

The Cosmesis: A Social and Functional Interface

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A

cosmesis fulfills multiple functions, from providing a cosmetic covering to increase social acceptance to improving the gripping capability of a prosthetic hand.

This article explores the requirements imposed on the cosmesis developed for the Revolutionizing Prosthetics (RP) 2009 program and looks at the dual glove-solution path that evolved during the development and testing. The requirements are drivers for the materials selection, and the processing method that was selected is an evolution of traditional cosmesis fabrication. Future directions in cosmesis fabrication are discussed.

BACKGROUND

A cosmesis is the last component to be placed on a prosthetic arm, hand, or both, and it is the first component that others interact with, either visually or by contact. Historically, the cosmesis has had two primary functions. The first has been to provide a cosmetic cover over the nonhuman-appearing mechanism of the prosthetic limb. This cover helps the patient feel more comfortable in social settings (Fig. 1). The second function has been to provide a better gripping surface than that of the underlying mechanism for the hand to promote picking up and holding objects. In the work described in this article, we imposed other requirements, such as providing a first barrier against the environment and allowing sensors to measure force, vibration, and temperature through the cosmesis.



Figure 1. Conceptual lower limb and hand with SG cosmesis (ring and little fingers left uncovered to show detail).

Designing and developing a cosmesis solution that maintains mechanical and environmental durability while minimizing mechanical drag and allowing sensor function was the crux of the challenge. For the

Revolutionizing Prosthetics (RP) 2009 program, the cosmesis (Figs. 2 and 3) was developed in two variants. The first variant was the work glove (WG), a functional glove that does not include artistic detailing to make it look similar to a human arm. This is the less expensive and more durable functional form. The second variant was the standard glove (SG), a fully realistic cosmetic cover that includes artistic detailing that makes it resemble a natural limb. A patient would have the option of switching between the gloves depending on the environment or just using one glove or the other.

REQUIREMENTS

We required that the cosmesis:

- Appear natural
- Be durable
- Be manufacturable
- Be lightweight
- Meet mechanical requirements
- Support sensor function
- Be repairable

Failure to meet these requirements reduces the likelihood that a patient will wear the cosmesis and deprives the patient of more normal and therefore comfortable social interactions.

The most important requirement for the SG cosmetic covering is that it appear natural. However, this requirement is only skin deep, and there are several derivative needs for both the SG and WG versions of the cosmesis.

A cosmesis must approximate the patient's matching limb in size, contour, and coloration to ensure the appearance is perceived by others as being natural to the patient. The materials can be colored, both intrinsically and extrinsically, to simulate the appearance of human skin, including translucency, and should appear natural over a range of skin tones and ambient conditions. Color matching is a difficult problem and is further compli-



Figure 2. A WG-style cosmesis on a hand mechanism model.

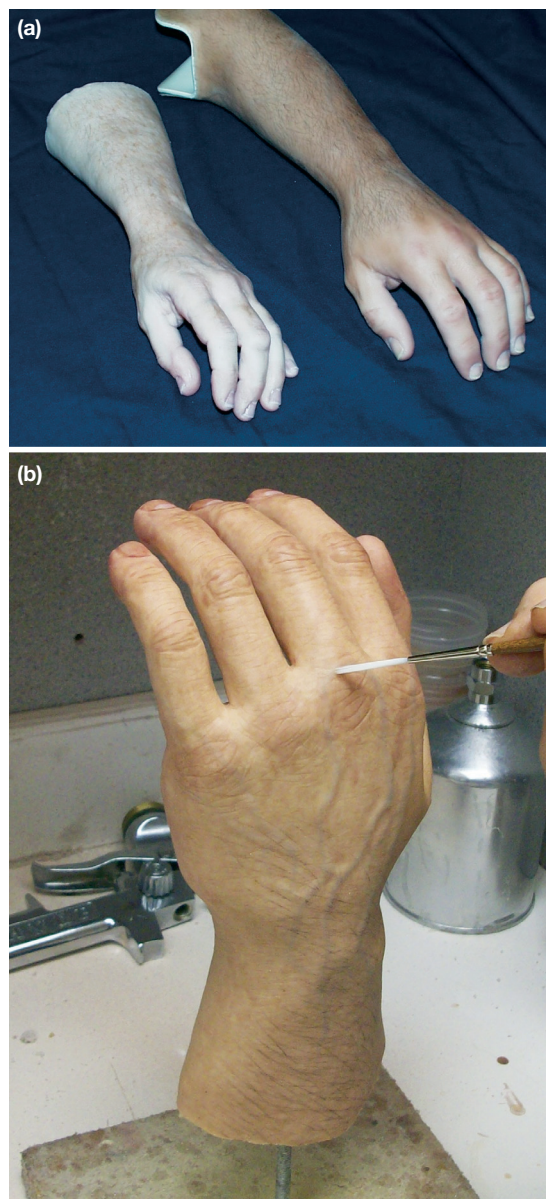


Figure 3. SG cosmesis examples.

cated by different lighting conditions (metamerism). Raising your hand above your head causes a change in blood flow due to gravity that affects the appearance of your skin on that limb. Flushing, reacting to hot or cold environments, sweating, tanning, and burning are all features of a natural limb that cannot currently be duplicated in a cosmesis.

The capabilities of many of today's cosmetic coverings are very limited in the sense that there is not a great intersection between appearance and function. The most common failure mechanisms of a cosmesis are cutting or pinching through the material by the mechanism, often against hard surfaces. Currently, most patients who have a choice will not use a cosmesis if they have to do heavy work or are interacting

with surfaces that will readily cut or tear the covering. The durability of the prosthetic limb and the cosmesis must exceed that of a natural limb. No matter how good the sensory capabilities of the prosthetic limb are, they will not equal natural senses. As a result, the prosthetic limb will be subjected to more wear and tear due to daily living than a natural limb. Added durability is also needed to accommodate the fact that the prosthetic limb is not capable of constant regeneration as is a human limb. To improve the overall durability of the cosmesis, a thicker cross section has been used at the cost of increased drag and weight on the mechanism. This has been shown to reduce the usable strength of a myoelectric hand and increase the power consumption. (The myoelectric hand uses signals from voluntarily contracted muscles within a person's residual limb on the surface of the skin to control the movements of the prosthesis.) In addition, a thick cosmesis does not transmit vibration or thermal signals well. The materials must be able to allow the required range of force, vibration, and temperature sensors to function through the thickness of the cosmesis glove.

The materials selected to meet the functional requirements must also be able to be fabricated into the cosmesis and produce repeatable articles. The constituent materials and the process must be scalable to production, and the costs must be reasonable. Traditional cosmesis fabrication is highly labor intensive, requiring great artistic skill, which makes cosmeses relatively expensive to manufacture.

All of these issues are further exacerbated given the full dynamic range of the advanced limb system developed under RP2009 and its ability to experience forces

far beyond current prosthetic technology. The prosthetic limb system has fully articulated digits capable of exerting high grip forces as well as supporting fine tactile discrimination.

The materials must achieve all other requirements at the lowest weight possible to minimize parasitic drag on the prosthetic power system. Target mass for a 50th percentile male glove is 150 g, and a complete arm cosmesis is 350 g. The selection of materials for the cosmesis is intimately tied to the fabrication processes. The current state-of-the-art material for cosmeses is silicone. It provides the best combination of mechanical and chemical properties, manufacturability, and ability to be realistically colored. The list of important properties can be seen in Table 1.

The materials must be able to withstand temperature, impact (such as when stopping a fall), and loads generated in normal daily environments and any specified extreme conditions. In addition, the materials must be able to handle objects that human skin can survive (sharp edges or points with a light grip), and they must help protect the limb from hazards such as dust, sand, and water. They must be maintainable and resistant to staining or damage from normal activities such as eating, drinking, writing with a permanent pen, or reading the newspaper. The cosmesis must survive being placed onto and removed from the prosthetic device.

The properties reported in Table 2 are not typically reported by manufacturers but were considered important for this application, and the relative performance of each was addressed during developmental testing of the cosmesis.

Table 1. Target material properties for a cosmesis.

Property	Description	Target value
Hardness or durometer	Resistance to compression forces. A lower-durometer material feels more pliant, like soft tissue and skin.	Max. = 20 Shore A
Strength	Resistance to breaking under load. Target is highest combination of strength and elongation.	Min. = 850 psi
Elongation	Ability of the materials to stretch. Target is highest combination of strength and elongation.	Min. = 850%
Tear resistance	Resistance to failure at an edge of the material under load.	Min. = 120 pli
Max. operating temp.	All silicones have approximately the same temperature resistance of 200°C or higher.	Min. = 100°C
Glass transition temp. (T_g)	Temperature at which a material changes from rubbery to glassy. For cosmeses, this relates to a lower temperature where the material loses its flexibility and becomes more rigid. All silicones evaluated have a T_g of -127°C , well below any envisioned operating conditions.	Max. = -40°C
Chemical resistance	Varies by chemical. The list is too long for this article.	Varies

pli, pounds per linear inch.

Table 2. Additional material properties for a cosmesis.

Property	Description
Abrasion resistance	Resistance to mechanical failure when rubbed or scraped against another material. Our target is to be no worse than human skin. There are no good reference data for this. Testing was conducted to begin establishing these values. ¹
Stain resistance	Resistance to common potential staining materials such as grass, ink, wine, mustard, and dirty oil or grease.
Internal and external surface friction	Can be separated into static friction, which is the resistance to sliding when two surfaces start pressed together, and sliding friction, which is the steady-state resistance between two sliding materials.
Creep resistance	Resistance to permanent mechanical deformation under load for long times.
Fatigue resistance	Resistance to failure induced by repeated loading such as finger flexing.
Translucency	Skin is translucent, and a good cosmesis material will reproduce this quality.
Ability to color	The material and its processing methods need to allow detailed coloring that varies from point to point on and in the cosmesis.

RP2009 COSMESIS DESIGN

The cosmesis is designed to provide a durable cover that helps protect the mechanism and sensor elements and provides abrasion and stain resistance. Additionally, the surface of the cosmesis does not sustain biological growth and helps to block environmental contaminants such as dust and moisture. The cosmesis is designed to help the hand grip the surface of objects by locally conforming and providing a tailored friction surface.

The aforementioned requirements for the cosmesis glove cannot all be met using a single solution. The dual-glove approach allows each glove to be optimized to meet certain requirements that are conflicting if imposed on the same glove. The SG is designed to provide the best cosmetic appearance while meeting as many of the other requirements as possible. It is more expensive and has a lower durability. Each SG requires a semicustomized to fully customized mold and coloration to match the patient (the base color is determined from photographs, and the final matching is done at the glove manufacturer's clinic). A SG can also be decorated to match documentation of preamputation tattoos (to aid psychological acceptance).

The WG is designed to focus on lower manufacturing costs through standardized molds, improved design features that minimize friction points at the joints, and increased durability in select locations. Although the WG is not specifically color matched, there can still be a degree of color customization; however, the options are generally limited to solid colors (including non-skin tones) or standard patterns—solutions that lend themselves to mass production.

The packaging challenge was to have the SG provide a “natural” appearance while covering a mechanism that is not anatomically exact. The target thickness of both gloves was 1 mm to allow flexibility and minimize

drag on the motors when moving the limb. Component packaging efforts focused on shaping the mechanical elements more closely to the human profile. One concern was how the wrist looks and acts. A human wrist is oval in cross section, not a rotary joint located next to the hand. This rotary motion imposes unnatural movement in the cosmesis at that location. In locations along the prosthetic limb where the mechanical surface is not anthropomorphic, a foam structure was added to provide a lightweight compressible layer to shape out the cosmesis. The same foam can provide a cushioning pad at the grip surfaces of the hand and fingers to allow more conformal gripping like a human hand.

The RP2009 architecture requires the sensory elements (primarily in the fingertips) to reside and perform under the cosmesis. There were candidate architectures in which the sensors are embedded within the cosmesis; however, these were discarded because of the costs of maintenance and replacement. The cosmesis allows the power system indicator lights [light-emitting diodes (LEDs)] to be seen through the back of the hand, and the flexibility of the cosmesis material allows the power switch to be operated through the glove. A slightly raised ridge around the power button aids the patient in locating the power switch on the back of the palm.

One method of addressing the durability of the cosmesis is the use of impedance control during selected operations of the prosthetic limb. When used by the controls system, impedance control can limit the grip and pinch forces to specified levels. Previous prosthetic limbs had no way to sense and control the ultimate forces exerted during daily activities. This system is able to control forces and should be capable of reducing the overloading conditions seen in past prosthetic systems. Another option to improve durability would be to wear an actual glove over the SG, similar to placing a glove

on any human hand (with similar diminishing joint flexibility and sensitivity).

Both styles of the cosmesis glove are designed to be repairable (by the prosthetist and/or patient). Damage will occur to the cosmesis, either through wear or contact with external objects. Small cuts, tears, or abrasions ranging from pin holes to holes that are 0.5-in. long may be repaired using one-part room-temperature-vulcanized (RTV) silicone. The success and durability of the repair will depend on the degree to which that portion of the cosmesis is stretched during limb motions. Although the cosmetic appearance may not be perfectly restored following self-repair, it should be comparable to scarring on human skin.

MATERIAL SELECTION AND FABRICATION PROCESS

Eleven individual materials, plus combinations of selected candidates, were tested. The primary driving forces were the need for manufacturability combined with material properties that meet the requirements of low durometer, high strength, high elongation, and high tear resistance. The candidate materials are reported in Table 3. All of these candidates are two-part liquid resin systems that are mixed, shot, or poured into molds and cured at room or moderate oven temperatures. These materials were each evaluated for force transmission and vibration attenuation to determine which could be used with the chosen sensor design.

After comparing properties and receiving feedback about each material's ability to be processed into a glove from our fabricator, the NuSil MED-4915 resin system was chosen as providing the best balance of properties,

manufacturability, and performance. Other products had better performance in one or more categories but missed something, such as the translucency in the case of the two Dow Corning products.

A modified commercial process was used to provide a cosmetic covering that is thin enough to provide the necessary motion and sensor discrimination and still provide adequate durability. Collaboration with ARTech Laboratory on the glove fabrication was done to leverage their extensive experience in manufacturing cosmetic coverings for prosthetic limbs.

Currently, ARTech is using a variation of a one-piece slurry mold process. This process is based on making a mold of a hand, casting a plaster model of the hand, creating a negative mold of it, then doing a "reverse dip molding" process (or slip casting). This gives full detail on the outer surface of the cosmesis—it actually can capture fingerprints. This process has some thickness control limitations, which need to be addressed in the production process. Using specific catalysts, promoters, and/or curing agents results in a more precise wall thickness and material characteristics.

SUMMARY

Using requirements developed under the RP2009 program, a series of candidate materials were evaluated for fabrication of two types of cosmesis. The SG provides the most lifelike solution while meeting the other physical and mechanical requirements. The WG offers improved durability and potentially lower cost. A medical-grade silicone rubber, NuSil MED-4915, which best matched the requirements, was selected. Samples of both types of cosmesis were fabricated and evaluated as part of the program.

Table 3. Candidate silicones for cosmesis fabrication.

Material	Durometer (Shore A)	Strength (psi)	Elongation (%)	Tear resistance (pli)	Max. temp. (°C)	T _g (°C)	Translucent
Dow Corning Silastic P-1	25	1090	850	131	200	-127	No
Dow Corning Silastic S	25	1020	850	131	200	-127	No
Factor II A-225-70 LSR-4370	68	1300	450	240	200	-127	Yes
NuSil MED-4915	15	925	975	125	200	-127	Yes
Rhodia Rhodorsil RTV-1556	30	1035	660	130	200	-127	Yes
Rhodia Rhodorsil V-1082	8	480	570	110	200	-127	Yes
Rhodia Rhodorsil V-3040	38	920	340	120	200	-127	Yes
Silicones Inc. P-10	12	350	450	75	200	-127	Yes
Smooth-On Dragon Skin Q	10	475	1000	102	200	-127	Yes
Smooth-On Ecoflex 00-30	00-30	200	900	38	200	-127	Yes
Smooth-On Mold Max 27T	27	575	400	110	200	-127	Yes

The material selected, NuSil MED-4915, is highlighted. pli, pounds per linear inch; T_g, glass transition temperature.

FUTURE WORK

Thermoplastic elastomers (TPE) seem to be a very promising material for a WG because of their extremely high elasticity, low durometer, and lifelike sensation. They can be colored in bulk and have the same translucency as silicones, but new fabrication methods would be required to duplicate the in-depth coloration layering currently used in silicone cosmesis fabrication. However, many TPEs require the use of injection molds, which would add to tooling costs. The development of low-cost tooling that can survive the process temperatures would open up the field for consideration of more TPE systems. Additionally, some products are melt-castable and do not require costly injection mold tools.

Other technologies that need to be followed include the following:

- Continued evaluation of 3-D scanning systems to utilize the best processes for cosmesis fitting and detailing
- Exploration of the possibility of using additive manufacturing to directly fabricate a cosmesis
- Evaluation of new materials as they become available

ACKNOWLEDGMENTS: The views expressed are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. government.

REFERENCE

¹Wing, I. A., Conner, H. D., Biermann, P. J., and Belkoff, S. M., "An in Vitro Biomechanical Comparison of Human Dermis to a Silicone Biosimulant Material," *Proc. of the 26th Southern Biomedical Engineering Conference*, College Park, MD, pp. 22–25 (2010).

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