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A Streamlined Algorithmic Process for Creating Three-dimensional Printed Forearm Casts

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Summary: Three-dimensional (3D) printing is a rapidly evolving field that has found its way into the medical field, providing unsurpassed contributions to the provision of patient-centered care. Its utilization lies in optimizing preoperative planning, the creation and customization of surgical guides and implants, and the designing of models that can be used to augment patient counseling and education. We integrate a simple yet effective method of scanning the forearm using an iPad device with Xkelet software to obtain a 3D printable stereolithography file, which is then incorporated to our suggested algorithmic model for designing a 3D cast, utilizing Rhinocerus design software and Grasshopper plugin. The algorithm implements a stepwise process of retopologizing the mesh, division of the cast model, creating the base surface, applying proper clearance and thickness to the mold, and creating a lightweight structure through the addition of ventilation holes to the surface with a joint connector between the two plates. In our experience, scanning and design of the patient-specific forearm cast using Xkelet and Rhinocerus, alongside implementing an algorithmic model through Grasshopper plugin has dramatically reduced the designing process from 2 to 3 hours to 4–10 minutes, further increasing the number of patient scans that can be sequenced in a short duration. In this article, we introduce a streamlined algorithmic process for the use of 3D scanning and processing software to create forearm casts that are tailored to the patients' dimensions. We emphasize the implementation of computer-aided design software for a quicker and more accurate design process.
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INTRODUCTION

Fractures are common injuries sustained by trauma patients,[1] with cast immobilization playing a pivotal role in their management. The ideal cast should be lightweight, durable, and patient-specific. This is paramount to ensure patient comfort,[2] and to avoid cast-associated complications such as pressure sores, ulcers, and compartment syndrome.[3]

With the unlimited capabilities of three-dimensional (3D) printing, such technology has been utilized in the creation of casts with achieving the above benefits. When compared with traditional casts, 3D-printed casts have demonstrated superiority in terms of comfort, compliance, cast odor, and skin irritation, yielding a high level of clinical efficacy and patient satisfaction.[4–6]

In our article, we describe our approach to the production and 3D printing of patient-specific casts. Our lightweight casts are created by adding ventilation holes to the design, which also avoids sweat trapping, reducing the risk of irritation and infections associated with damp environments.[7] We share our streamlined algorithmic process, which yields a significantly shorter production time.

METHODS

The process of creating a 3D-printed cast involves three main steps:

1. Obtaining a mesh model of the patient's limb using a 3D scanner;
2. Designing the cast using computer-aided design (CAD) software; and
3. Producing the cast using a 3D printer.

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We describe the use of two software programs throughout the process of creating our casts, Xkelet and Rhino 3D, in addition to the plugin Grasshopper.

Step 1: Scanning

The initial step involves creating a 3D digital model of the patient's forearm. This is achieved by scanning the patient's forearm using an iPad device on a program known as "Xkelet" (Xkelet Holdings Limited, Girona, Spain). The device is orbited around the patient's outstretched hand to capture a 360° view. This information is stored in the form of a stereolithography file, which is the standard format used in 3D printing. The next step involves exporting the stereolithography file to 3D software (Rhino 3D) (Robert McNeel & Associates, USA) for the design and production of the final model.

Step 2: 3D Design and Algorithmic Script

Once the file is exported, the design phase of the patient-specific forearm cast begins. To streamline the process of designing the 3D model, a tree branching algorithm was created using a plugin Grasshopper (Robert McNeel & Associates, USA) implemented in the 3D software. After obtaining the dimensions of the forearm, a set of parameters were fed through the algorithm to create a sequential script for creating a 3D mold of the arm. Subsequently, the cast was created on top of the mold based on the specified measurements of the patient's limb.

Initially, the script starts with retopologizing the mesh from a dense random mesh configuration to fairly uniform and equally distributed mesh edges. This aids in reducing unnecessary information that would otherwise consume computing power. The first phase of this process involves making the start and end points of the desired cast by adjusting the location between the first and the last curve-line (Fig. 1). The next step is making an outline cross-section of the hand in order to initiate a sweep which will eventually create a surface around the hand. This is a crucial step to the process because it creates a fully operable surface that can be controlled and altered more freely than a ready topologized mesh.

Takeaways

Question: Is it possible to implement three-dimensional (3D) scanning and processing software for quick design of 3D casts?

Findings: We integrate a simple yet effective method of 3D scanning, alongside an algorithmic model for designing patient-specific 3D forearm casts. In our experience, this has dramatically reduced the time involved in designing a 3D forearm cast.

Meaning: Implementation of 3D scanning and processing software allows for a quick and accurate design of patient-specific forearm casts.

Cross-section and rails are calculated to run a sweep resulting in the base surface, which is then offset from the hand with a distance of 2 mm as clearance to allow for comfortable fitting. The next step is to cut the base surface into two parts (Fig. 2). This allows for an easy assembly and removal of the cast and a jointing feature that would be generated in a later stage between both parts. Moving forward from this step, the script will run twice, once for each part of the cast. This allows for a customizable outcome and a more liberal integration of the design process. The surfaces are then rebuilt into the desired resolution for the targeted pattern outcome.

In our script, a pattern of parametric circular openings is applied where the holes get smaller as they approach the edges of the surface (Fig. 3). The output of splitting

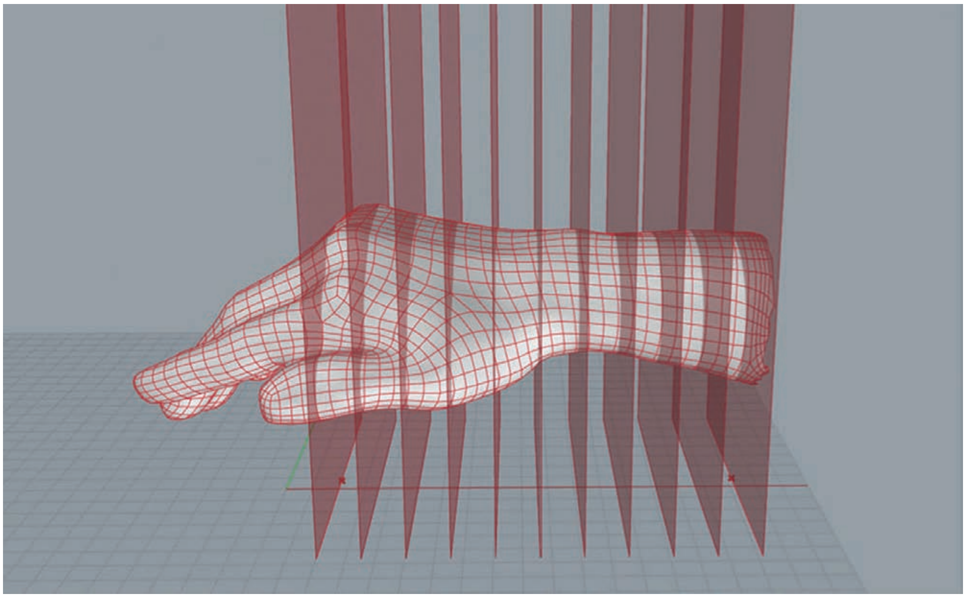

Fig. 1. The retopologized mesh of the 3D scanned forearm in the process of identifying the start and end points of the desired cast by adjusting the location between the first and last curve-line.

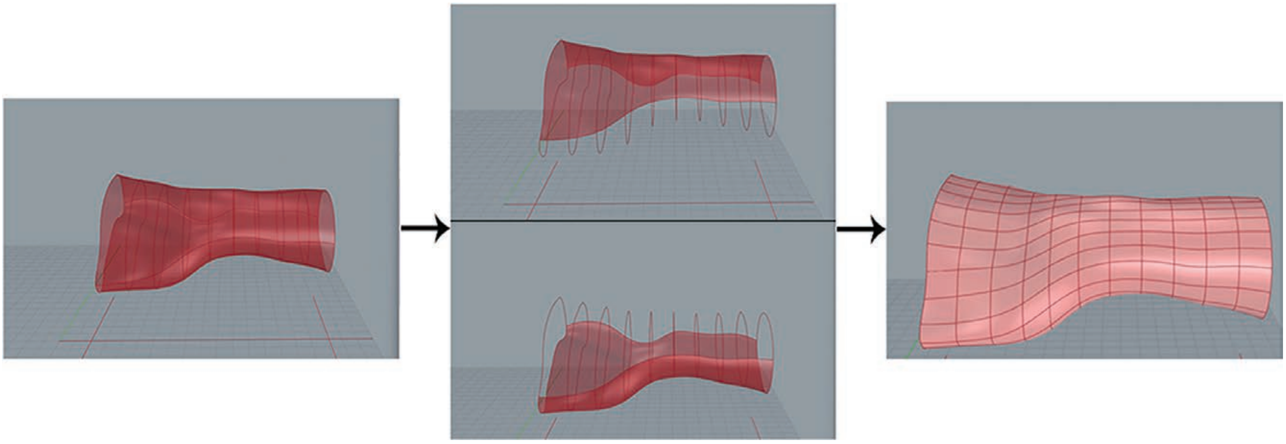

Fig. 2. The process of calculating cross-section and rails to run a sweep resulting in the base surface, followed by cutting the base surface into two parts and rebuilding the surfaces into the desired resolution for the targeted pattern outcome.

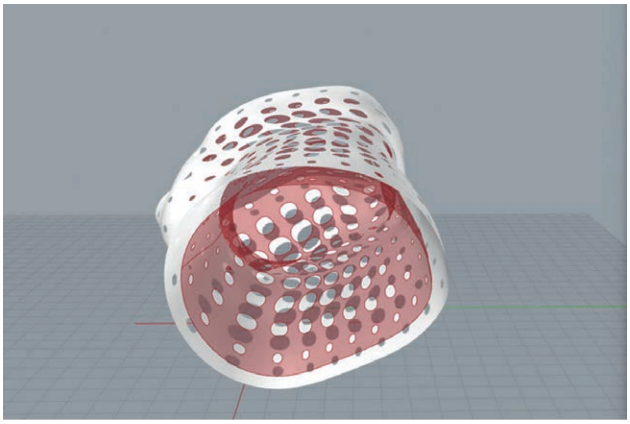

Fig. 3. The pattern of parametric circular openings being applied to the 3D cast surface.

the circles with the surfaces results in a perforated parametric design. Sizes of openings and the pattern shape are all controlled by numerical parameters that can be altered easily without restarting the process. These gaps allow for the cast to be airable and lightweight. Afterward, a thickness of 4 mm is given to the base surface to make it durable and 3D printable. Finally, the last phase involves generating a jointing connector between both parts that allows for a reliable assembly and removal of the cast.

Step 3: Production of the Cast

Once the design process is finished, the cast is ready to be transferred to the 3D printer for fabrication. We have used the Photocentric Liquid Crystal Magna 3D printer, with Black Durable Resin material to print the cast. The time required to produce the cast was 10–12 hours, with 12 minutes of washing using 2-propanol (which contains 90% isopropanol) followed by 2–4 hours of curing to achieve the finalized result.

RESULTS

Figure 4 displays a printed model fitted on a patient who had undergone extensor pollicis longus tendon reconstruction with a reverse radial forearm flap for soft tissue coverage, after sustaining a degloving injury from a road traffic accident. He was fitted with the arm cast that was scanned using Xkelet software and printed using Black Durable Resin with the Photocentric Liquid Magna 3D printer. Our algorithmic process was used in the production of his cast. The end pieces of the cast were joined using two rubber bands for ease of application and disassembly.

Fig. 4. Photograph of our printed model using Black Durable Resin on a patient who had had undergone extensor pollicis longus tendon repair.

DISCUSSION

The process of 3D printing starts with an initial step of obtaining a 3D model of the organ and/or structure of interest. Traditionally, the model is extracted from a computerized tomography or a magnetic resonance imaging scan. The images are then exported to CAD software and thereafter the process of designing starts. This might be an ideal option if the intended model is of an internal organ/structure. However, in scanning patients' limbs, a wide variety of software is available to acquire a 3D model.

The Xkelet software has proven to be a simple and convenient scanning tool that only requires an iPad to run. We have persistently found the software to yield an accurate scan of patients' limbs and a faster acquisition of the 3D model. This was extremely valuable in allowing for the production of customized casts in a more time-efficient manner.[6–8] Additionally, it avoids exposing the patient to unnecessary radiation and obviates the need for costly and cumbersome testing that is associated with traditional methods of acquiring a 3D model. After the creation of a 3D model, we follow an algorithm that cuts down the designing process considerably from 2 to 3 hours to only 4–10 minutes.

A wide variety of materials have been described for use in 3D printing. A number of factors are to be considered, which include but are not limited to weight, biocompatibility, durability, and water or heat resistance. Choosing the ideal material is largely dependent on the goal of the intended model. In producing our casts, we use the Black Durable Resin material.[9] We have found it to be ideal for creating casts, owing to its tensile strength and durability.[10]

LIMITATIONS

Despite the effectiveness of 3D printing in creating patient-specific casts, the process remains in its infancy. Although establishing a 3D printing facility along with hiring CAD specialists seems relatively costly,[7] further studies of cost analysis are required to ascertain its long-term cost effectiveness when compared with traditional casts.

CONCLUSIONS

We describe a streamlined and efficient process of creating customized 3D-printed casts. We integrate a simple and effective method of scanning, alongside an algorithmic model for the process of designing. In our experience, this has dramatically shortened the designing phase from 2 to 3 hours to 4–10 minutes, further increasing the number of patient scans that can be sequenced and printed.

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