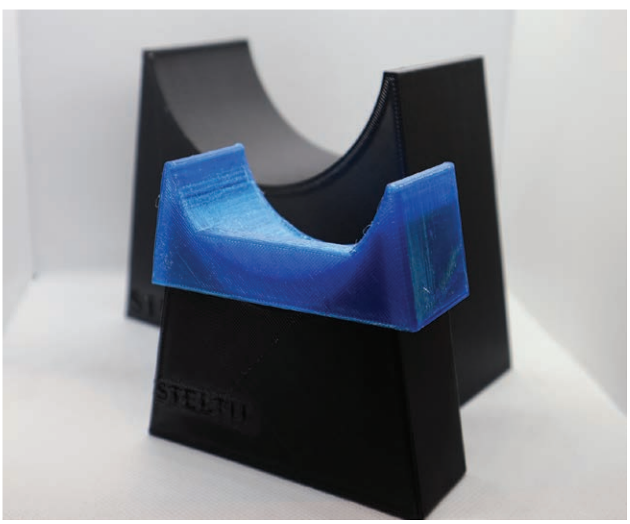

**Fig. 2.** Photograph displaying an adult and a pediatric device for comparison. Pediatric device is provided with an elastic cap.

then manufactured on a commercial Fusion Deposition Modelling (FDM) Ender 5 3D printer (Creality, Shenzhen, China) in Polylactic Acid (PLA) sourced from RS UK (1.75-mm filament by RS, Northants, United Kingdom). A scale version of the above design (60% overall volume) was also produced to serve as the pediatric analog (Fig. 2). The two constructs required 311 g and 76 g of PLA material and 240 minutes and 145 minutes of printing time, respectively. For the elastic caps, a flexible polyurethane filament was used (TPU by YOYI, China) to provide an upward direction to the rested forearm while also being elastomeric. For the cap construct, 69 g and 19 g of material was required, respectively. The choice of a flexible material for the cap module was made so as to minimize the possibility of any pressure points manifesting to the arm of the patient by virtue of the elastic nature of the material (Table 1).

## POSITIONING OF DEVICE

The arm stand was positioned by the leading surgeon before scrubbing in. The device was then placed under the elbow joint and due to the design it provides an upward projection to the forearm. This improves the positioning of the hand avoiding contact with the operating table. The scrub nurse who is already scrubbed in starts skin preparation, exchanging between pronation and supination, while the surgeon is getting ready (**See Video 1 [online],** which displays the use of the arm stand device on a pediatric patient, facilitating skin preparation for hand surgery.)

Once the skin preparation is complete, the surgeon positions the drapes. Once the bottom drape is positioned,

**Table 1. Parameters and Settings for 3D Printing the Adult and Pediatric Version of the Arm Stand Device**

| | Size Ratio | | | |
|---|---|---|---|---|
| | Adult Device | | Pediatric Device (60%) | |
| **Manufacturing Parameters** | **Arm Stand** | **Elastic Cap** | **Arm Stand** | **Elastic Cap** |
| Material | PLA (18.56 GBP/Kg) | TPU (23 GBP/Kg) | PLA (18.56 GBP/Kg) | TPU (23 GBP/Kg) |
| Max speed (mm/s) | 80 | 40 | 80 | 40 |
| Nozzle diameter (mm) | 0.4 | 0.4 | 0.4 | 0.4 |
| Filling density (%) | 20 | 20 | 20 | 20 |
| Infill pattern | Cubic | Cubic | Cubic | Cubic |
| Printing time (min) | 240 | 120 | 145 | 70 |
| Layer height (mm) | 0.28 | 0.28 | 0.28 | 0.28 |
| Weight (g) | 311 | 69 | 78 | 19 |
| Nozzle temperature (°C) | 200 | 235 | 200 | 235 |
| Bed temperature (°C) | 70 | 70 | 70 | 70 |
| Cost (GBP/USD) | 7.22/9.45 | | 1.88/2.46 | |

The overall material cost for each type of arm stand device has been provided.

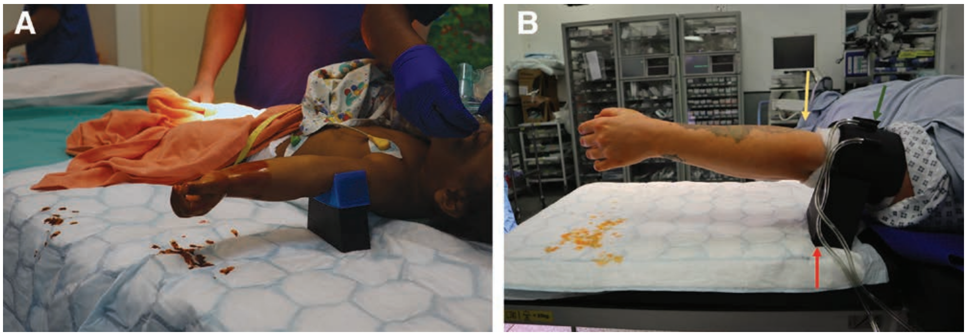


**Fig. 3.** A, A 1-year-old patient under GA on the pediatric arm stand having the elastic cap. Adequate lift of the hand to facilitate skin preparation is demonstrated. B, An adult patient (aged 37 years) under LA on the arm stand device without the elastic cap. The red arrow shows the positioning of the device. The yellow arrow shows the level of the elbow. The green arrow shows the position of the arm tourniquet. The position of the device is superior to the olecranon. In both views, adequate lifting of the hand for skin preparation is demonstrated.

**Table 2. Breakdown of Manufacturing Cost and Turnover Period of Investment**

| | Adult | Pediatric |
|---|---|---|
| 3D printer cost (GBP/USD) | 262/350 | 262/350 |
| Material cost (GBP/USD) | 7.08/9.45 | 1.84/2.46 |
| Software cost (GBP/USD) | Open access | Open access |
| Overall cost (GBP/USD) | 269/359 | 264/353 |
| Estimated daily earnings of better allocated UK theater personnel (USD) | 77/100 | 77/100 |
| Estimated turnover time (d) | 3.59 | 3.52 |

Average cost of printer is 350 USD, with a turnaround period of 3.5 days.

the surgeon pushes the device away from the patient and releases the hand on the drape. The device is then taken away by the anesthetic nurse and cleaned for next time. The choice of material allows for easy and thorough cleaning.

## COST REDUCTION

When our device was implemented, one member of the theater staff was used more efficiently. Based on data from our hospital practice, it is projected that the savings per operating list per day would amount to 77 Great Britain Pound (GBP)/100 USD. Table 2 contains the cost breakdown used to calculate this estimate. This is a value that will have a significant impact on the institution, provided that there are multiple hand surgery theater lists running simultaneously and on a daily scale. Comparatively, the estimated one-time manufacturing material cost for the adult size device is 7.22 GBP/9.45 USD, and for the pediatric-size device, 1.88 GBP/2.46 USD. (Table 1) Finally, we found extra practical uses for the device including arm tourniquet positioning and plaster application. (**See Video 2 [online],** which displays use of the arm stand device to facilitate positioning of arm tourniquet.)

## CONCLUSIONS

Positioning of the developed 3D printed arm stand device is simple, comfortable, and improves the efficiency of the operating list. The device was found to decrease manual handling hazards and the overall cost in operating theaters, as no extra personnel is required during skin preparation.

Small optimizations such as the production of bespoke instruments for theater tasks can have a big impact when considering the overall running costs of daily lists.[2] To that end, the rapid-prototyping cycle of 3D printing renders it a promising new in-house technology to explore how these optimizations can be achieved.

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*This study conforms to the Declaration of Helsinki.*

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