Red blood cells: a 3D printed approach

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Purpose

The purpose of this study is to develop a methodology to print red blood cells (RBC) to establish a tangible model of RBC aggregation seen in microcirculation.

Computer aided design was used along with 3D software for printer input to create printed models of individual RBCs, RBC rouleaux.

Introduction

Red Blood Cells (RBCs) are imperative to animal life as they provide a medium of transportation for oxygen to cells throughout the body. RBCs have a constant volume and surface area, but they are able to deform in various ways in order to squeeze through microcirculation vessels. Also know as erythrocytes, they interact with the environment around them as well as with each other in very unique ways.

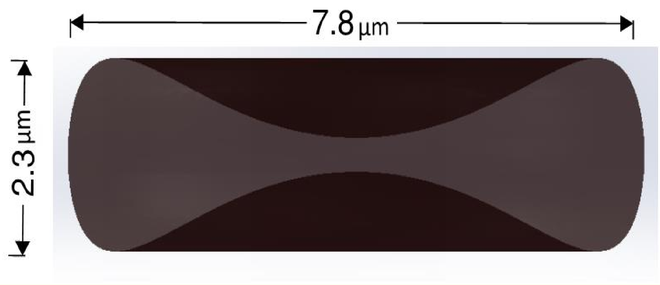

Fig.1: RBC dimensions

When there is low velocity (or a low shear rate) in the vein or artery, stacks of RBCs assemble themselves together to form what is named a rouleau. The reason for the formation of the rouleau is generally accepted as being through “monolayer bridging of macromolecules” (1. Chien & Jan 1973).

RBCs are in the micrometer range and therefore very difficult to visualize without using enhanced imaging. This project was inspired by research currently underway by Rym Mehri on RBC aggregation in fabricated microchannels. This is to be used as a tool to better understand how red blood cells appear and aggregate using tangible 3D printed models based on actual pictures of rouleaux.

Fig.9: 3D print overlaid into rouleau outline

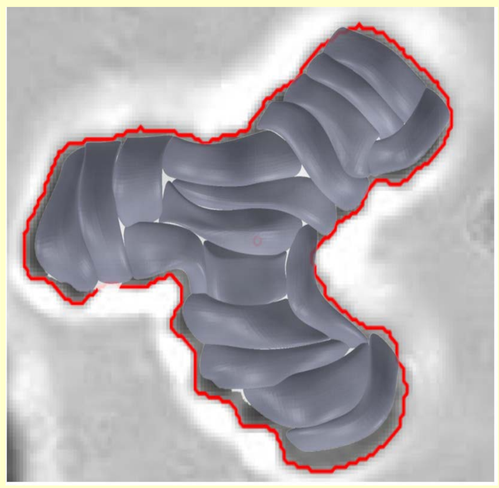

Fig.10: Y-shaped 3D models overlaid into X-Ray outline

References

1. Chien, Jan, *Ultrastructural basis of the mechanism of rouleaux formation*, 1973.
2. Liu Y, W Liu, Zhang, Wang, *Coupling Navier-Stokes Equations with Protein Molecular Dynamics,* 2004.

Method and materials

To create the first large scale RBC, a baseline model was created using a mathematical model of the cross-sectional area of a red blood cell (2. Liu Y, W Liu, Zhang & Wang 2004) along with Solidworks® to create the computer based object.

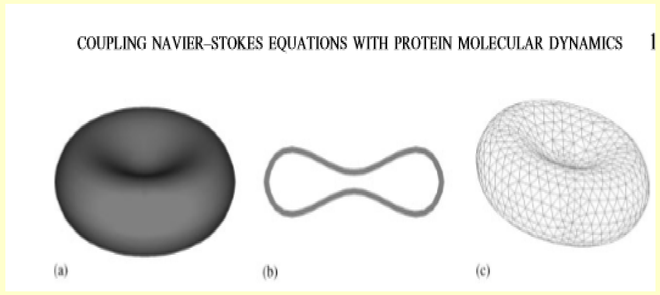

Fig.3: RBC cross-sectional area (2. Liu Y, W Liu, Zhang, Wang 2004)

Printing and grouping:

1. Makerbot Replicator 2® used for this research
2. Printing a 3 dimensional object can prove to be challenging, due to the lack of support in voids such as the bioconcave region found in a red blood cell.
3. Most 3D printers work similar to a hot glue gun but much more precisely (and with plastic); it must have something to build on, therefore holes or convex and concave regions cause print failures.
4. In order to account for the voids with it’s bioconcave form and add the supplemental feature of artificial attraction, the RBCs were split down the middle, printed flat side down and assembled with magnets inside the center. The magnets would serve to group several RBCs which form a rigid rouleau.

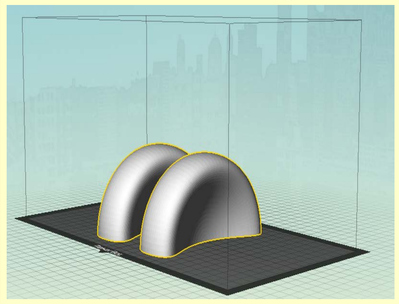

Fig.4: RBC split into two halves seen in the Makerbot® software

A key issue remains: with a rigid plastic object, how can a deformed RBC be created? High speed camera captures of pig blood obtained in the lab show actual rouleaux. The large RBC computer model mentioned above can be used in conjunction with Rhinoceros® to manipulate standard RBCs in the shape of the actual deformed RBCs observed.

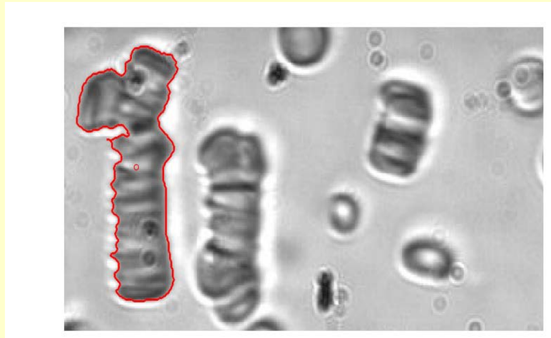

Fig.5: X-Ray image with rouleau outlined in red (see Fig. 8 for print)

Results

The first model was created using the outlines of the red blood cells of the X-Ray images to determine how many RBCs there are in the rouleau. Then the base model is scaled to match the 2D counterpart in the image. The image in Fig. 6 has the stack outline in red as interpreted using a Matlab program of Mehri’s, with the 3D printed object overlaid into the image.

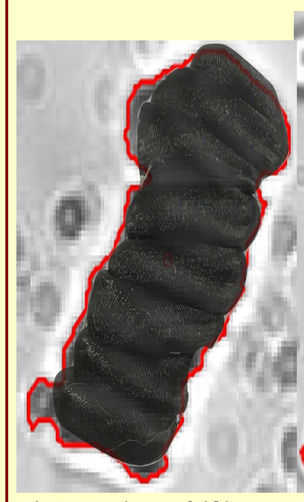

Fig.6: 3D print overlaid into X-Ray 1

Fig.7: 3D print overlaid into X-Ray 2

Fig.8: 3D print overlaid into X-Ray 3

The next two images seen in Fig. 7 & 8 were created using the same method and are displayed using the same technique.

In order to ensure that all possibilities were explored, just the outline was extracted from the image and RBCs were deformed therein (see Fig. 9). While this yielded a similar product, it does not contain the same detail as those found above due to the lack of the outline of each individual red blood cell making the process not always predictable.

Finally, the “Y” shaped rouleau (see Fig. 10) is very complex and surely is not always able to be properly demonstrated in the 2D image as it likely has many RBCs in the z-direction (out of the picture). Therefore this “Y” shaped rouleau model was made simply as an extra challenge. Considering that 3D printing these rouleaux requires assembly, printing the “Y” was simply not feasible as it would be very difficult to ensure all RBCs stay connected and therefore would not be an accurate representation of the 3D form.

Conclusion

To summarize, this research project was conducted successfully by accurately illustrating the abstract interpretation of 2D images of red blood cells rouleaux into a 3D product. The importance of the success of this experiment is that it opens the door for the possibility of large scale tangible simulation, which is far away but very possible using the methods established here as a baseline. With new advances in science everyday and the better understanding of the way the human body functions. This research of RBCs and their unique properties can serve to be essential in helping us further our knowledge and improve teaching methods.