Analysis of foot shape acquisition techniques and methodologies for the purpose of making custom shaped speed skate boots

Methods used for acquiring foot shape

Alginate box pour

The feet are positioned in a box and dry alginate is mixed with water and poured around the foot. Once hardened the alginate is cut along the top of the foot allowing the foot to slip out of the mold. Plaster can then be poured into the mold cavity.

Plaster wrap foot cast

The entire foot is rapped with a plaster of Paris bandage and then positioned either partial or full weight baring on the floor or a molding platform. Once hard, the cast is cut down the top of the foot and pulled off of the foot

Plaster clam shell cast

Plaster of Paris wrap is molded on the base of the foot and the top. Then the foot is positioned either partial or full weight baring on the floor or a molding platform. Once hard, the top portion is removed, then the bottom portion, then they are put back together

STS Foot molding Sock

The polyurethane prepreg sock is activated and rolled on to the foot. Then the foot is positioned either partial or full weight baring on the floor or a molding platform. Once hard, the sock is cut down the top of the foot and pulled off of the foot.

3D scanning

There are three main methods used to acquire the foot shape through 3D non-contact scanning.
All allow the foot to be positioned and scanned within 30 seconds.

1) Optical laser scanner

2) 3D picture captured

3) 3D video laser scanner

Major Advantages/Disadvantages

Alginate box pour	Plaster wrap foot cast	Plaster clam shell cast	STS Foot molding Sock	3D scanning

All of the above methods have a very poor accuracy of within 5mm for a professionally cast foot mold, for the following reasons:

1. The foot has many concavities, especially around the hyper sensitive ankle bones, for all the methods, except alginate box pour, the molding material must be manual forced to the shape of the foot, which is very tricky and impossible to do perfectly and uniformly.
2. All of the above methods require at a minimum 10 minutes to solidify and therefore it is extremely difficult to hold the foot in the correct anatomical position for the entire time. Movement of the foot during the hardening time distorts the mold and creates inaccuracies.
3. All the above methods require the foot to be removed from the hardened cast/mold, which is impossible to do without distorting the shape of the mold.
4. The negative cast/mold of the foot needs to be poured with plaster of Paris or expanding polyurethane foam to a achieve a positive foot shape that the custom boot can eventually be built off of. The problem is that plaster, and to a much greater extent expanding PU foam, applies outward pressure to the negative cast distorting the shape while solidifying.

With the above method a very accurate 3D (noncontact) scan of the foot is taken, which results in a near perfect digital representation of the customer's actual foot shape. With an accuracy of within 0.5mm. Because the scan can be completed within 30 seconds it is very easy to hold the foot in the correct anatomical position.

Analysis of the 3D scanning technologies

Optical Laser Scanner

A highly sensitive laser runs over the foot in a zero light enclosure. Eight cameras capture digital slices of the foot, which are reconstructed into a 3D shape within the software program. This is the oldest method of 3D foot scanning, which has been around for over 15 years.

3D Picture Capture

Four 3D still cameras take a digital picture of the foot, which are reconstructed into a 3D shape within the software program. This is a newer method, which has been around for over 8 years

3D video laser scanner

A 3D video camera with accelerometers projects a laser grid onto the object being scanned, and collects true shape data while the camera and laser grid is moved over the surface of the foot. The 3D shape of the foot is constructed real time on the computer screen while the foot is being scanned. This is the newest technology and has only been around for about 6 years

Major Advantages/Disadvantages

Optical Laser Scanner	3D Picture Capture	3D video laser scaner
		
Highly accurate (0.5mm), and the scan takes 30 seconds or less per foot	Highly accurate (0.5mm), and the scan takes 30 seconds or less per foot. The scan can be performed on a contoured surface, critical for acquiring the proper foot shape for custom speed skate boots and especially custom cycling shoes.	Highly accurate (0.5mm), and the scan takes 30 seconds per foot. The scan can be performed on a contoured surface. Because of the portability of the system specialized platforms can be engineered to optimize the partial weight baring position ideal for optimal anatomical bone position.
The major disadvantages of this method are that the foot can only be scanned on a flat surface. A contoured platform can not be used because it distorts the optical laser. The optical laser is extremely sensitive and any light leaking into the scanning box or even dust particles will distort the scanned image. Because the foot is concealed during the scan, proper anatomical positioning is impossible to monitor.	Some disadvantages of this system are that it is difficult to scan with a partially weight baring foot, which is important for optimal anatomical bone position. The system isn't transportable.	One disadvantage of the system is that the operator of the scanner needs to be more skilled than with the other systems

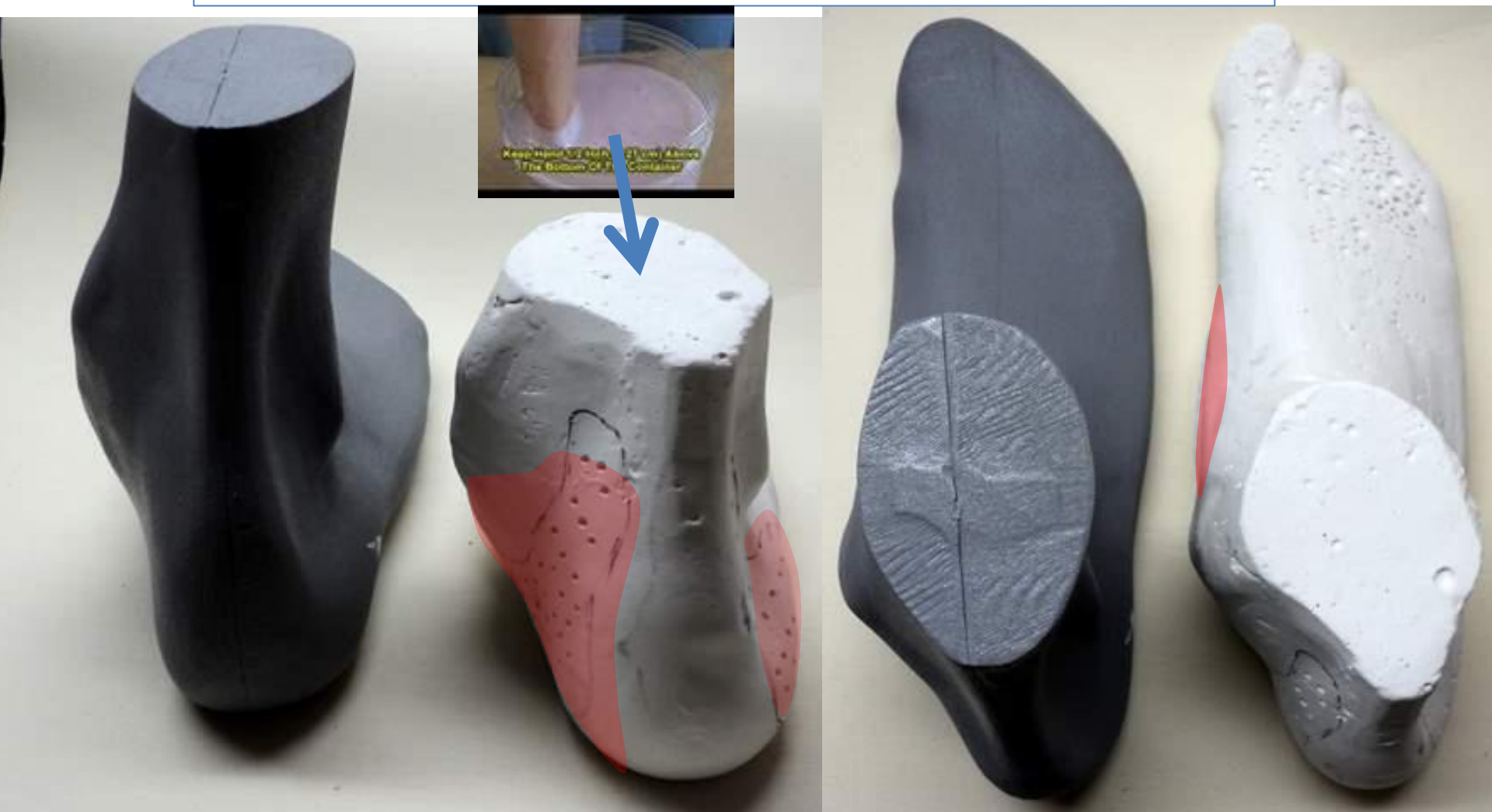
After the 3D Scan

The 3D foot data is sent directly to a CNC mill, which carves the foot out of a block of high density PU Foam

The CNC milled PU foot mold can now be sanded and shaped just like a plaster foot mold. Because the PU foot mold starts with a far more accurate and anatomically superior shape, much less reshaping needs to done to the PU mold than a plaster mold. Therefore, higher precision and less error in the foot mold will result in a more consistent and potentially better fitting custom skate boot . Every foot is slightly different and therefore requires different adjustment and reshaping, making it impossible to design a computer program that can properly and precisely do the job for every foot. Meaning, the reshaping still needs to be done by hand, by an expert.

Comparison of an alginate box pour foot mold (white) vs a 3D video laser scanned foot CNC milled out of PU foam (grey)

Without being an expert custom boot maker, you can see how much more reshaping the white plaster foot mold requires (red areas)



Comparison of an alginate box pour foot mold (white) vs a 3D video laser scanned foot CNC milled out of PU foam (grey)

Picture Comparison of the actual foot to the same foot 3D video laser scanned and CNC milled out of PU foam (grey)

Comparison of the actual foot to the same foot 3D video laser scanned and CNC milled out of PU foam (grey)