Use of rapid manufacturing technology in comprehensive rehabilitation of a patient with physical body disorders

Luka Botolin[a], Samo Gazvoda[a], Tomaž Maver[b], Gašper Gantar[a]

[a] TECOS- Slovenian Tool and Die Development Centre*)*
[b] Institute for Rehabilitation, Republic of Slovenia

Abstract

The paper presents a novel approach to creating customised aesthetical prostheses for people with body malfunctions, caused by surgical removal, amputations or birth disorders. Such patients suffer both physically and mentaly, resulting in deep traumas. For a successful rehabilitation, the production of customised aesthetical prostheses is very important. Together with Institute for Rehabilitation, Republic of Slovenia, TECOS developed a new approach for production of tailor-made aesthetical prostheses. New technology customizes the final product to such measures, that it significantly contributes to successful post-traumatic rehabilitation of the patient from personal, psychological, aesthetical and practical aspects. The whole working process is shown, which includes digitising of healthy and impaired part of the body, modifications of digitised data with CAD/CAM software, rapid manufacturing for building up the first model or mould and finally moulding of the silicone epithesis.
The results were very promising and eventually proved that the approach, with further improvements, will provide final products with better quality, providing a ground for better and faster rehabilitation of patients.

Keywords: *Silicone, moulds, Digitising, Rapid prototyping, Epithesis, Prosthesis*

1. Introduction

People with body malfunctions, caused by surgical removal, amputations or birth disorders, suffer both physically and psychicaly, resulting in deep traumas. Some experiences show that patients wish to replace the lost part of their body with a prosthesis that is a mirror image of the relevant healthy part of the body.

At the Institute for Rehabilitation and most of the centres for manufacturing silicone hand prostheses [1, 2], the manufacturing of silicone prostheses has so far based on the shape of similar PVC cosmetic gloves or on the model of a similar hand of a third person. None of the mentioned methods has allowed manufacturing of prostheses that would be similar enough to the patient's healthy hand. Therefore the Institute for Rehabilitation has developed in collaboration with TECOS a CAD/CAM technology for manufacturing of tailor-made prostheses, which shape is a mirror copy of the patient's healthy hand. The approach has been succesfully applied in the field of mouldmaking [3] and also already used in designing and making of epitheses [4]. The same procedure is also mentioned by Didrick [5], the author of an article on the manufacturing of finger prostheses. New approach is presented on practical cases in following chapters in a form of case studies.

2. Case study 1: Aesthetical and functional prosthesis made by new approach

The first case study was made on a patient who lost his finger (Fig.1). In order to reproduce the closest match of the original finger the only way is to capture the shape of its counterpart on the healthy hand. For mirroring and mould production, the use of state-of-the-art measurement devices and computer hardware and software had to be implemented. Epithesis production can be divided into the following steps:

1. 3D digitising (capturing of the physical shape)
2. CAD modelling (modifications on the computer model)
3. Mould design
4. Computer aided mould manufacturing
5. Mould finishing
6. Moulding and finalization of the epithesis

The fixation of the epithesis was made by tight fit of the silicone epithesis on the impaired part. For that, the negative impression of the impaired part had to be introduced into the finger epithesis. The model of the impaired part must therefore be used during moulding as an insert, leaving the needed negative impression in the epithesis.

2.1 3D Optical Digitalisation With ATOS II 400

First, healthy part of the body was digitized. But due to problems with muscular and nerves vibrations a silicon mould was made, which was used for moulding of plaster. The result was an exact duplicate (including all skin details, also fingerprints) which was than digitized without problems. (Fig.1).

Fig 1: Finger duplicate made of plaster

The same procedure was used for making a plaster model of the impaired part of the body that had previously been corrected and than digitized. Results of 3D optical digitalisations are shown on Fig.2.

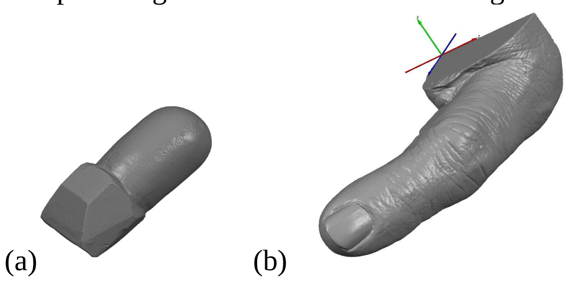

Fig. 2: Results (STL-models) of 3D optical digitalisation of impaired part of the body (left) and corresponding finger from the healthy hand (right)

Digitalisation was made with 3D optical system ATOS II 400 using measurement volume 100*80*80 mm, which resulted in 0,01 mm accuracy. All finger details were kept. This flexible optical measuring machine is a high end digitising system based on the principle of triangulation. Projected fringe patterns are observed with two CCD cameras. 3D coordinates for each camera pixel are calculated with high precision. As a result a polygon mesh of the object's surface is generated, exported in neutral STL format.

During the development phase, three digitising systems were tested, among which the highest quality of scanning was achieved by ATOS. The latter was also the only one that enabled digital models with visible skin details, including fingerprints.

2.2 Virtual mould

Virtual mould was made on the base of digitized results. As a start the finger model was mirrored and repositioned to the coordinate system of the impaired part. This revealed an obvious problem: circumference of impaired part was substantially lower than that of the finger. Both parts had to be fitted into one with a smooth transition between them (Fig. 3). That is the only guarantee that the transition on the actual epithesis would also be smooth.

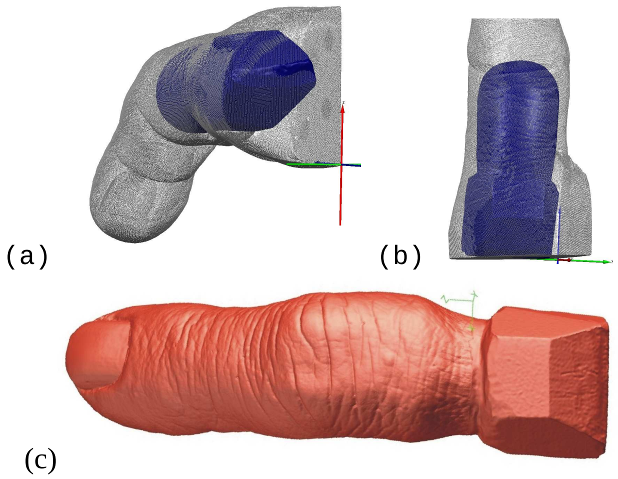

Fig 3: Modifications on the model of the finger; (a) repositioning into the same coordinate system, (b) difference in the circumference, (c) final result

Because the STL model was used, which is still hard to work on due to the hardware and software limitations, this was not an easy step. The Tebis RSC v3.3, which was used for modelling, proved to be a good solution. Final steps included design of parting surface, cutting of the finger into bottom and lower part and design of upper and lower part of the mould.

2.3 Mould manufacturing

For manufacturing of the mould traditional methods are not suitable since all the skin details would be lost. The use of additive processes was necessary. But the question was which prototyping technology to choose for mould production in order to keep all details captured with the high-end digitiser.

Three procedures were tested: DMLS (metal), SLS (polyamid) and 3D printing (ABS plastic). The best reproduction of skin details in the mould was achieved by the DMLS technology (Direct Metal Laser Sintering) with 0.02 mm layer thickness (Fig. 4).

Fig 4: DMLS technology was used to make a mould for manufacturing silicone finger epithesis

In the testing of the SLS (Select Laser Sintering) technology (Fig. 5) and the 3D printing technology, the layer thickness was was 0.1 mm. When inspecting the tools, the most accurate surface was found to be that produced by the DMLS technology.

Fig 5: At the last trial, SLS technology was used to produce a tool for manufacturing a silicone finger epithesis

Silicone was poured into the moulds and after the vulcanization the quality of test prostheses was found to depend on the apparency of skin prints. The highest quality of the mould surface was achieved by the DMLS technology and the lowest by the 3D print technology, which produced a rougher surface of the prostheses test model despite the satisfactory apparency of the skin prints. The SLS technology was selected for tool manufacturing due to its accessible cost. The appearance of skin prints achieved by the SLS was not essentially lower than that achieved by the DMLS technology.

3. Case study 2: Manufacturing of hand prosthesis

Hand prosthesis is more difficult to manufacture than finger. The reason for that lies partly in the size of the STL model which makes it hard to manipulate, and also the complexity because of negative angles. Other than that, the procedure is similar to that of the finger example.

3.1 Difficulties in the design phase

After 3D optical digitalisation parting line was defined. Because of uncomfortable fingers setting up a decision for division of mould into 4 pieces was made (upper and lower die, insert around thumb and insert of impaired part of the body).

Fig. 6: Hands parting line marked on plaster model

While comparing the mirror image of healthy hand to the impaired part it was observed that the impaired part was too thick on some areas. Those areas had to be thickened on the model of the healthy part in order to enclose them under the surface (Fig.7).

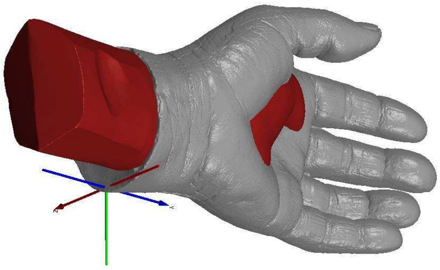

Fig. 7: Figure shows some interference between two parts

We also must assure smooth transition between prosthesis and impaired part of the body. The problem which has to be solved in the future is how to deal with all modifications while retaining skin details. The present results are satisfactory, but not perfect (Fig8).

Fig 8: Final repaired STL prepared for mould design

On the base of repaired STL of digitised hand and parting planes we made 4 pieces mould in STL format, which was the base for SLS rapid prototyping technology (Fig.9).

Fig 9: Upper and lower die in STL format (without inlets)

The final result after moulding of silicone is shown on Fig 10. In general, the majority of skin details on prosthesis was kept so the it is consequently comparable to the healthy right hand. Finishing procedures include some minor hand work on the prosthesis, incorporation of finger nails and painting at the end.

Fig 10: Finished silicone prosthesis with all skin details, including fingerprints up to an extent

4. Conclusion

The final appearance of the prosthesis depends greatly on its shape. Our experiences in using the CAD-CAM high resolution technology have shown that such technology enables computer-based manufacturing of prostheses, which in their form mirror the healthy body parts. This technology provides the patients with the highest-quality lifelike prosthetic design.

Future work includes improvements on the procedures of all stages. The shape must be captured directly from the body, not via intermediate plaster phase, software must be improved in a way that it will keep more details after modifications of STL models and last but not least, the rapid manufacturing technology must improve the layer thickness so more details can be preserved while manufacturing. Ideally, the prosthesis would be manufactured directly from the computer model, without mould manufacturing.

5. References

[1] O'Farrell DA, Montella BJ, Bahor JL et. al. (1996) Long-term follow-up of 50 Duke silicone prosthetic fingers. J of Hand Surgery. 21B: 5: 696-700, 1996

[2] Pilley MJ, Quinton DN.(1999) Digital prostheses for single finger amputations. J Hand Surg [Br]. Oct;24(5):539-41

[3] Gazvoda S, Botolin L, Nardin B, Kmet B. (2003) Product Development and Mould Production Time Decrease by Use of Reverse Engineering Methods. 6th International Conference on Management of Innovative Technologies MIT 2003: 47-52

[4] Sykes LM, Parrott AM, Owen CP et.al. (2004) Application of rapid prototyping technology in maxillofacial prosthetics. Int. J Prosthodont. Jul-Aug;17(4);454-9.

[5] Didrick D at http://www.oandp.com/edge/issues/articles/2005-11_06.asp