Rib cage recreation: Towards realistic neonatal manikin construction using MRI scanning and 3D printing.

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Abstract

Within our research, the human body plays a central role. The human body is one of the most visually fascinating shapes, but our research goes further. We focus on the dynamic aspects of the body regarding interaction. Within this paper, we focus on the creation of manikins for the training of chest compressions, which is an essential procedure during cardiopulmonary resuscitation (CPR). We expect that the same techniques can be deployed for manikins in different applicational fields, such as fashion dummies, toys, and artistic installations. Within medical simulation, it is important that manikins have realistic anatomical and physiological properties. By embedding these properties, a more realistic tactile experience can be created. From our findings, we conclude that additive manufacturing materials have a broad mechanical stiffness range, with the potential to mimic that of the neonatal rib cage.

Vision and Introduction

CPR is an important procedure to ensure survival of patients suffering from cardiac arrest. One part of this procedure is the compressions of the chest to manually take over the function of the heart. To receive adequate training on how to perform CPR we find that it is of importance that the manikins used during training provide realistic anatomical and physiological behaviour to the trainees. The benefits of realistic tactile experience are that it can enhance effective learning[1]. For the training of chest compressions, a thorax with embedded rib cage is essential for a realistic tactile experience of chest deformation. Recently we turned our attention from adults to newborns and began collaborating with neonatologists. The training of performing chest compressions on a newborn is crucial. Newborn tissues are of a much lower density than those of the adult[2], and therefore require more care when being compressed. Realising this manikin realism in organic, tactile experience can only be obtained through additive manufacturing, or 3D printing as it is more commonly known, not through traditional mass manufacturing techniques such as injection molding. Although injection molding has since the discovery of plastics been the main production method for user products, it is difficult for this technique to meet the demand of mixed material properties providing differing movement and flexibility throughout the material. As the human body is constructed out of multiple tissue types, it is only possible to achieve the desired material complexity through 3D printing, where multiple material types can be mixed, and printing densities can be varied. Secondly, with 3D printing we free ourselves from the mold making process, which is time-consuming and expensive. Currently, there are no simulator manikins on the market which provide a realistic tactile experience relating to newborn chest deformation. Within this paper, we will show our explorations to find whether it is possible to recreate realistic neonatal rib cages with the materials available to us in 3D printing. First, we will explain our reconstruction method of the rib cage, using MRI imaging and additive manufacturing. Next, we will show the methods and results of our vertical force-deformation testing performed upon five rib cages following chest compression depth guidelines[3].

Building models

For building virtual models of rib cages, we use the Mimics software [4] to segment a complete rib cage from a high-resolution neonatal magnetic resonance imaging (MRI) scan (Figure 1), which was provided by the UMCN Sint Radboud museum of anatomy and pathology. The segmentation was done by hand, through marking the bone and cartillage parts of the rib cage on every image of the digital imaging and communications in medicine (DICOM) image set generated by the MRI. After marking was completed the software rendered a stereolithography (stl) file of the marked parts of all images in the DICOM set to create a 3 dimensional shape. We segmented the bone and cartilage components of the rib cage separately. We did this so that we would be able to give both components separate material properties. After segmentation, we used the 3-Matic software [5] to smooth the segmented model(Figure 1) and prepare it for the additive manufacturing process by closing errors and gaps in the stl model.

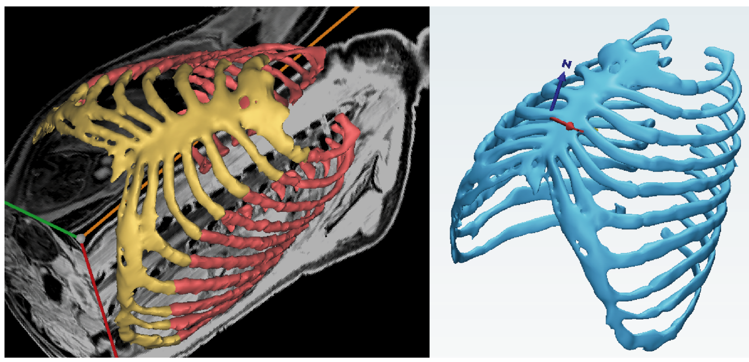

Figure 1: *Left: MRI segmentation of the rib cage with bone(red) and cartilage(yellow). Right: Smoothed rib cage model in 3-Matic.*

We produced five 3D rib cage models(Figure 2), using four different materials compositions, and two separate additive manufacturing machines. We printed the first model on an Ultimaker [6] printer using the Flexifill [7] material. The second and third models were also printed using the Ultimaker but were printed using the Filaflex [8] material. One of these two rib cage models had its ribs thickened by 100 percent before printing. The final two rib cage models were printed on an Objet printer [9]. The material loaded into this printer was Tango black [10] and Vero white [11]. Tango Black is a rubber-like material while Vero White is solid plastic. During printing, these materials can be mixed to create different densities and elasticities in the final product while still building the rib cage in a single print. One of these models had a printed bone structure using the G60 setting and a cartilage structure printed using the S95 setting. The second rib cage had a bone structure printed using the S95 setting, and a cartilage structure using the S70 setting.

Test setup and Measurements

We wanted to explore the material behavior range of our newly printed rib cages through force-deformation measurements. This with the purpose of exploring how much additive manufacturing can offer for the recreation of the dynamic properties of the human body. We built a measurement setup (Figure 3) on which the rib cages can be fixated. From medium-density fibreboard (MDF) [12], we laser cut a bottom plate and backboard on a Speedy 300 laser engraver [13]. On the backboard of the setup, a dimension grid is plotted with 1x1 cm squares. A drill column was used to attach an Imada force measurement system [12], which had a 1 cm^2 compression surface. The data from our measurement system were stored on a computer. We fixated and compressed each ribcage once at the center of the sternum to the recommended depth of 1/3 of

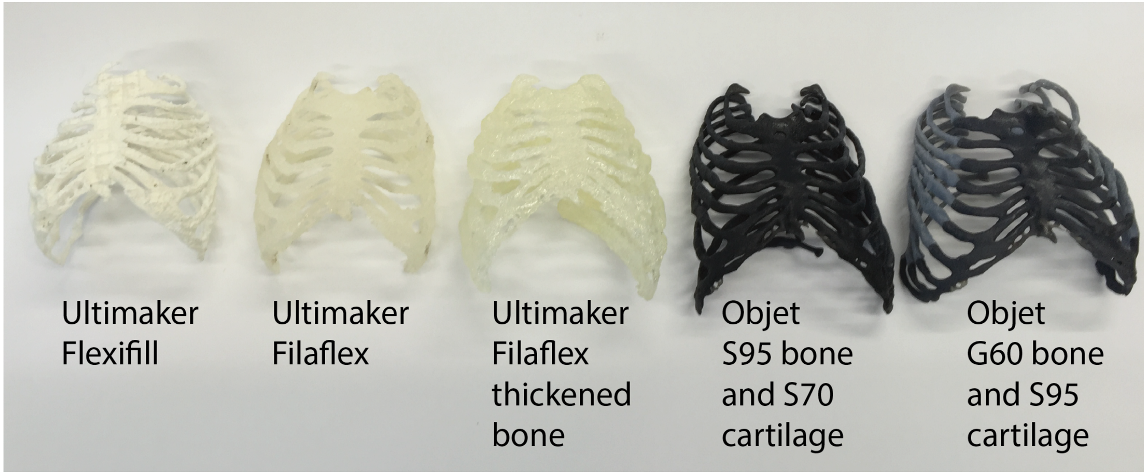

Figure 2 : *The five printed rib cages.*

its total height. In our case, this was 2 cm. In the table below we show the data we collected. We measured the peak force at the maximum displacement of 2 cm and deduced the stiffness parameter of the material used from this.

Figure 3 : *The compression position of our rib cages alligned with our construction.*

From our found data (Table 1) we learned that there is an enormous degree of freedom to alter the stiffness properties of rib cages through using different additive manufacturing machines and materials. This indicates that there must be a matching material and 3D printer combination yielding a realistic copy of the neonatal rib cage. However, until research of neonatal thorax deformation is published, we have no reference.

Material	Peak force (N/cm^2)	Stiffness (k)
Objet S95 bone S70 cartilage	1.16	0.58
Filaflex	1.77	0.885
Flexifill	3.30	1.65
Objet G60 bone S95 cartilage	4.71	2.335
Filaflex thickened bone	5.62	2.81

Table 1 : *Table of tested materials, the peak force at 2 cm displacement of the rib cages, and their stiffness parameters.*

Conclusion

From our data, we conclude that there is a wide variety of mechanical stiffness parameters to be found within 3D printing materials. Although no studies have been done on the area of neonatal thoracic force deformation properties, we find that recreating a realistic anatomical and physiological model of the neonatal thorax must be possible. With the advances of 3D printers and their materials we also think that more complex organs could be realistically recreated (such as the lungs, or heart), and will lead to more advanced training manikins to improve medical education.

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