The O&P EDGE

BUILDING A BETTER ARM

Design and Fabrication in Upper-limb Prosthetics

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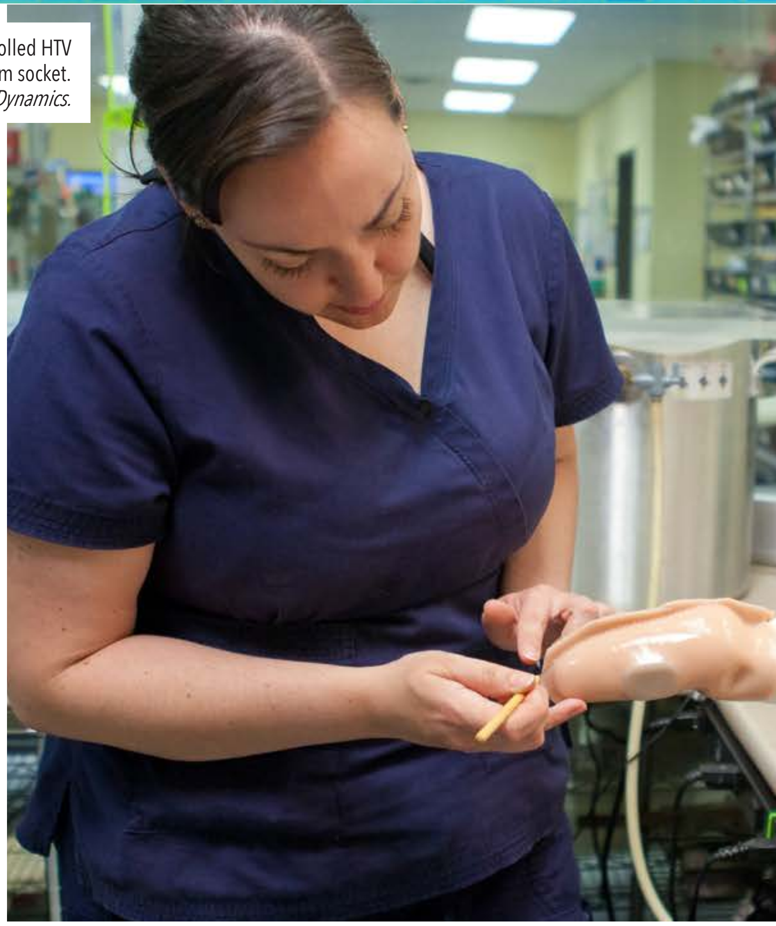


Silicone coordinator Mariya Cameron applies rolled HTV silicone on top of RTV silicone to create a custom socket. *Photographs courtesy of Advanced Arm Dynamics.*

Prosthetic arms and hands have advanced significantly in their functional capabilities and appearances over the past few years. Component manufacturers have introduced new multiarticulating hands and electric fingers, and smaller research labs have developed innovative control systems that improve function. The process of building a better arm takes many talented minds, and as upper-limb prosthetic specialists and technicians, our task at Advanced Arm Dynamics (AAD) begins with understanding each patient's goals. From there, we use advanced fabrication tools and techniques to create comfortable sockets and then select the appropriate components for each unique prosthesis. The latest trends in fabrication are elevating upper-limb prosthetic comfort, function, and appearance for thousands of prosthesis users.

BETTER MATERIALS: SILICONE

There is one word that sums up the most significant advancement in materials for prosthetic interfaces: silicone. Room-temperature vulcanized (RTV) silicone is soft and comfortable to the touch. High-temperature vulcanized (HTV) silicone is strong and durable with a high tear strength. HTV silicone is often referred to as rolled silicone, and may also be called high-consistency rubber (HCR). Both RTV and HTV silicones are synthesized from silicon, a naturally occurring chemical element with a range of properties that make it ideal for use in fabricating prosthetic sockets or liners. Silicone provides a biocompatible, safe interface with skin that is burned, scarred, or sensitive to synthetic materials like plastic. Over time, silicone that is in contact with the injured skin of a residual limb has healing properties and promotes the growth of new skin.[1,2]

Silicone is a dynamic material that moves with the body while simultaneously offering an enhanced grip on the residual limb and improved suspension of the prosthesis. A good analogy is the feeling of wearing a shoe that fits securely and comfortably around the foot, with no concern about the foot slipping out.

We fabricate silicone sockets for all levels of upper-limb amputations: partial finger, partial hand, wrist disarticulation, transradial, transhumeral, and shoulder. Typically, we combine RTV and HTV silicones to create those sockets; the more dynamic RTV silicone provides interior suppleness and comfort against the limb, and the stronger HTV silicone provides the exterior structure.

Detail of a combination RTV/HTV dynamic silicone socket and a carbon fiber frame.

Silicone sockets are highly customized to accommodate the unique contours and bony prominences of each patient's residual limb, and fabrication requires several days of careful work. The relative hardness of silicone is measured as shore value or durometer. A low durometer is softer and a high durometer is harder. A silicone technician begins the socket fabrication process by painting RTV silicone onto a plaster model of the residual limb. The exact areas that require more suppleness receive additional layers of RTV silicone, creating a lower durometer precisely where it is needed.

The next steps are to mill the HTV silicone through an automated silicone roller, flattening it out, and to incorporate pigment of virtually any hue. Having a silicone interface created in any color the patient chooses is an aesthetic feature that many people appreciate. The rolled silicone is then carefully applied on top of the RTV silicone, which creates the higher durometer outside structure of the socket. The

Cameron mills HTV silicone with an automated silicone roller.

John Miguelez, CP, makes final adjustments on Michael Findley's prosthesis that combines an RTV/HTV silicone liner, carbon fiber frame and Michelangelo Hand.

variable durometer of silicone sockets mimics the dynamic nature of an actual arm, and some people say it feels more like a natural extension of their bodies. Varying the durometer allows patients to maintain more of their natural range of motion (ROM) and lets them comfortably wear their prostheses for longer periods.

The security and durability of HTV silicone on the outside, combined with the suppleness of RTV silicone against the skin, have been a great advantage for our patients. An additional benefit of fabricating with RTV/HTV silicone is that accessories and components such as distal pins, batteries, wires, fabric, and ports can be imbedded in the silicone.

CASE IN POINT:

In 2014, we conducted a survey of 14 patients with transradial amputations who compared their custom silicone sockets with their previous thermoplastic sockets. Seventy percent reported increased physical comfort; 93 percent reported increased dependability/secure suspension; and 50 percent reported increased hours of wear per day. Survey participant Michael Findley had worn a thermoplastic socket for two years, and reported he was able to tolerate wearing his prosthesis an average of five hours per day. After upgrading to an RTV/HTV silicone socket, he reported that his comfortable wear time per day had increased to 11-14 hours. "I highly recommend the silicone socket and would hate to imagine wearing anything else," he says.

One of the challenges of using silicone to fabricate sockets is that, unlike thermoplastic, silicone cannot be modified or reshaped by heating it. That's why we continue to use thermoplastic for test sockets and diagnostic fittings. Thermoplastic may also be favorable in cases where the socket design requires more rigidity for stabilization around the residual limb. A further consideration is the amount of time involved for fabrication. HTV silicone sockets can take up to a week to fabricate, while thermoplastic sockets require a few hours from start to finish. In cases where a person with a silicone socket loses volume in his or her residual limb, we can modify the interior shape of the interface by adding inflatable silicone bladders to fill in spaces and stabilize the limb.

ADVANCED TOOLS FOR DESIGN AND PROTOTYPING: 3D CAD AND 3D PRINTING

3D CAD and 3D printing are useful tools that speed up the process of designing and prototyping upper-limb prostheses. Using 3D CAD, we design detailed graphic representations of prosthetic components, make modifications as needed, and have the option of 3D printing in plastic. This is a convenient method of rapid prototyping for shape and proof of concept on designs, particularly for partial hand and activity-specific components. Traditional components available from manufacturers may not be sufficient to meet the individual requirements of our patients. In these cases, after achieving proof of concept with 3D CAD and 3D-printed plastic prototypes, we may fabricate definitive partial hand devices with more robust materials. We may also rely on selective laser sintering (SLS), an additive manufacturing technique, to fabricate durable, carbon fiber finger and partial finger components. SLS uses heat from a high-power laser to fuse together small particles of polymers or metals to create a component that was designed in 3D CAD.[3] SLS can also be a favorable option for fabricating some activity-specific devices out of alloys like titanium. Our best practice regarding current 3D-printing technology is judicious use that supports our commitment to providing the highest possible level of upper-limb prosthetic rehabilitation.

MORE OPTIONS: CHOICES FOR INDIVIDUALS WITH PARTIAL HAND AMPUTATIONS

More than 90 percent of patients with upper-limb loss are classified as partial hand amputees. Historically, there have been limited functional prosthetic options for people who have experienced amputations distal to the wrist, including the loss of multiple digits. It's exciting that in the past few years partial hand prostheses have advanced to include silicone interfaces, viable electric fingers, passive designs with multipositional finger joints, and body-powered partial fingers.

Dynamic RTV/HTV silicone interfaces conform well to the underlying bone structure of the hand and fingers, protect the residual limb, and help to heal and desensitize amputation sites. Silicone interfaces also improve ROM in the residual hand, which enhances prosthetic function for patients with electrically powered finger components.

Adrian Albrich wears a custom partial hand prosthesis with electric fingers.

Electric prosthetic finger solutions feature individually powered prosthetic digits that can bend, touch, pick up objects, and point. These devices are custom built for people with amputations below the wrist, through the palm, or at the knuckles. In the past year, a smaller size of electric digits has been introduced, which gives women, teens, and others who are smaller in stature the opportunity to have fingers that are in proportion with their body sizes. This looks and feels more natural, and can improve the user's ability to be successful with two-handed tasks.

Multipositional finger joints in passive partial hand prostheses are an innovative way to add functional grasp and prepositioning. Using their sound hands, users can bend the finger joints into positions that enable them to hold a can or bottle or grip a handle. For patients using partial hand prostheses who have their natural thumbs, multipositional finger joints provide opposition and enhance their ability to grasp and release.

CASE IN POINT:

DeVern Smith lost multiple fingers when he was 12 years old and lived without a prosthesis for 50 years. He now has an activity-specific device for using tools and a passive hand with multipositional finger joints. "My hand looks like it's just a cosmetic hand, but in fact it's an actual functioning hand that has moveable joints in the fingers," he says. "You can set the different adjustments for what you want to grip with the hand. The reason we picked this hand over the bionic hand was because of the durability and strength. The confidence that's come along with it has made me feel safer in some of my activities, like motorcycling and snowmobiling, and even doing stuff around the house, like gardening."

Smith shows how his multipositional finger joints allow functional grasp with a passive prosthesis.

Body-powered partial fingers protect the amputation site against hypersensitivity or further injury, and also increase the user's dexterity, grip strength, and articulation. Partial finger prostheses help with picking up and carrying objects, typing, and using a cell phone. Viable thumb and partial thumb prostheses are currently under development. A thumb or partial thumb prosthesis can help restore the opposability and strength that are unique to this digit.

NEW STRATEGIES: ADJUSTABLE COMPRESSION SOCKET SYSTEMS

Some upper-limb prosthesis users would like to adjust the fit of their sockets over the course of each day. That's why in the past couple of years at AAD, we've been fabricating adjustable compression socket systems composed of a dynamic RTV interface, a flexible outer frame with unique cutouts, and a Click Medical RevoFit™ lacing closure system powered with components from Boa Technology, Denver, for dialing in the right amount of compression. The closure uses lightweight steel laces that encircle the outer frame and connect to a mechanical dial that the user turns to tighten the laces, thus compressing the frame. To release the compression, the user simply pulls out the dial.

An adjustable compression socket system works particularly well when the residual limb has a more bulbous shape, as is often the case with a wrist disarticulation or partial hand

Jameson Davis wears an adjustable compression socket with a lacing closure that allows for growth in his residual limb.

amputation. People with congenital limb differences may also have residual limbs that are less cylindrical, and it is usually more comfortable and secure to wear a socket that contours to their unique limbs. Sockets with a lacing closure system work well for young children too since the socket can expand to accommodate a growing limb and allow for longer periods of use between fittings. The outer frame is fabricated from a thin yet strong carbon fiber lamination. Portions of the frame are then cut away to further increase compression or expansion of the socket. Just as every residual limb is unique in its shape and dimensions, the pattern of cutouts is also different on every frame. The primary goal for any upper-limb socket is to provide comfort and secure suspension, and for specific types of residual limbs, adjustable compression socket systems are an excellent solution.

Adjustable compression socket systems offer multiple degrees of fine-tuning and are easy to adjust with one hand. If a person is using his or her prosthesis to lift a heavy object or work out at the gym, he or she can tighten the socket to increase security and suspension. For light activity at home or work, the user can readjust to a moderate amount of compression. And when just relaxing, the user can adjust it to a looser, more comfortable fit.

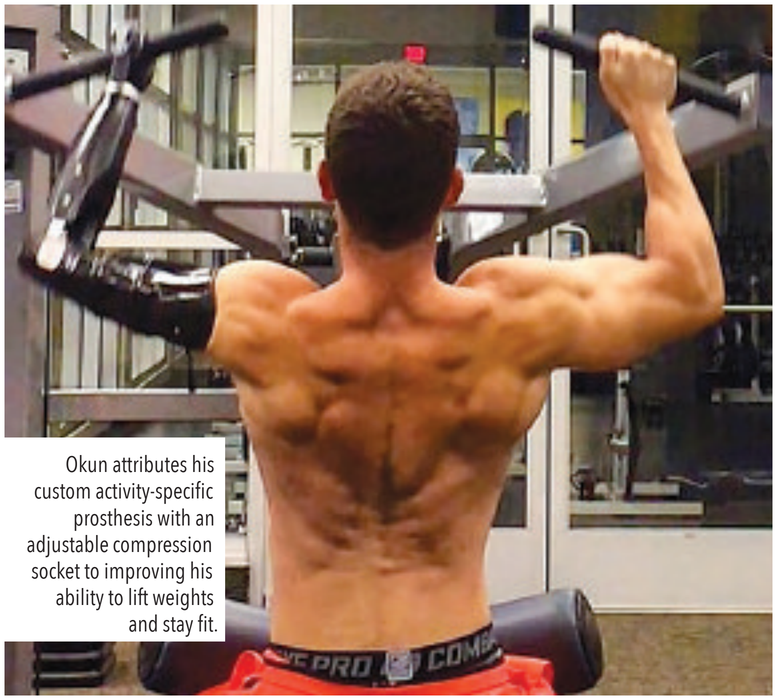
CASE IN POINT:

Max Okun is a great example of how an adjustable compression socket system can change a person's life. Growing up with a congenital transhumeral limb difference, Okun elected not to wear a prosthesis. He got into fitness and weightlifting as an adult, and spent six months working out his left side without wearing a prosthesis. He then added a protective socket, with no elbow joint or terminal device, and after about a year, he decided to explore his options for an activity-specific prosthesis. The custom device he uses now includes a suspension liner with a pin lock, and a RevoFit closure system that compresses the socket comfortably and securely around the unique shape of his residual limb. Okun tightens the dial to full compression while he is working out.

"The adjustable socket, lacing system, and elbow joint mean that for the first time I can use my left arm to do anything in the gym that requires a bend or a push," Okun says. "The intense compression of the socket around my upper arm lets me transfer pressure into the forearm portion of the prosthesis. I can lift in a more complete way."

BETTER ARMS, BETTER OUTCOMES

Building a better arm is made possible by merging new materials and technologies with creative designs and fabrication. Upper-limb prosthetic specialists and component manufacturers are committed to creating solutions that push past the functional boundaries our patients face. As components, materials, tools, and techniques continue to advance, our essential goals remain the same: providing comfortable, durable, and innovative prostheses that improve people's lives. O&P EDGE



Okun attributes his custom activity-specific prosthesis with an adjustable compression socket to improving his ability to lift weights and stay fit.

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