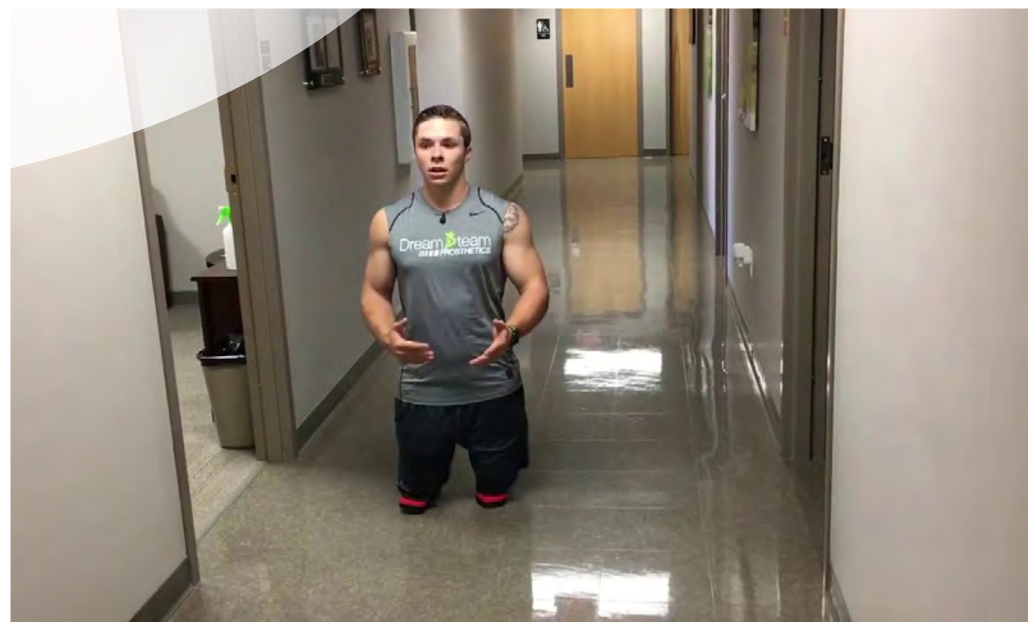
Kinder Arm

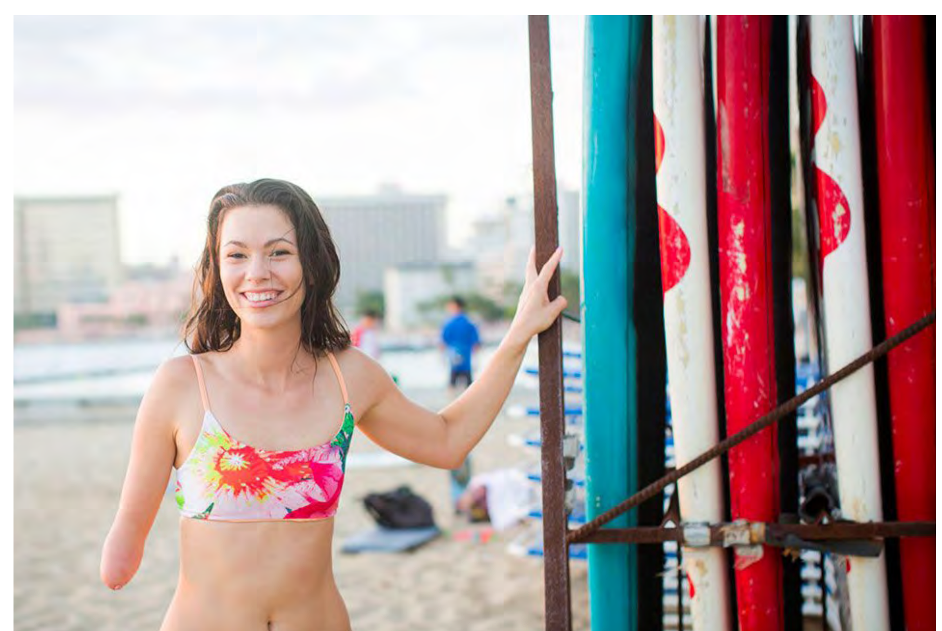
Zach Montague

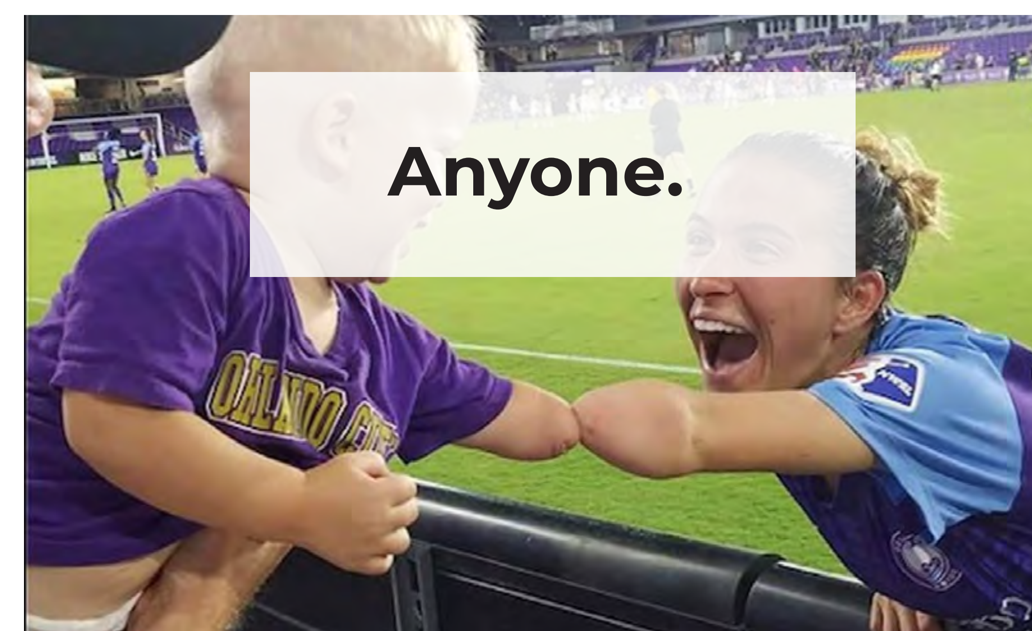
Richard Perfetto

Design an extensible and component-based infant transradial prosthesis in order to increase the product's useful life and reduce the amount of replacements needed.

Who can be affected by limb deformities?





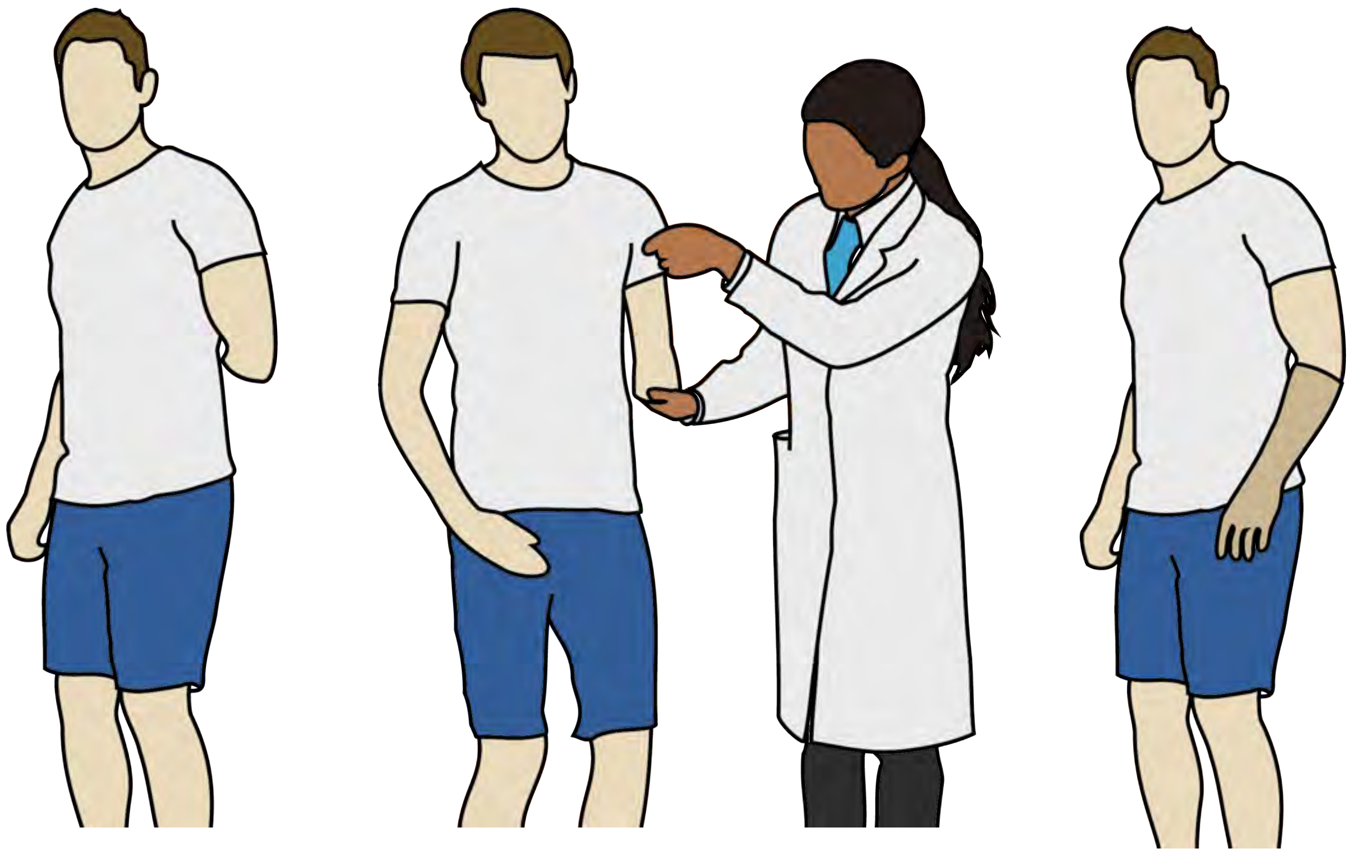


Anyone.

Research

How Adults Receive Prosthetics

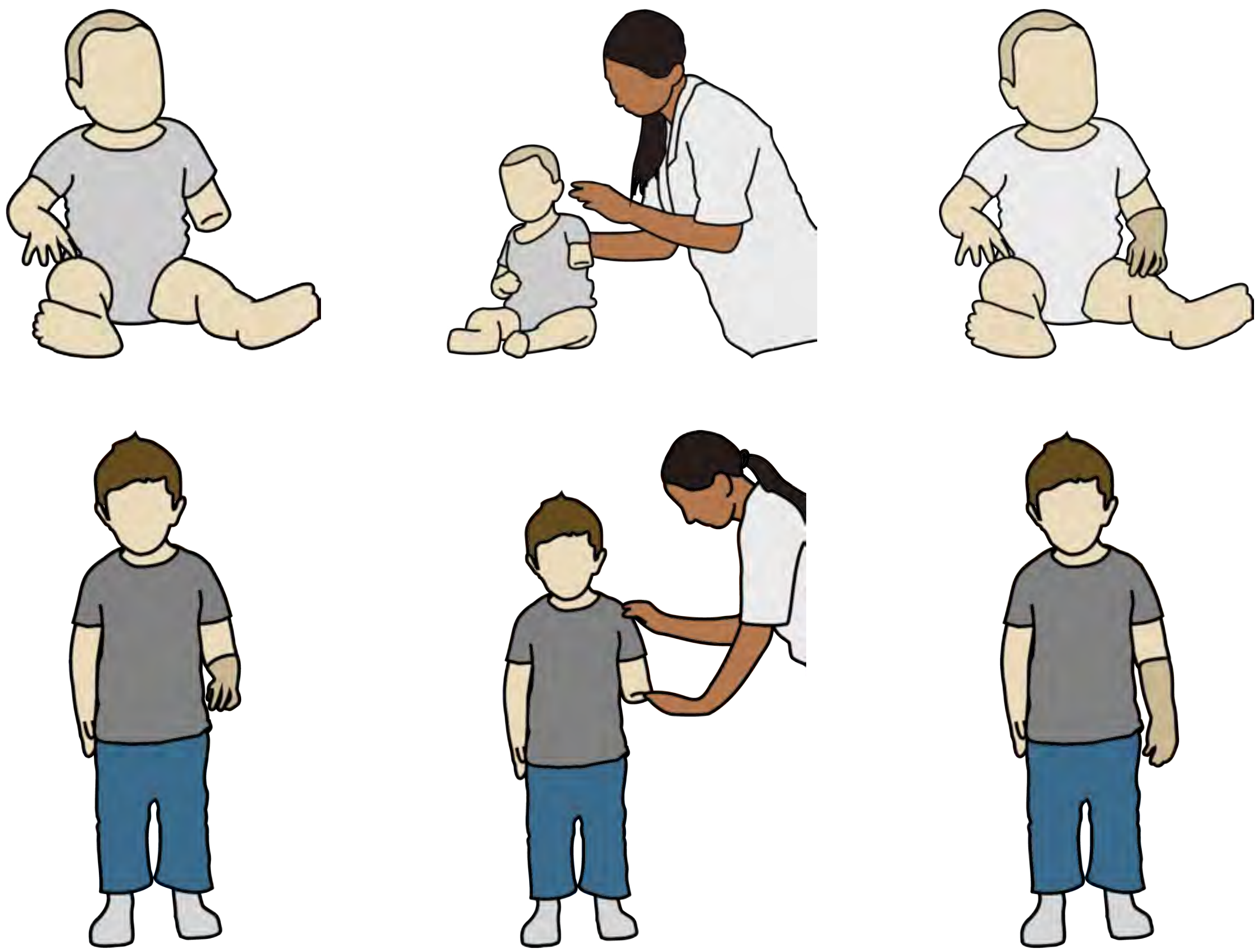
Prosthetics are **designed for adults**. A prosthetic specialist **initially measures** the body of an adult amputee for proper fitting. The prosthetic is adjusted to fit the patient **as comfortably and securely** as possible.



The prosthetic is then **good for the next few years**, until it needs to be **repaired** from normal wear-and-tear or damage. Adult prosthetics usually last between **five and ten years**.

How Children Receive Prosthetics

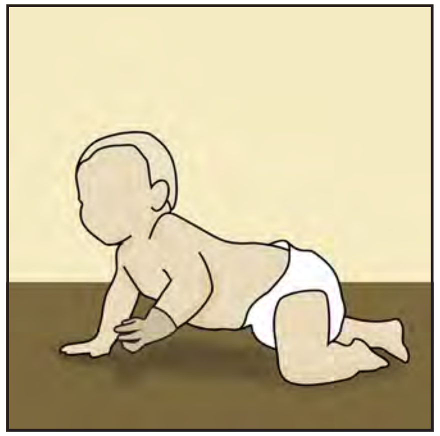
Providing prosthetics for children is much **more complicated** and requires a lot more thought than for adults. A prosthetic specialist **initially measures** an infant or child patient for proper fitting. They then need to decide whether to fit the child correctly for their **current size, or fit the prosthetic to a larger size**, to let the child grow into it.



How ever the prosthetic specialist decides to fit the device, the child will need to be **remeasured and refitted for a new device** as their **body changes**.

Why is it so Important for Children to have Prosthetics?


Initial Fitting


Learning to Crawl

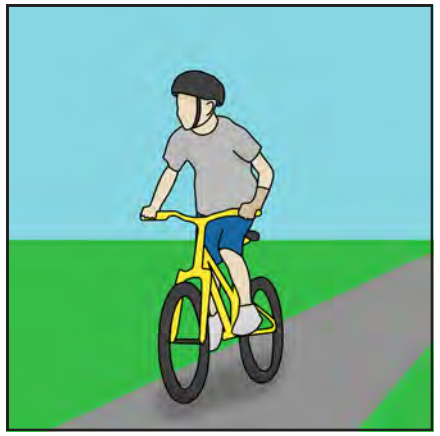
A child fitted as early as possible has the opportunity to use the device to learn skills that help movement, such as **crawling around on the floor during their first year.**


Begining to Play


Moving Around More

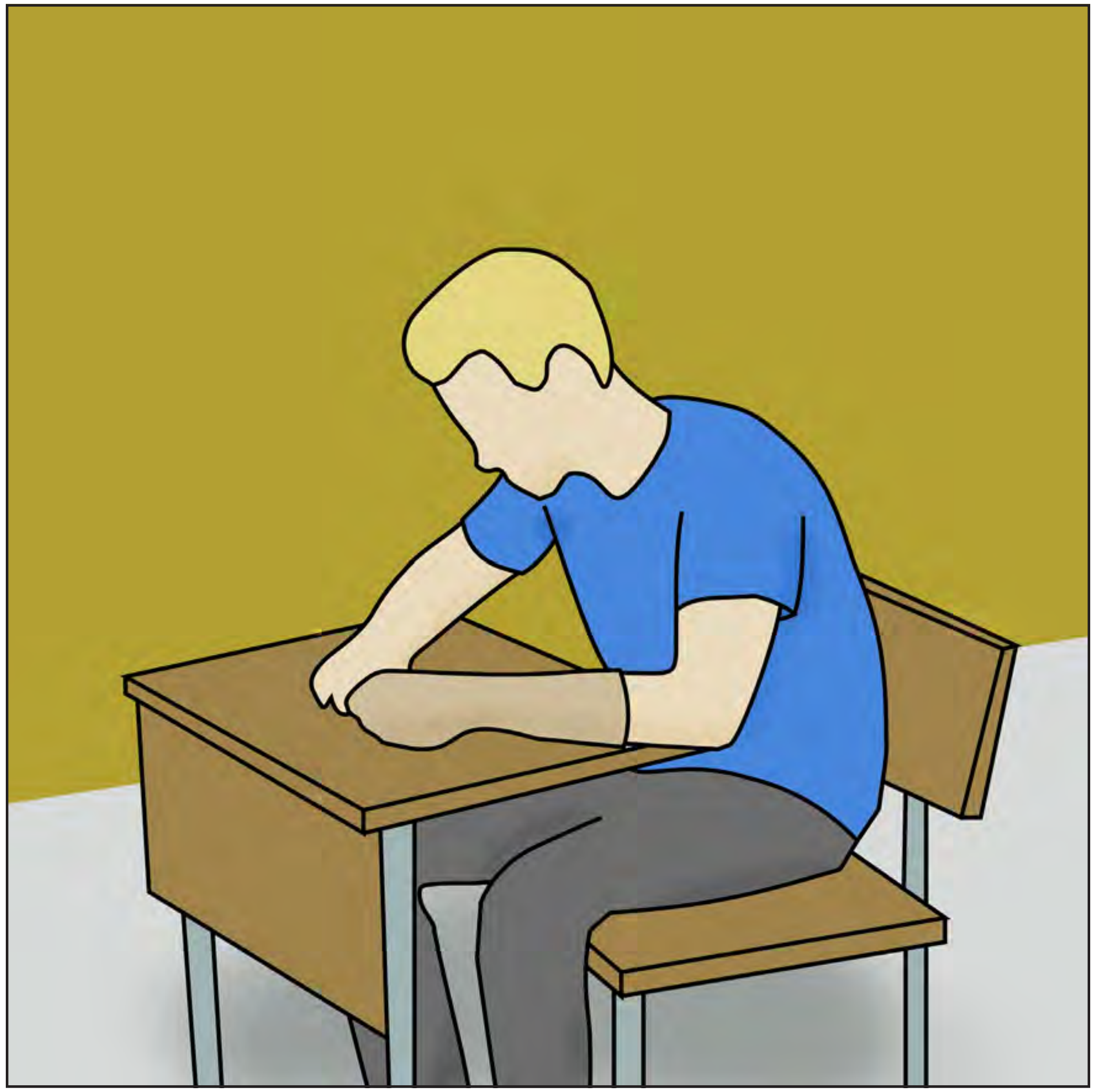
As the child grows, they use the device during certain activites, for example, when playing with basic toys and learning how to **climb stairs within their second and third years.**


Socializing


More Sophisticated Skills

The child will use their prosthetic when socializing as they reach years four and five, which helps them adapt to **more sophisticated skills, such as riding a bike.**

"We recommend fitting infants with a prosthesis **as early as possible** to encourage babies to accept and use a prosthesis as they **begin exploring the world around them**."
- Arm Dynamics

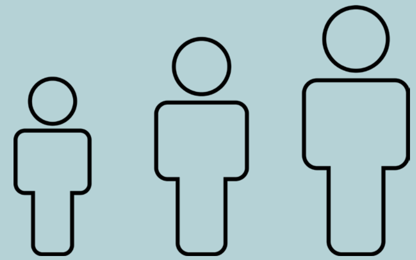

Early fitting leads to better comfort later in life.

By using a prosthetic as early as possible, the patient grows up comfortable with this way of life. This empowers the child, **helping reduce stress and anxiety**.

Problems Children Face with Prosthetics

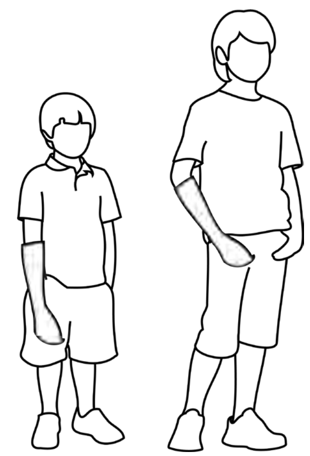
Changing

"**Children grow**. Their bodies change, and just as they outgrow shirts, pants and shoes, **they will outgrow their prosthesis.**"
- Amputee-Coalition



Oversized

"Traditionally, when a child gets a new prosthesis, **it is oversized** to give the boy or girl a period of **time to adjust and grow into it.**"
- Amputee-Coalition

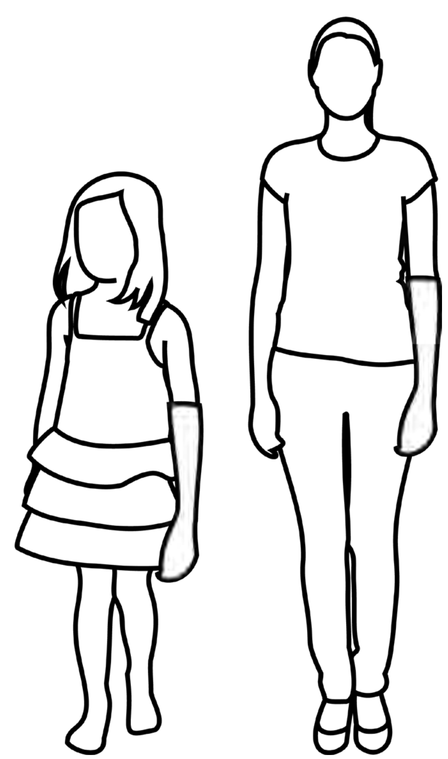


Built for Adults

"Prosthetics are built for adults, and, eventually, the **adult designs trickle down to children.**"
- Kenny Orthopedics

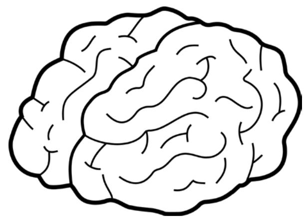
Using Adult Prosthetics

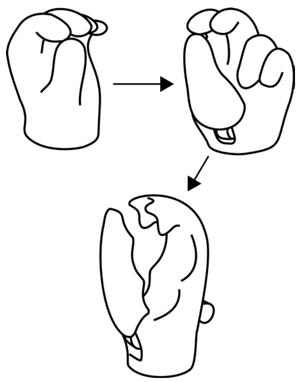
"Often, **pediatric specialists are forced to customize adult sized prosthetics to fit children,** which has varying results that are dependent on the familiarity and resourcefulness of the specialist.
- Kenny Orthopedics



Age and Development

"**Age and where a child is developmentally are important** when considering which prosthetic a child should have."
- Amputee-Coalition





Activity-Specific Attachments

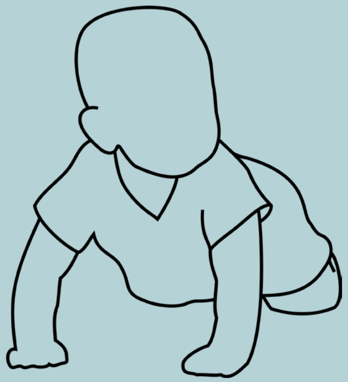
"For infants up to 18 months, tiny passive hands are the usual choice. Starting around age two, children often benefit from activity-specific prosthetic attachments for sports and play."
- Arm Dynamics

Comprehension

"A young child with a lower arm amputation **may not be able to comprehend** how to use a bionic hand."
- Kenny Orthopedics

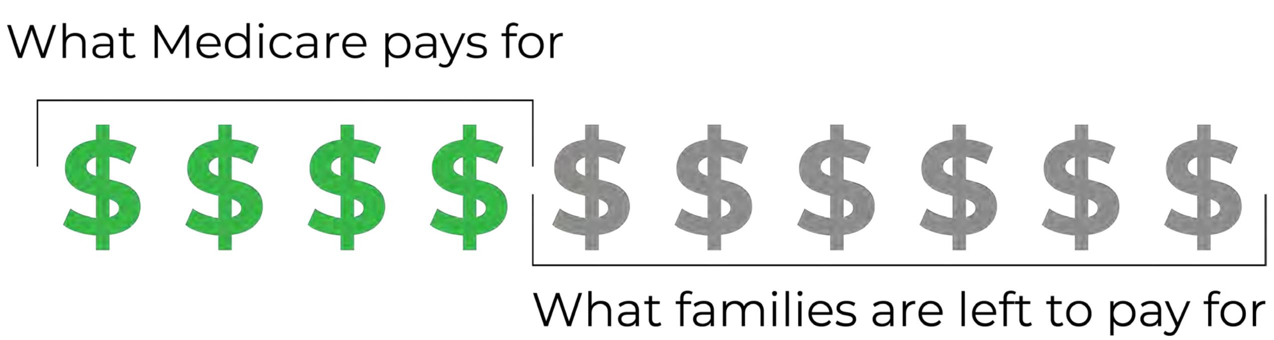
Level of Mobility

"When selecting a child prosthetic, the child's **level of mobility must be thought about**, such as whether a child with a leg amputation is crawling, standing, walking, or running. This same age-considered process applies to **all types of pediatric prosthetics.**"
- Kenny Orthopedics



Expense - Adults

Adult prosthetics are expensive, but **when a prosthetic is only purchased once every five to ten years, it can be worth the expense**. Customization is one of the leading factors in determining price. When the prosthetic is only customized once over many years, the **price is worth it.**



Insurance **rarely covers the cost** of a prosthetic. Those with insurance are still left with **over half of the bill** to pay out of pocket.
- Medigap

Depending on the **complexity** of the prosthetic, adult limb prosthetics can cost **several thousand dollars,** upwards of a **hundred thousand dollars**, yet these costs are paying for a prosthetic that will **last a long time.**

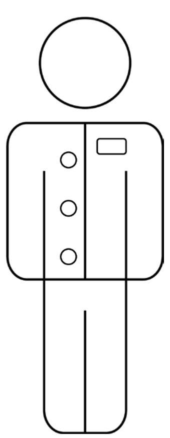
Adults

Adult prosthetics **don't need to be adjusted and refitted often**. This **reduces the amount of specialist visits,** saving on time and effort needed to adjust prosthetics.

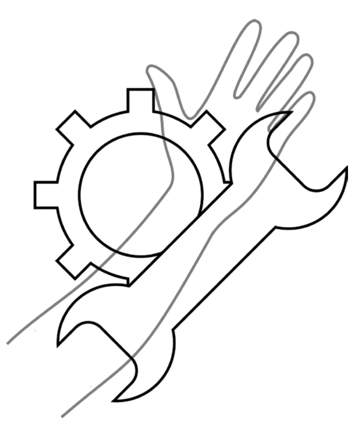
Children are Already Expensive

Children's prosthetics are just as expensive as adult prosthetics, yet **they do not last as long**. The prosthetic might get replaced once a year, or even once every few months. Each time the prosthetic is **refitted and customized, the cost goes up significantly**. These amounts are not included in the cost it takes to raise a child and get **added onto the average $250,000 anticipated cost.**

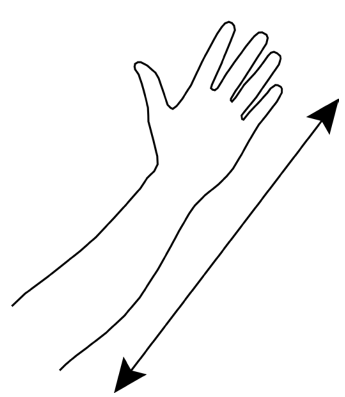
"The USDA states that it costs an **average of $250,000**, (not including pregnancy or college) **to raise a baby to adulthood** in America."
- Jordan Thomas Foundation



Specialist Visits



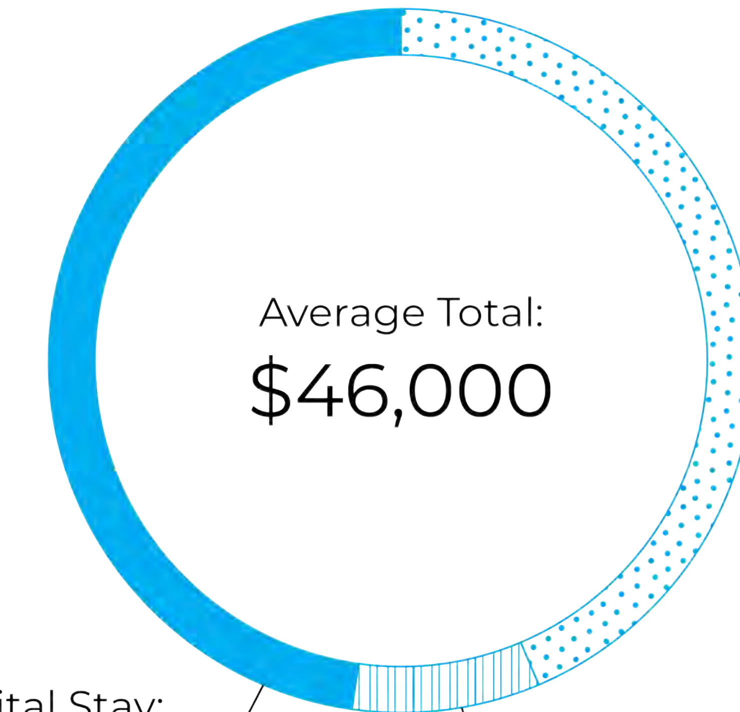
Materials



Refittings

Specialist visits for both the **initial fitting** and **follow-up refittings,** in addition to the **materials** required to make the prosthetic, all contribute to a **significant amount of money.**

Children



"While an adult may be able to use one prosthetic for a decade, a child will likely **require several prosthetics** in that same time period."
- Kenny Orthopedics

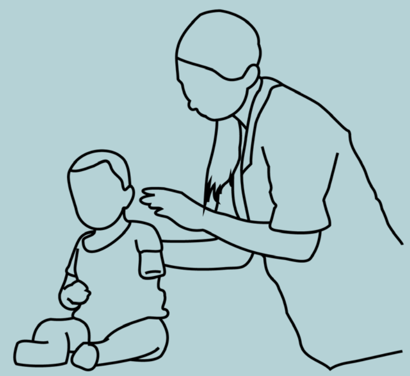
"Trautwein et al. in their study of 74 patients, reported a mean stay of 11.3 days with an average of 4 procedures, **costing up to $22,015."**
- World Journal of Plastic Surgery

"Upper-limb, pediatric prosthesis range from **$3,500 to $50,000** depending on the functionality and style."
- Jordan Thomas Foundation

Emotional Connection

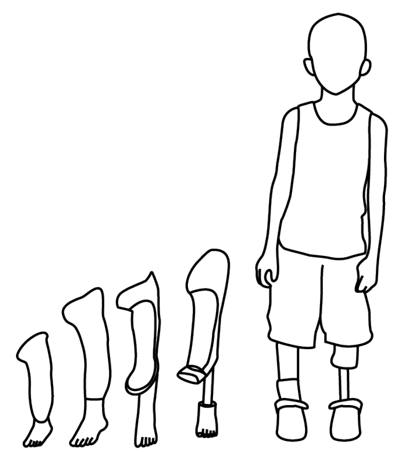
Connection to their environment

"Traditionally, an upper-limb prosthetic fitting is **started earlier for infants** than a lower-limb prosthetic fitting would be so that they can **get their hand and prosthesis to the same level** and start touching and moving things."
- Amputee-Coalition



Always Adjusting

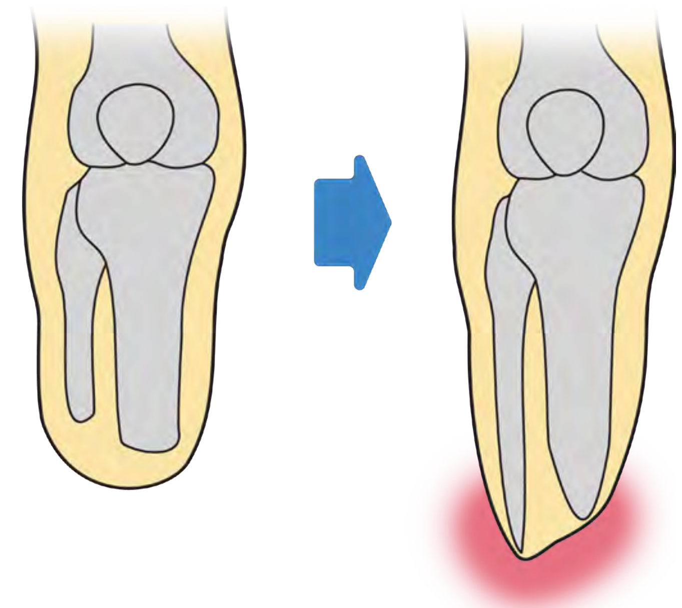
"Most people believe that a child who receives a new artificial limb too often **never fully adapts** to the one he or she has. The child is **always adjusting to a new one**, and that takes time."
- Amputee-Coalition



Future Goals

Being uncomfortable with a prosthetic can lead "...to problems including depression, confusion, problems with everyday activities, phantom limb sensations and pain, all of which **affect their future goals**."
- World Journal of Plastic Surgery

Overgrowth



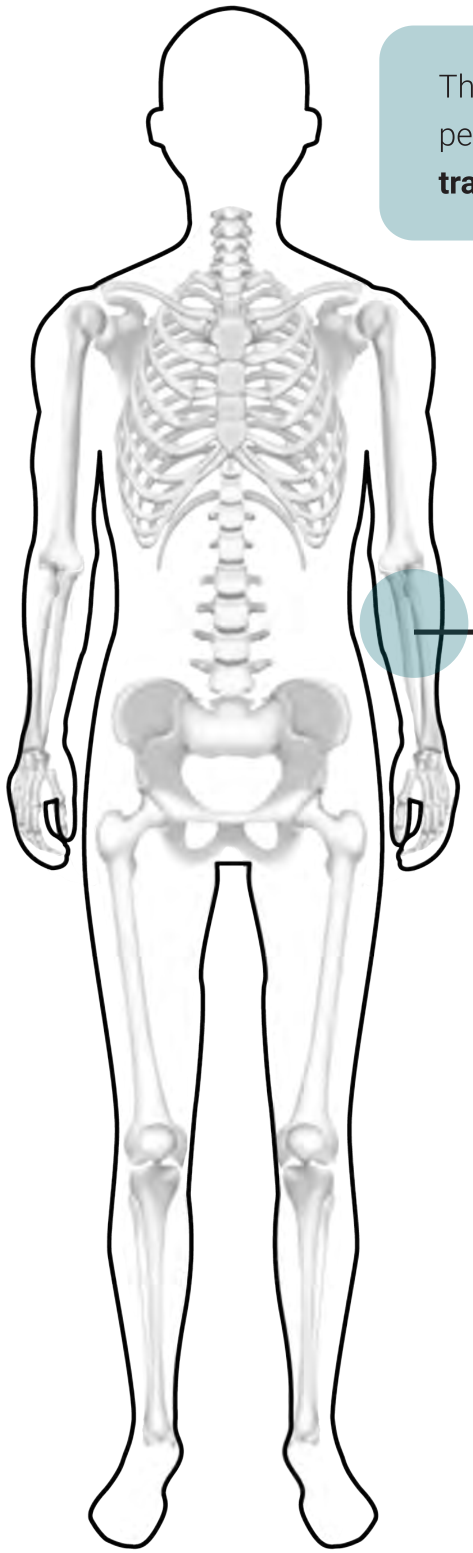
Dr. Sheena Ranade
Pediatric Orthopedic Surgeon
Mount Sinai Medical Hospital

Problems

"...Amputation issues include **overgrowth,** which creates bony prominences that can **lead to ulceration, and adequate bone-stock/length to allow fitting**."
- Dr. Sheena Ranade

"The bone tends to grow and **cause pressure areas on the stump**. The treatment is typically going back to the OR to revise the stump."
- Dr. Sheena Ranade

Transradial Amputations



There are many different types of amputations that a person can experience in their lifetime. **We looked at transradial amputations.**

Transradial

Transradial is essentially the **forearm part of the arm.**

We chose to focus specifially on **children's transradial prosthetics.**

This type of amputation makes up about **31% of all amputations**, which is the largest percentage.

The soft tissue in the forearm has **suboptimal padding on the residual limb, leading to the problem of overgrowth.**

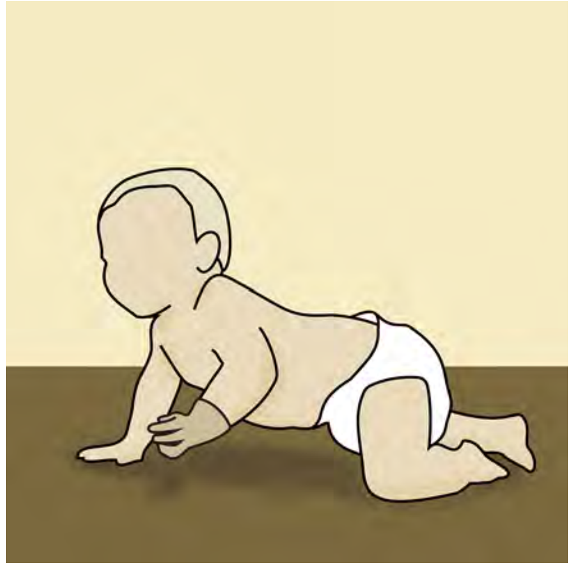
It gives us an **opportunity to focus primarily on the size concern** regarding prosthetics.

Prosthetic Hands are Complicated

Hands are a very complicated part of a prosthetic, partially because they are complex forms and there are a variety of different types of hands.

They are also very complicated because **as children grow, their hands grow.** Children with amputations **require many different hands** to accommodate for growth.

Lastly, as children grow, they also **mentally mature and develop new skills that need to be nurtured.** Prosthetic hands **need to accommodate the new skill levels that children learn as they grow.** Using the same type of hand is not sufficient to support that child's learning.



Passive Hand

Children usually need to **start out with a passive hand initially.** This helps when learning to crawl and move around. It is important for them to learn these skills with a hand, but **does not require actual movement of the hand.**

Articulated Hand

As children begin to start to play and learn how to pick up items and move them around, they need a hand that will allow for this transition. **This requires a hand with movement, but not too much movement.** The child needs to slowly grow into more complex hands.

Body-Powered Hand

Once the child starts to learn more complicated skills, and become more active, **they require a hand that is more complicated, too**. Once they learn how to control their movements, a **body-powered hand is the ideal option.**

Market Research

Prosthetic Categories

There are **many different categories** that prosthetic hands can fall in. These categories include **passive hands, articulated hands, body-powered hands and myoelectric hands**.

Passive Hand

These hands are in one set position. They are generally **intended to be used cosmetically**. A passive hand can be used for very simple activities, such as holding something, or moving something.

Articulated Hand

These hands provide slightly more function than passive hands. **They are capable of being adjusted to different positions, but only manually.** This variation in position allows for the hand to function in more activities.

Body-Powered Hand

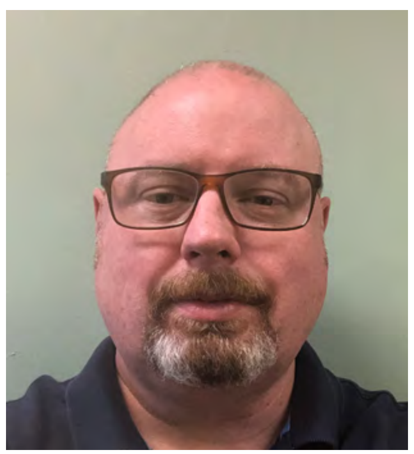
These hands are similar to an articulated hand, but **are powered using cords and pully systems that are attached to other parts of the body.** By flexing specific muscles, an amputee patient can change the position of the hand to adapt to whatever they might need to do. For example, a patient can shrug their shoulders to pull a cord, which closes the grip of their prosthetic, allowing them to pick up an object with the prosthetic alone.

Myoelectric Hand

These hands are essentially an electronic version of the body-powered hand. **There are sensors inside the prosthetic that understand which muscle is being flexed, and determines what hand position to form.**

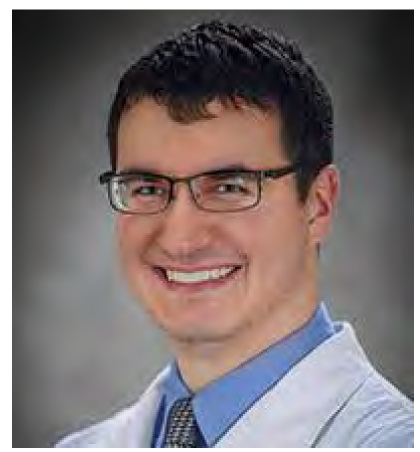
Market Research and Network

After researching various companies that produce prosthetics for children, we narrowed our focus down to **three popular companies** that produce prosthetics that encompass a **large range of features. We analyzed these products to determine the pros and cons for each feature.**



Andrew Lerman

Lauren Rossi



Joe Kersh

We reached out to a network of prosthetic specialists to help us **determine any openings in the market and current flaws with these designs.**

Open Bionics Hero Arm

Open Bionics Hero Arm is known for being a **myoelectric powered** children's prosthetic. Each prosthetic is **custom fit per patient, and is 3D printed to look like a character in a movie that the child likes.**

Pros

The prosthetic is **custom fit**

It **can look like a super hero** or any other characters.

It is **myoelectric powered**.

Cons

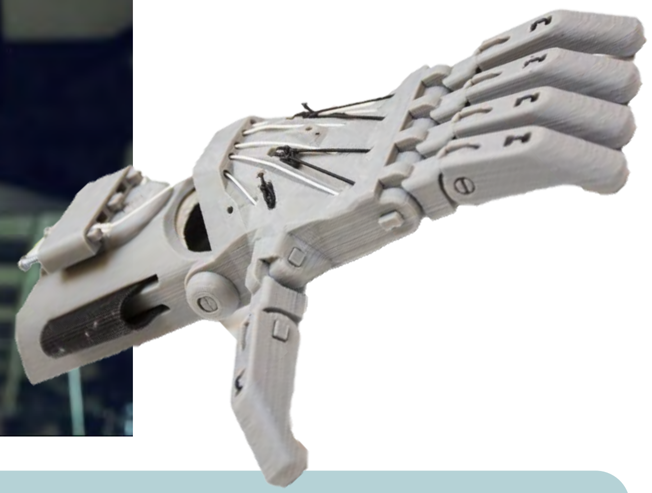
The prosthetic can cost between **$50,000 -$100,000.**

Prosthetic Specialist Joe Kersh stated that it can **take months to deliver the prosthetic.**

It is **difficult to replace components** because of how custom fit it is.

Children cannot get sized **until age 8,** missing out on years of development.

Market Research and Network



e-Nable

e-Nable is a prosthetic designed for children with missing hands and is **completely open source.** Volunteers around the country help size and print these hands for children, and they are **body-powered.**

Pros

The prosthetic is body-powered and **opens and closes all fingers.**

The prosthetic is **free.**

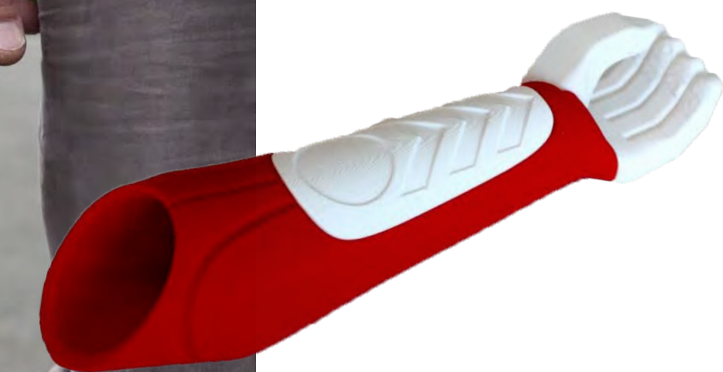
It is very **quick to make.**

Cons

This prosthetic cannot expand in any way. It **must be reprinted.**

It is made from 3D filaments, which is **not durable and can break easily.**

A child **must be 3 years of age** before they can get fitted.



Ambionics

Ambionics is a prosthetics company designed for children with transradial amputations. It uses **fluid pressure to close the thumb, and is 3D printed.**

Pros

The prosthetic is **3D printed,** which reduces the price.

Children can be fitted **as early as possible.**

The thumb opens and closes with **body-power.**

The **socket is replacable.**

Cons

Once the child's arm grows too long, the **prosthetic must be completely replaced.**

It is made from **3D filaments, which is not durable** and can break easily.

Network

Throughout the project, we had a lot of help from professions in various industries.

Joe Kersh
Occupational Therapist
Prosthetic Specialist
Hanger Clinic

Lauren Rossi
Occupational Therapist
Prosthetic Specialist

Andrew Lerman
Occupational Therapist
Prosthetic Specialist

Dr. Sheena Ranade
Pediatric Orthopedic Surgeon
Mount Sinai Hospital

Eric Schneider
Industrial Designer
Materials and Processes Specialist

Mike Leonard
Industrial Designer
Medical Design Professional

Socket Development

Hand Development

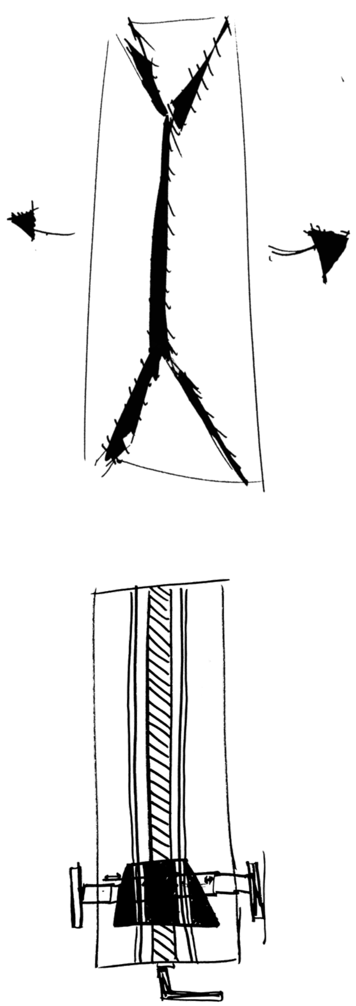
Armband Development

Forearm Development

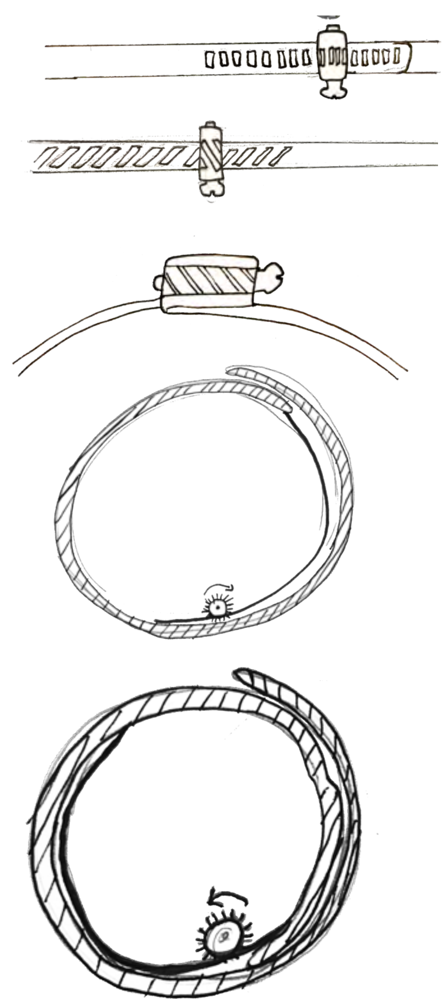
Extending the Prosthetic

Understanding that growth is a concern when fitting a child, many prosthetic **specialists tend to oversize the fit of the device,** if they do not want to replace the prosthetic often.

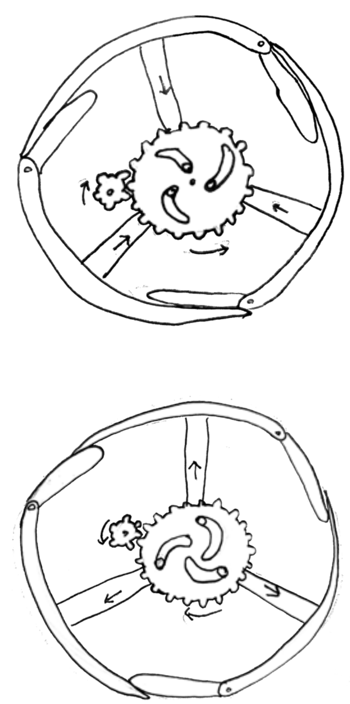
Expanding Mechanism



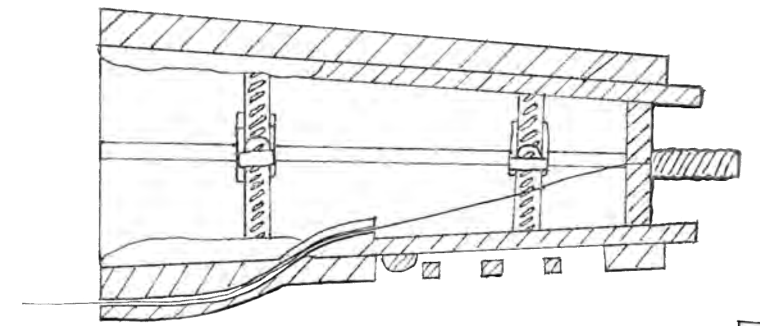
Using Hose Clamp

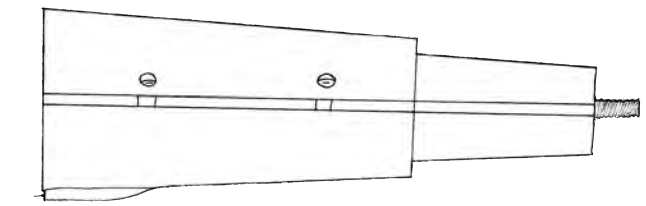


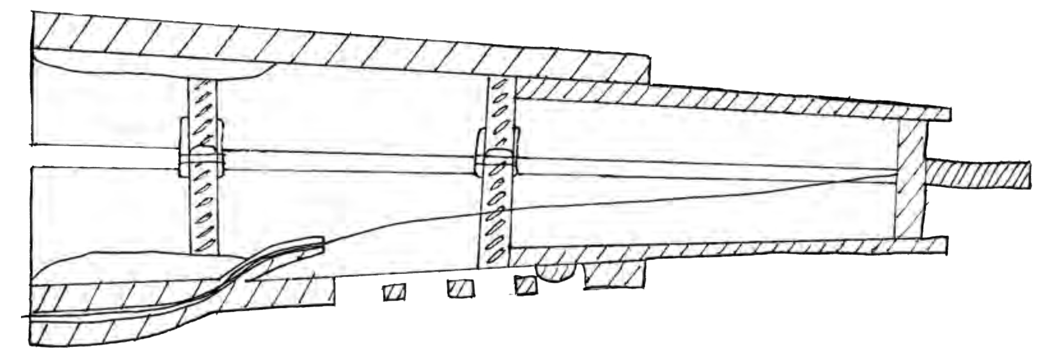
Rotational Extension

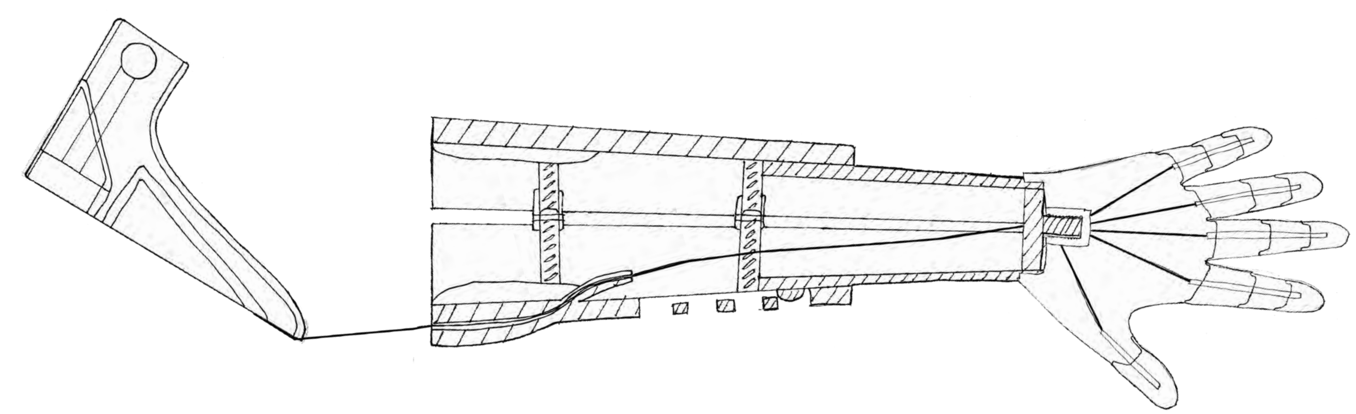


We started to sketch and develop ideas that would possibly work to make **prosthetics expand and extend** to accommodate for **various size changes.**





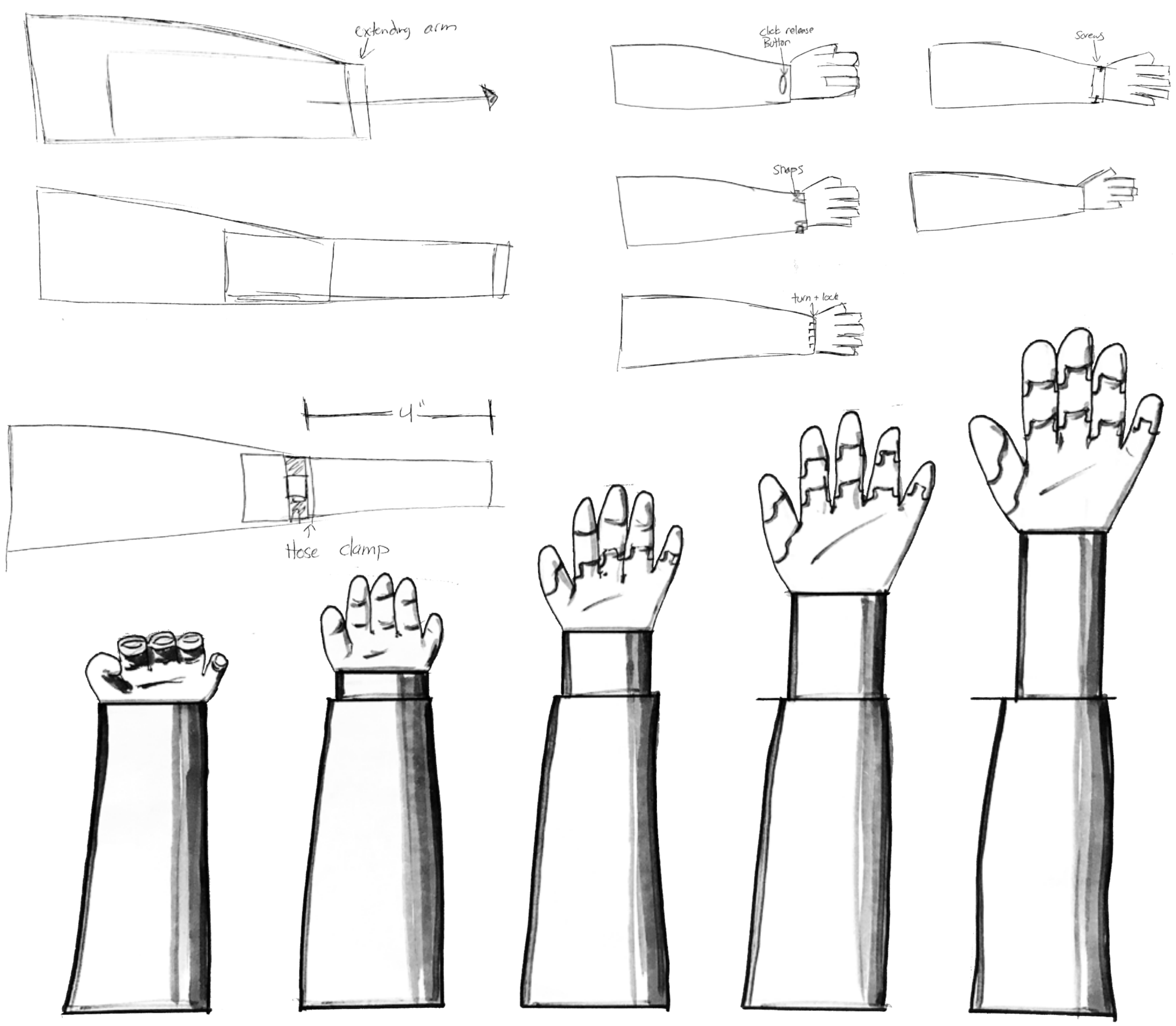




We sketched out initial systems that **expand in diameter and length.**

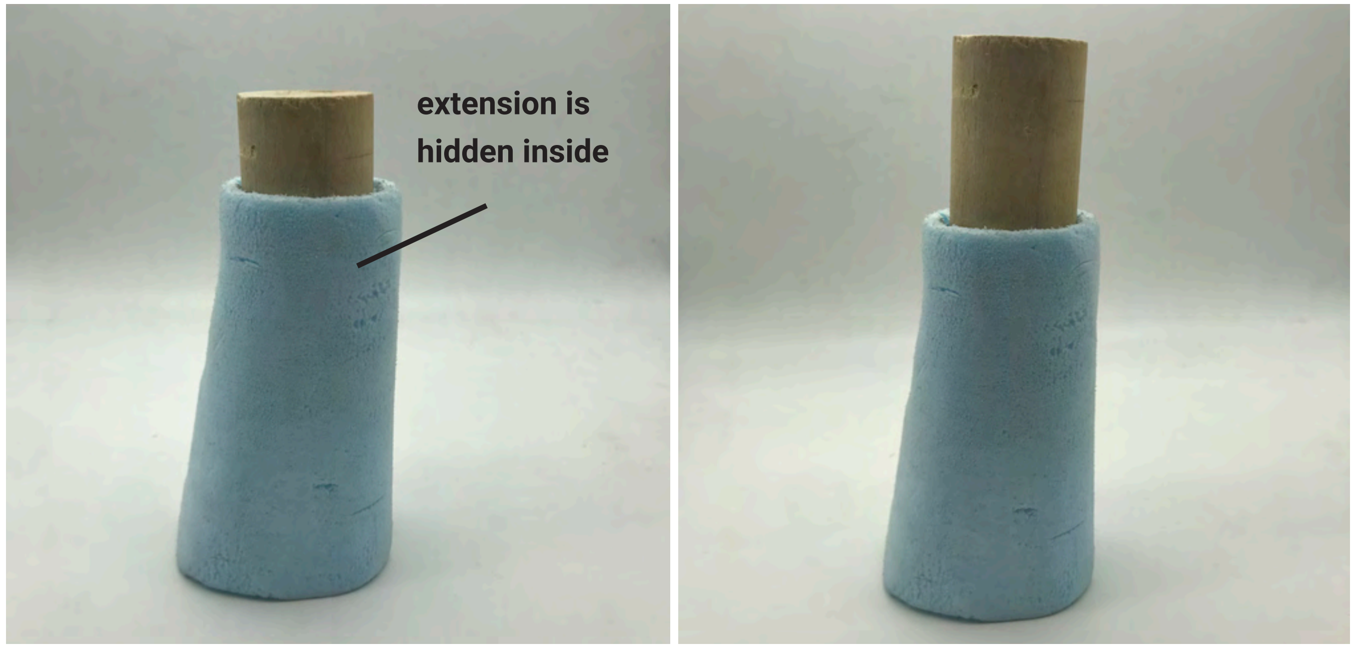
Lengthening the Forearm

After determining our age range to be from **six months to five years**, we started to **sketch out more simple designs** for extending the prosthetic.



Working with this age range allowed us to **focus solely on the lengthening aspect**, as children at this age do not grow much in diameter in their arms.

We started to test the concept, determining **how far we could extend the forearm**, and what forms would make sense.



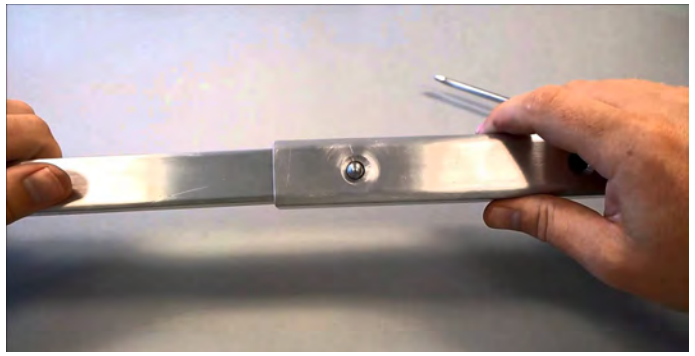
We determined the potentials with this form.

Printing the form introduced the idea that **we need a way for this extension to lock** in place securely.

Internal Mechanisms

We started to look at **simple, common locking mechanisms** that are currently used on a variety of different products.

Garret Button Spring Clip

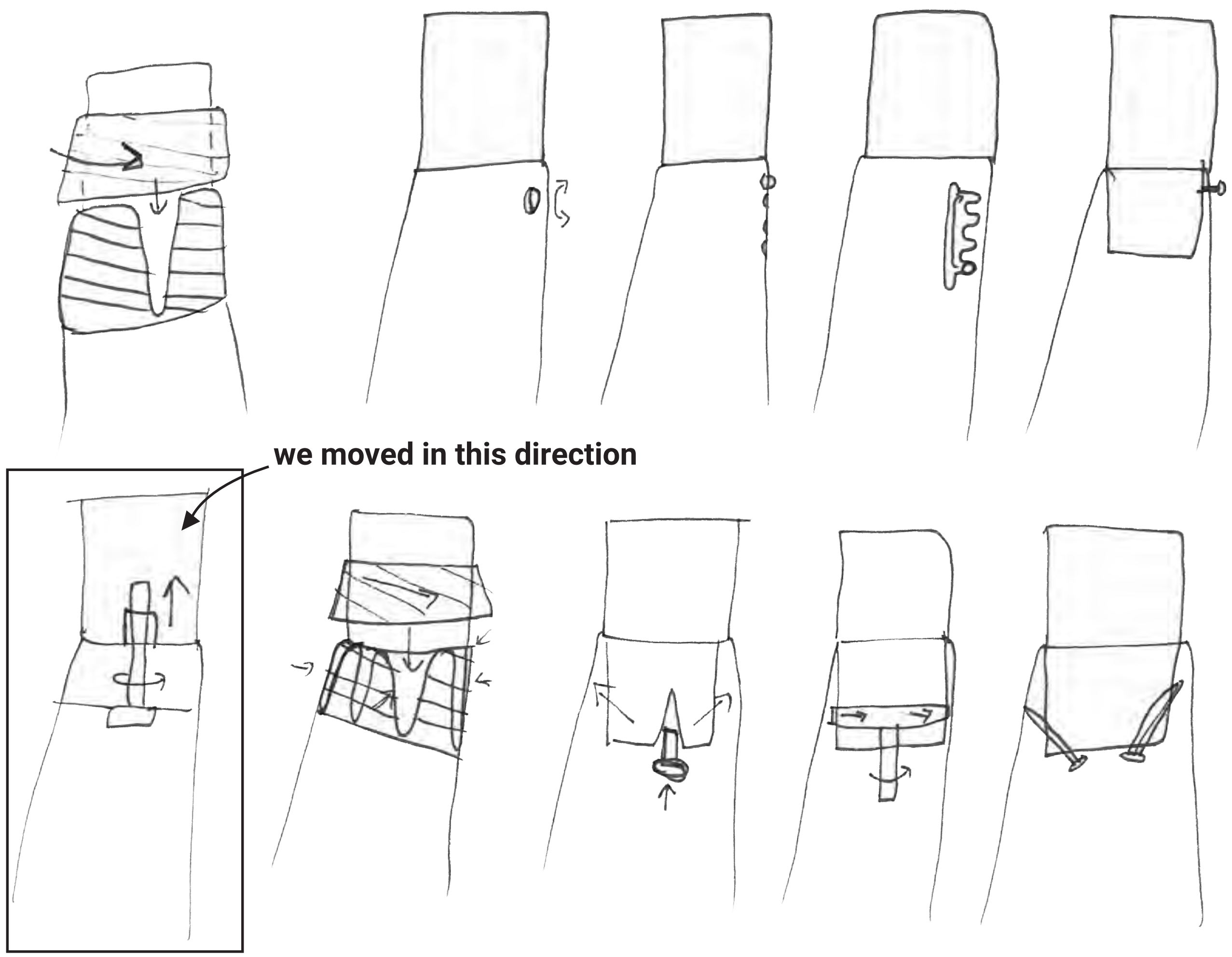


Squeeze Clamp

Twist Clamp

We sketched ideas to **incorporate these locking methods into our form**, and developed our own locking concepts, as well.

Screw Clamp **Garret Button Spring Clip** **Pin**

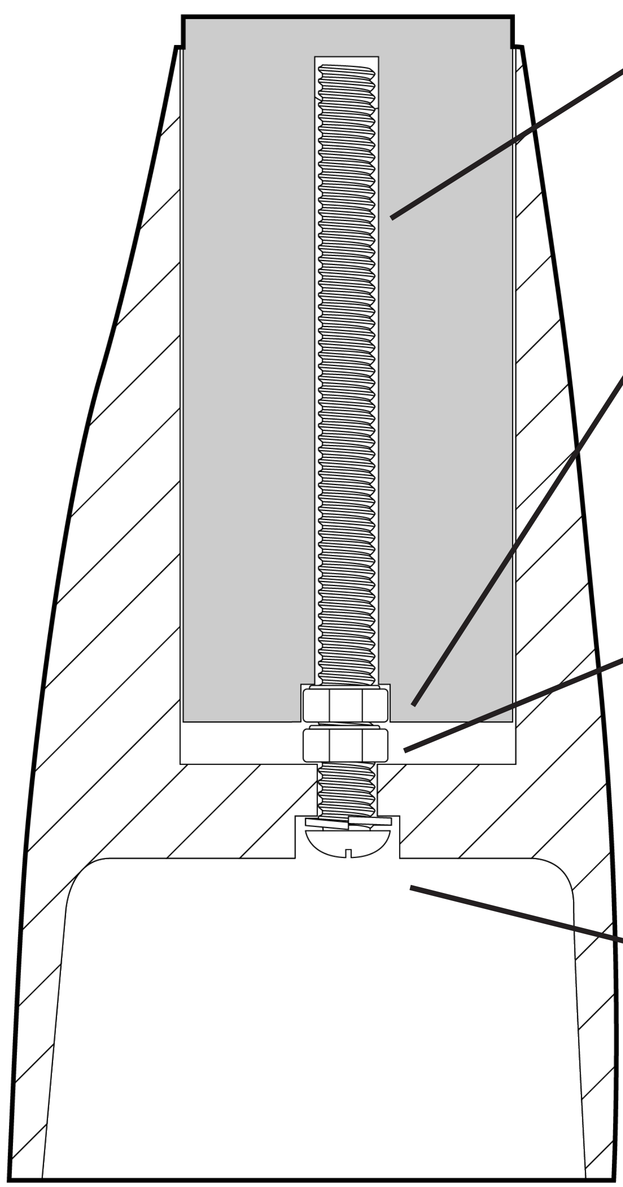


Nut and Bolt **Pressure Squeeze** **Two Pins**

What we discovered from this exploration was that we had the opportunity to **both lock and extend the extension with the same mechanism.**

Nut and Bolt Mechanism

After exploring how a nut and bolt is used to extend, **we incorporated it into our design** with as much efficiency as possible.

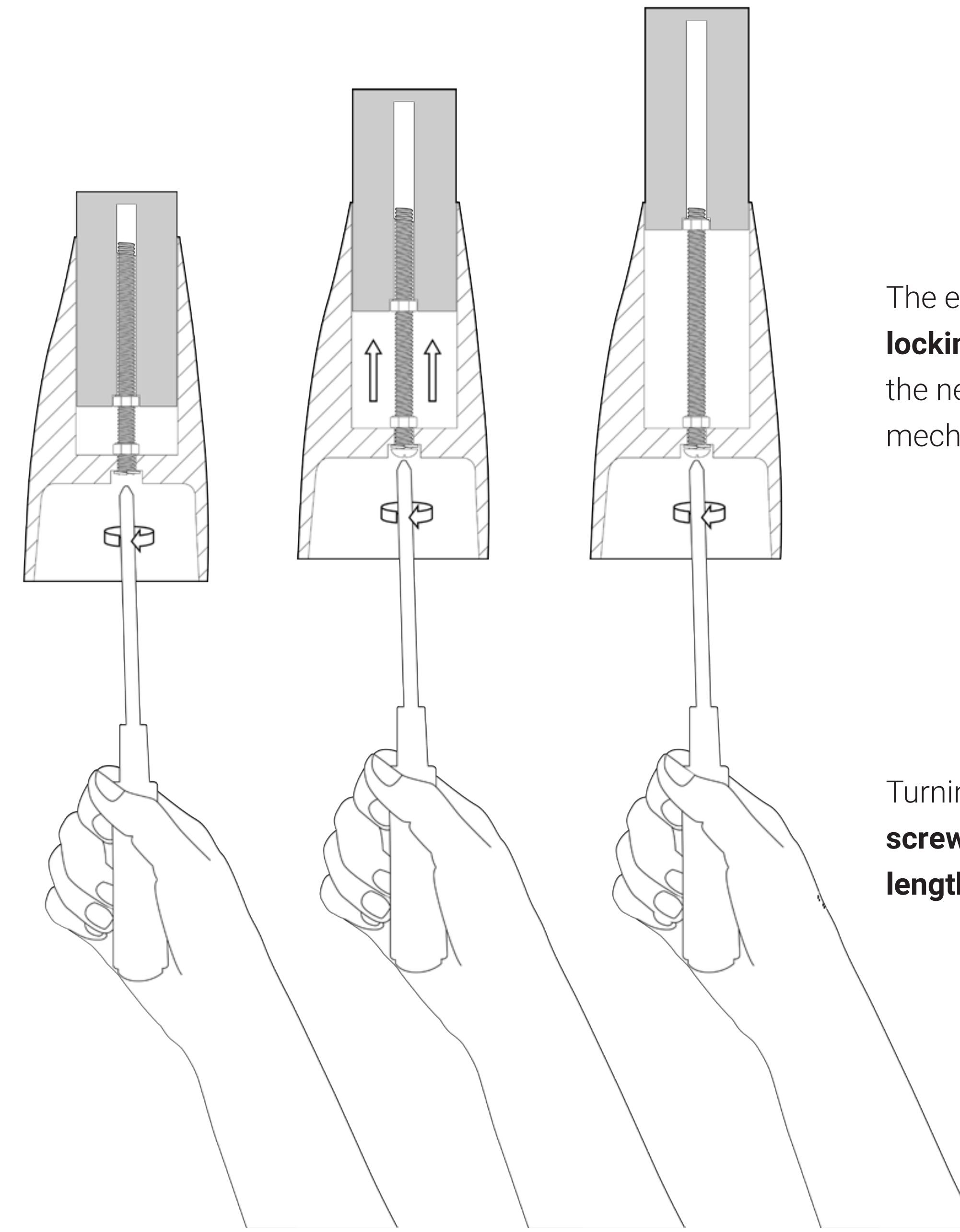


Extension can reach **as far as the bolt goes**.

The bolt rotates, which forces the nut up, **pushing the extension out.**

This nut **prevents the bolt from moving up** and down on its own.

The bolt access is in the socket, **only accessible for the prosthetic specialist** to adjust.



The extension stays in place, **locking itself in** without the need for an additional mechanism to lock it.

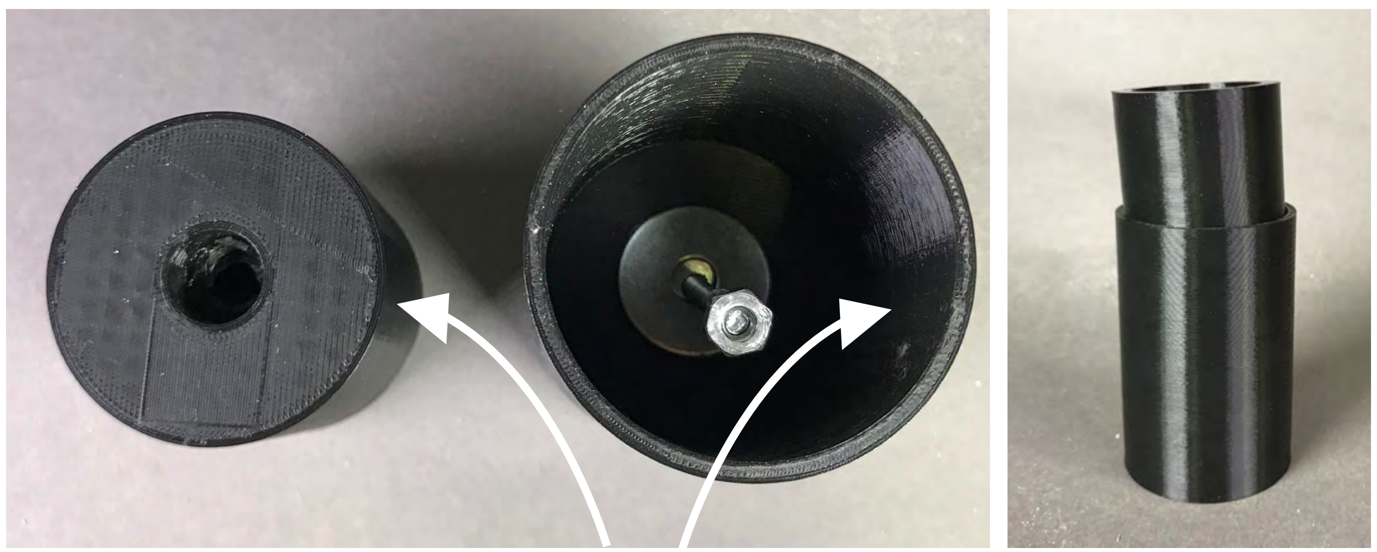
Turning the bolt with a **screwdriver adjusts the length.**

By using nuts and bolts, the extension can actually be **adjusted with the mechanisms, in addition to locking it in place**. This provides an advantage for the prosthetic specialist, as they will be able to **fine-tune adjust the length properly**.

Nut and Bolt Mechanism

It is very important that the extension mechanism is **secure when both adjusting and locked in place**. We performed a variety of different tests to determine how to ensure the extension **would not rotate on its own.** It is extremely important that the extension feels secure, so that there is **no concern that it will fall out, or break** when extended on a patient.

Testing the Concept

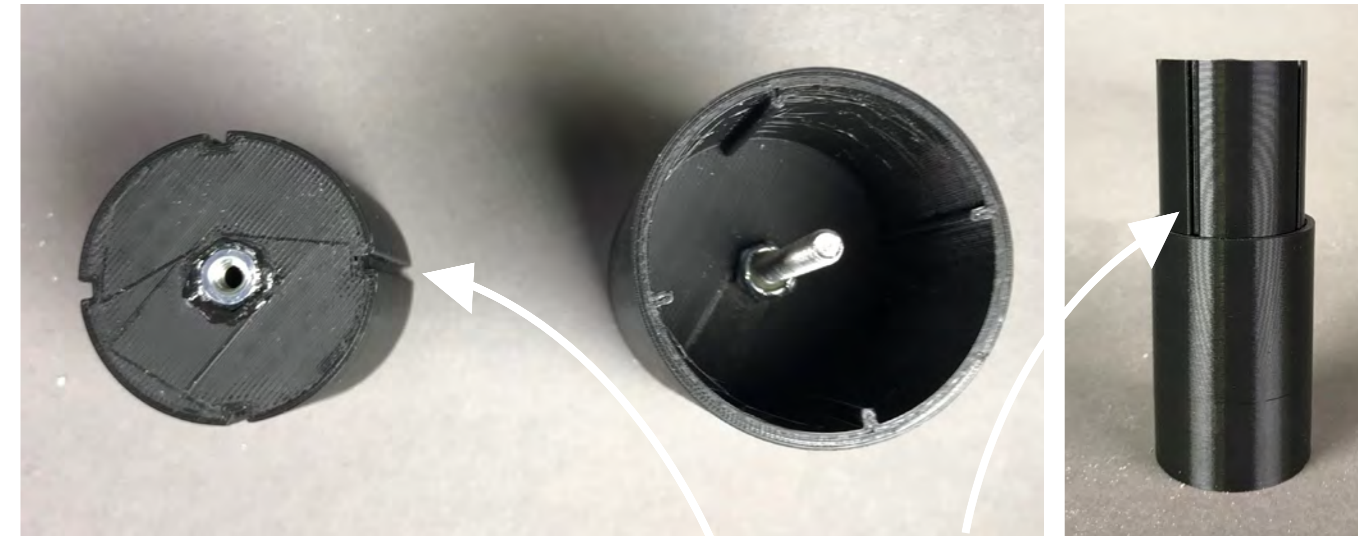


completely smooth surface

The concept worked in this test as we had planned when sketching the idea.

We learned from this test that **the extension felt too loose and unsecure**. Completely **circle walls would not be sufficient** to prevent the extension from **rotating on its own**.

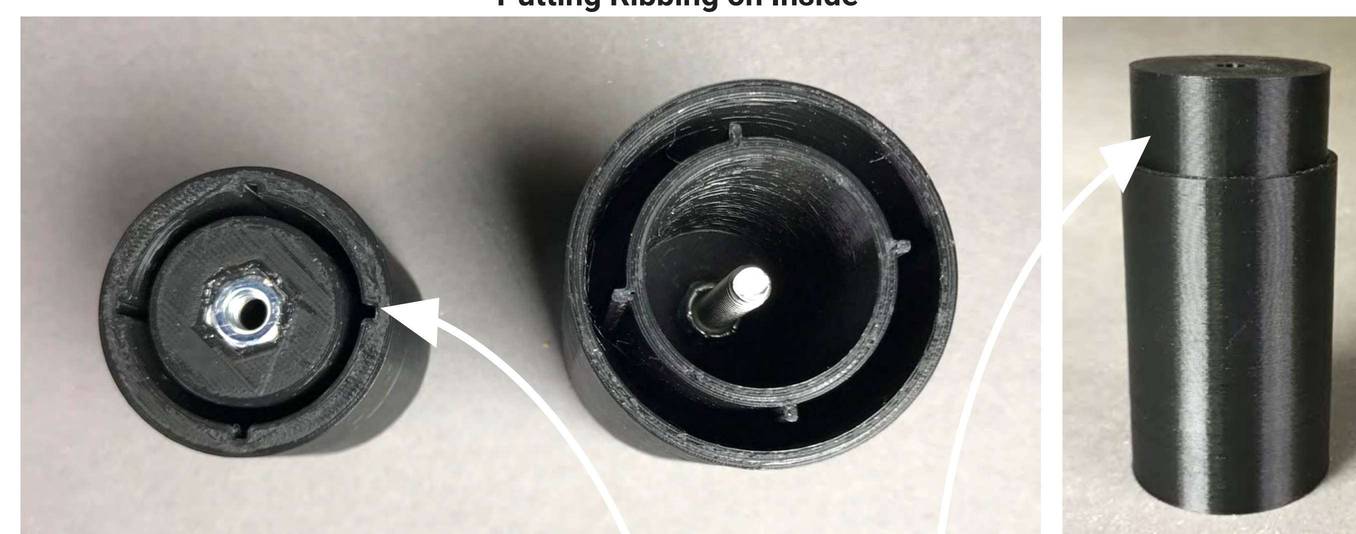
Adding Ribbing



groove on the outside

For our next test, we added a **smaller tolerance and a groove**. This helped with it's delicate feeling. The **grooves were on the outside** which aesthetically is unpleasing.

Putting Ribbing on Inside



groove on the inside

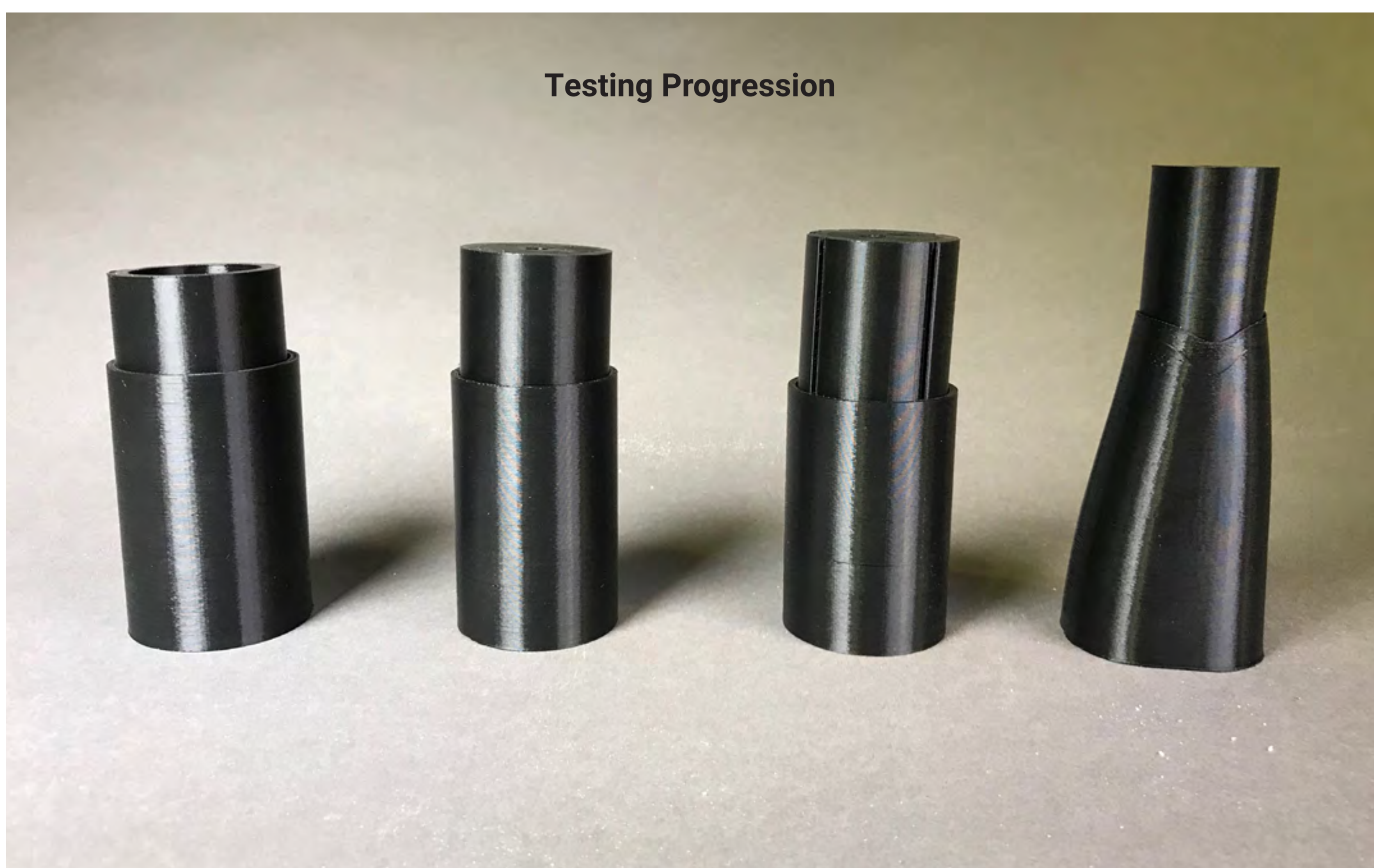
We created ribbing that prevents rotation and is not visible from the outside, **which addressed all our concerns** throughout this testing process. The ribbing prevents the extension from rotating, which **allows the nut to be pushed upwards**.

Mechanism

We **combinded the updated mechanism into the form of the forearm** and made sure it worked well with these slight modifications.

Fitting Mechanism Design into Form

Testing Progression



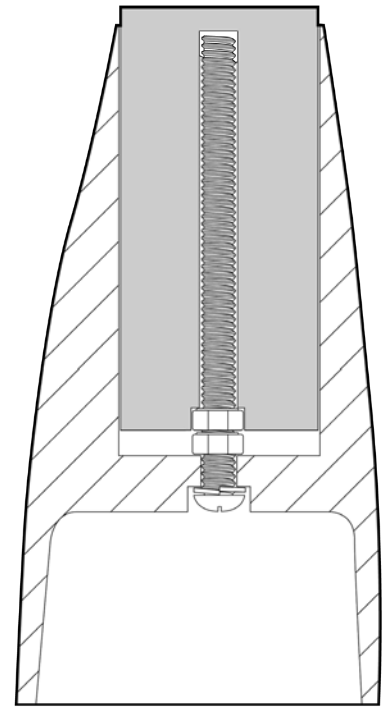
Prosthetic Slightly Extended

Prosthetic Fully Extended

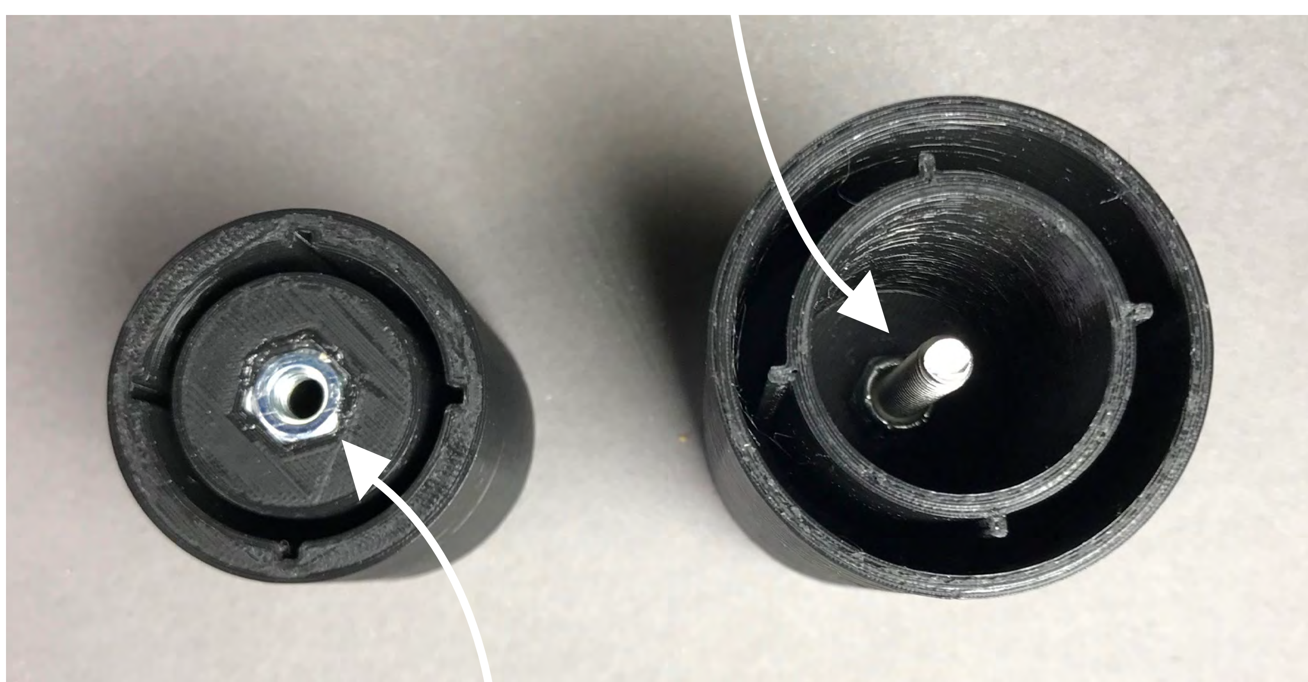
We tested to make sure the prosthetic would **extend properly with the fitted mechanism inside** and whether it would extend enough.

Internal Hardware

Through our testing, we learned that using the **proper type of hardware is crucial**. The hardware needs to provide the proper support that is **secure and will not break**, yet **does not add too much weight to the forearm**.



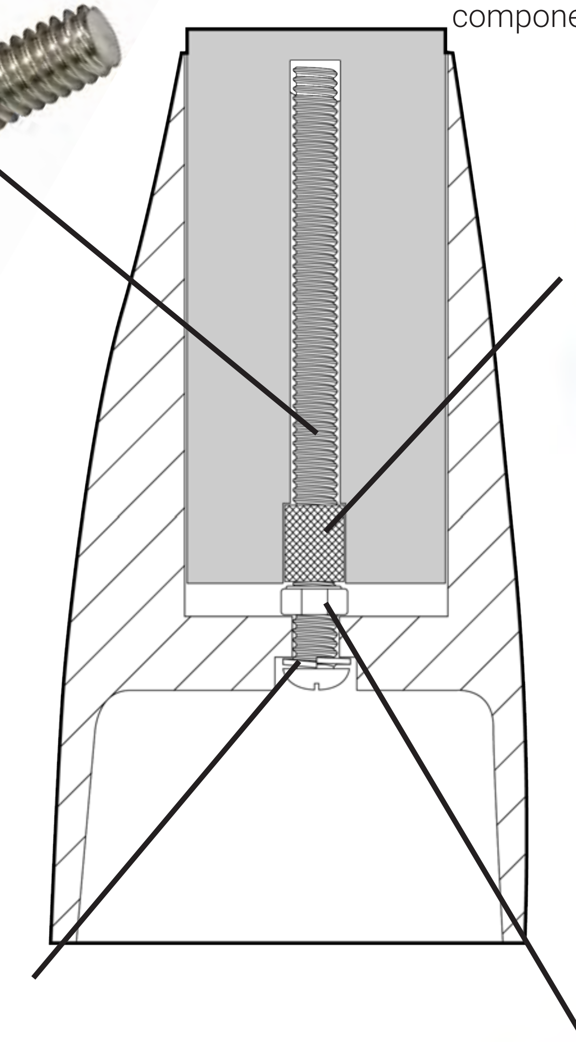
In these testings, we used an **1/8" bolt** with it's appropriate nut, which was **too delicate.**



We also **glued a nut** in the extension, but this would **not secure enough** for final production.

Components

A threaded insert **act as the nut** that was previously glued into the extension. This is a more secure component.



A **1/4" bolt** is used to extend the forearm through the **use of a screwdriver**.

A self-locking nylon nut **creates a tight fit** that ensures there will be no loosening of the prosthetic on its own.

A split washer is between the bolt and the prosthetic to **act as a "spring," further tightening and preventing loosening**.

The nut prevents the bolt from falling out.

Socket Development

Hand Development

Armband Development

Forearm Development

Socket

As children grow, their **amputated limbs change shape and size**. Generally the prosthetic needs to be **replaced if the socket no longer fits.** This is a separate problem from the issue of length, and is just as much of a concern. The **cost is extensive.**

To prevent the entire prosthetic from being replaced, **the socket needs to adjust as well**.

Ambionics' prosthetics' design utilizes **a replaceable socket** that interchanges as the child grows.

This concept can be **adapted to our design.**

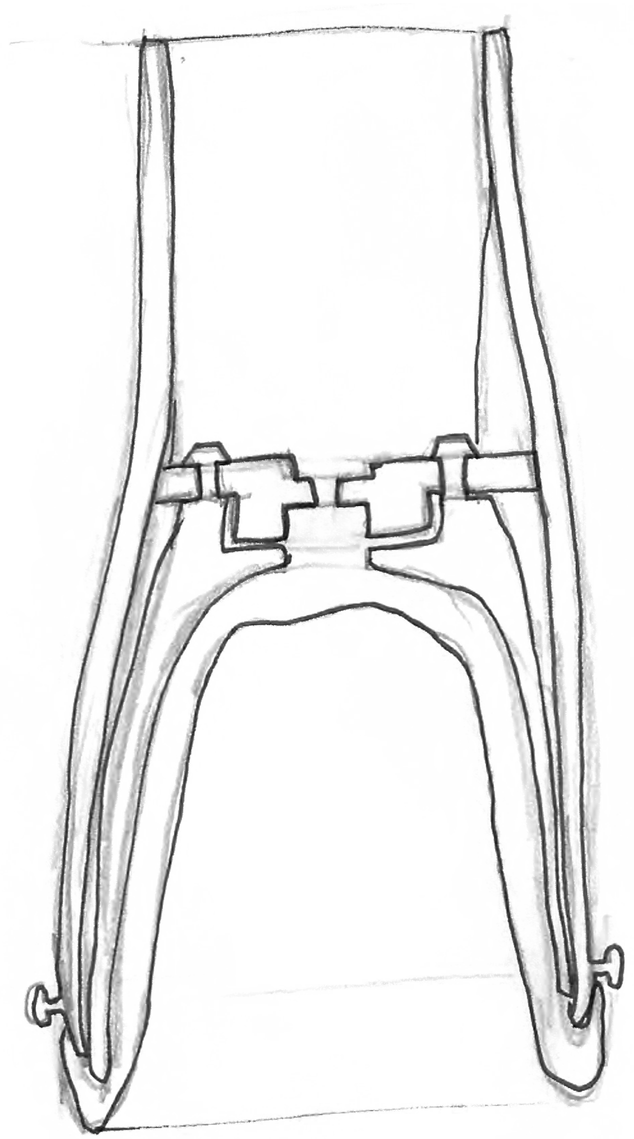
We looked at different materials for the socket, and how to create a **gentle attachement to the child.**

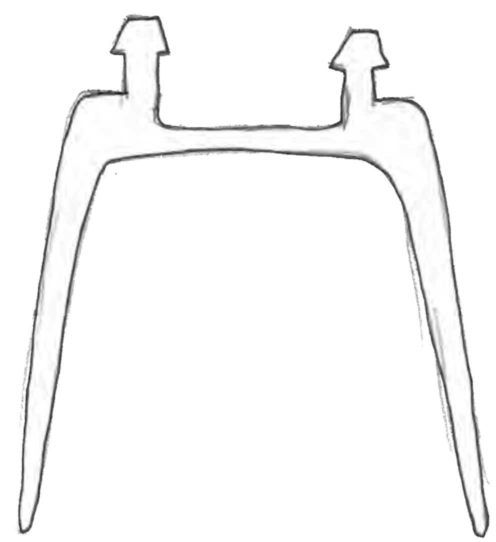
WillowWood sent us a sample of their prosthetic socket sleve, which is a **fabric material with silicone on the inside, to mold to the limb.**

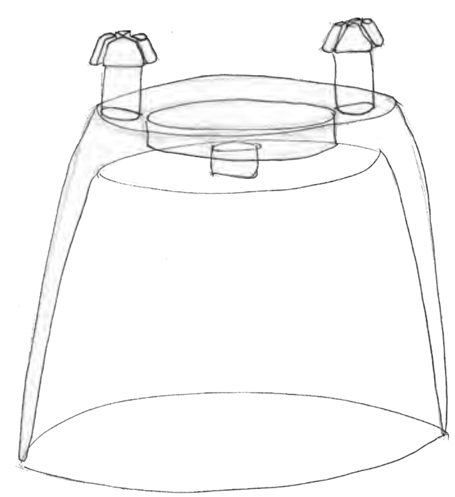
A common method of creating a socket is to **take a cast of the limb, and then create a mold** with that cast to produce a **silicone socket.** This use was much **simpler to include in our prosthetic** than WillowWood's sample.

Socket Insert Cup

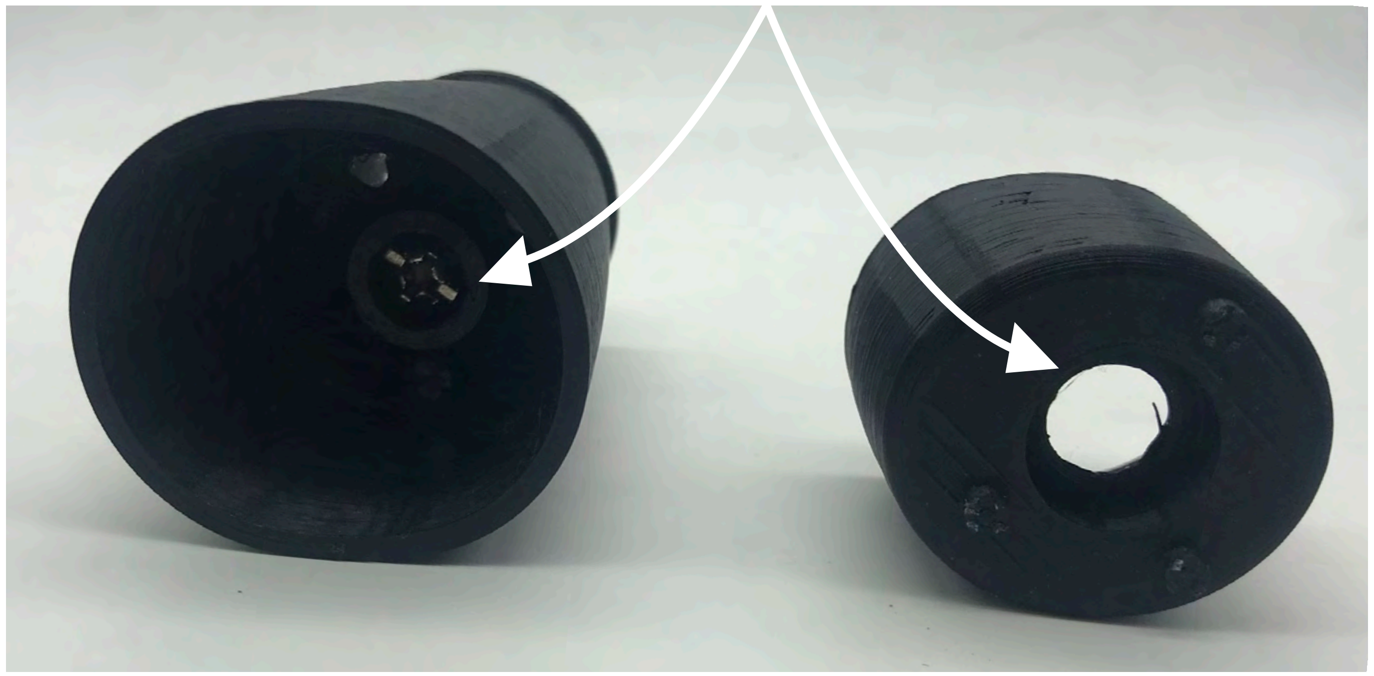
We determined that the socket can **snap into place** inside the forearm. These snaps are able to be **released with a tool from the other side**, pushing them back out. The socket itself is a **cup shape, that is replaced** over time as the child grows.

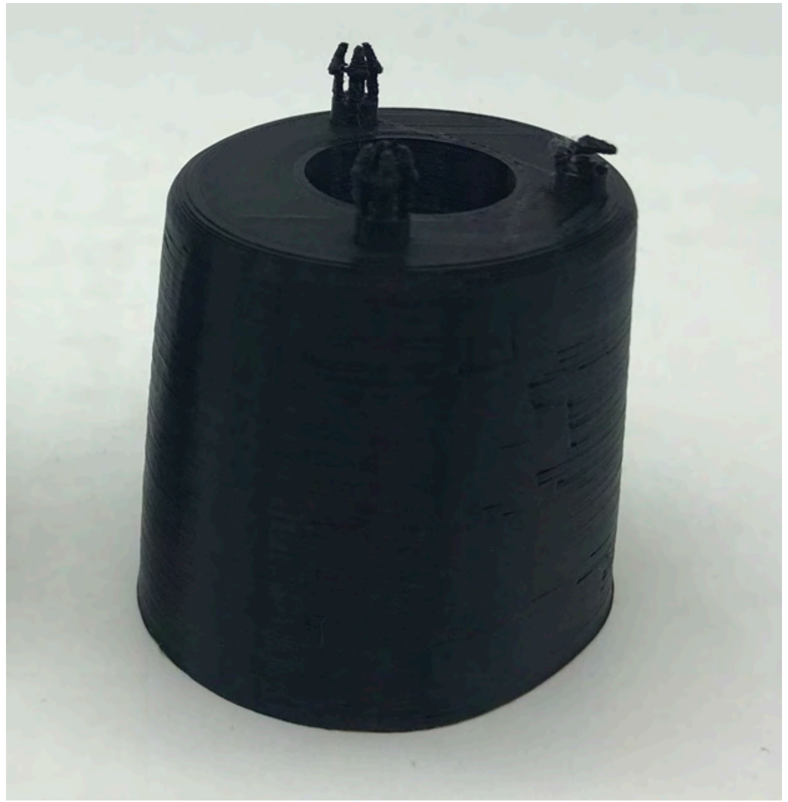






A hole in the cup is needed to **access the adjustment bolt** for the forearm extension.



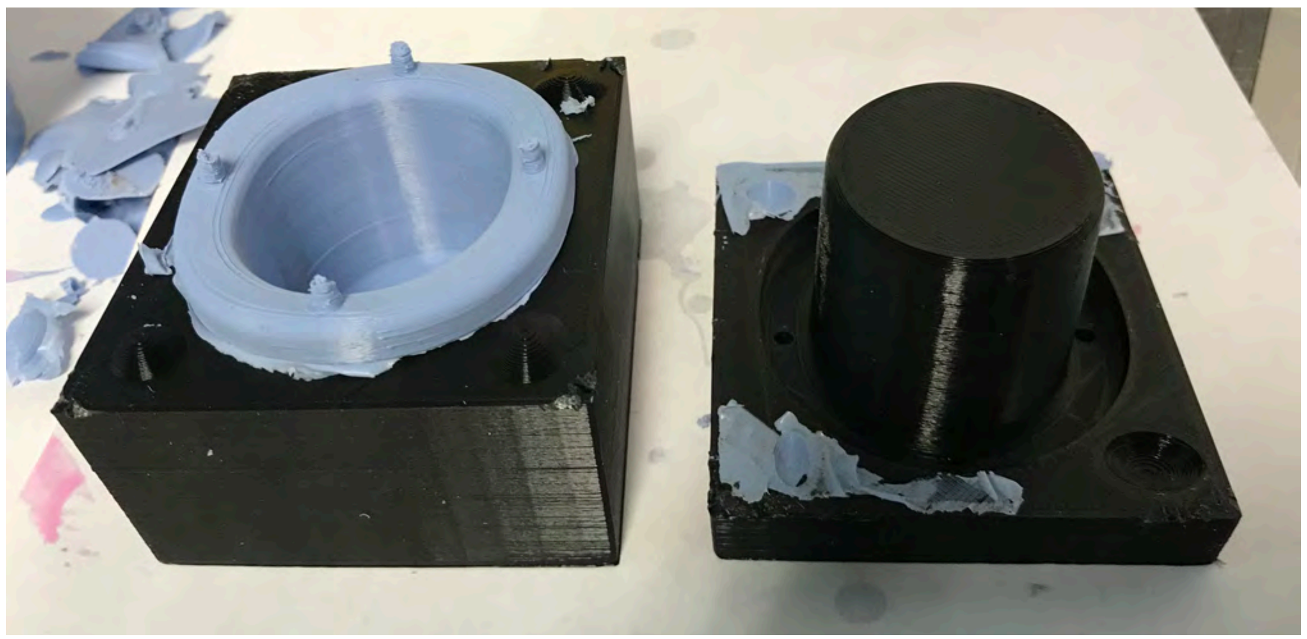


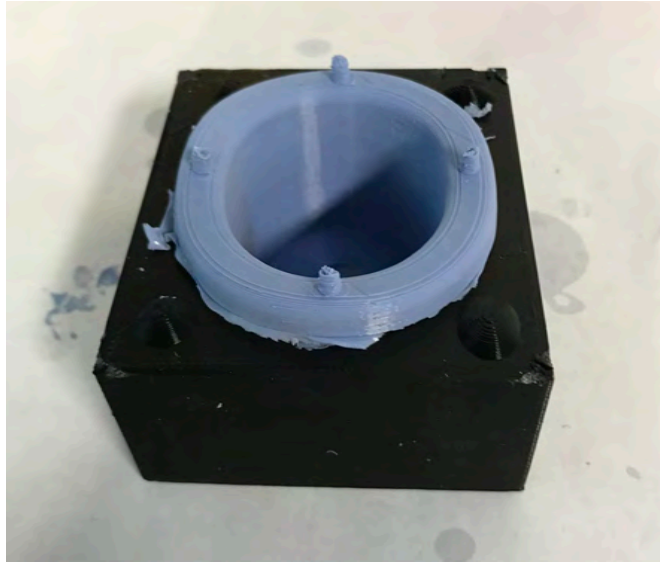
We printed the shape of the cup to **test out it's fit** in the prosthetic. We made **adjustments to the form** of the prosthetic to allow for this cup form to be inserted inside. **Holes for the snaps** needed to be placed, and tested as well.

Socket Insert Padding

The **padding on the inside** that is touching the skin of the limb is what is **actually changing as the prosthetic insert is replaced**. We tested how this insert would be created and attached to the cup.

Creating a Mold to Cast a Test Silicone Insert





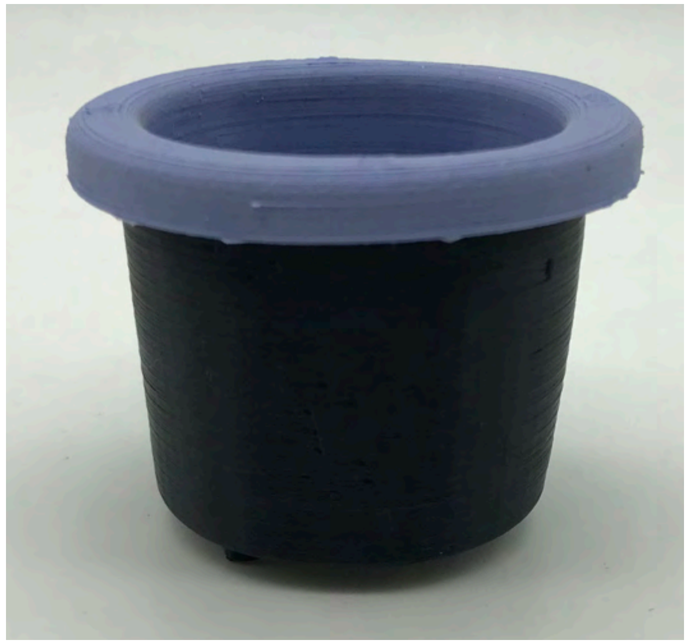
By creating a **3D printed mold**, we could test how easy it is to cast the silicone insert. The **amount of silicone that this required was also extremely small**. This is a benefit, as it will **reduce waste when the socket gets replaced.**

Top View of Casted Silicone

Hole to access bolt

Side View

Silicone Inserted in Cup

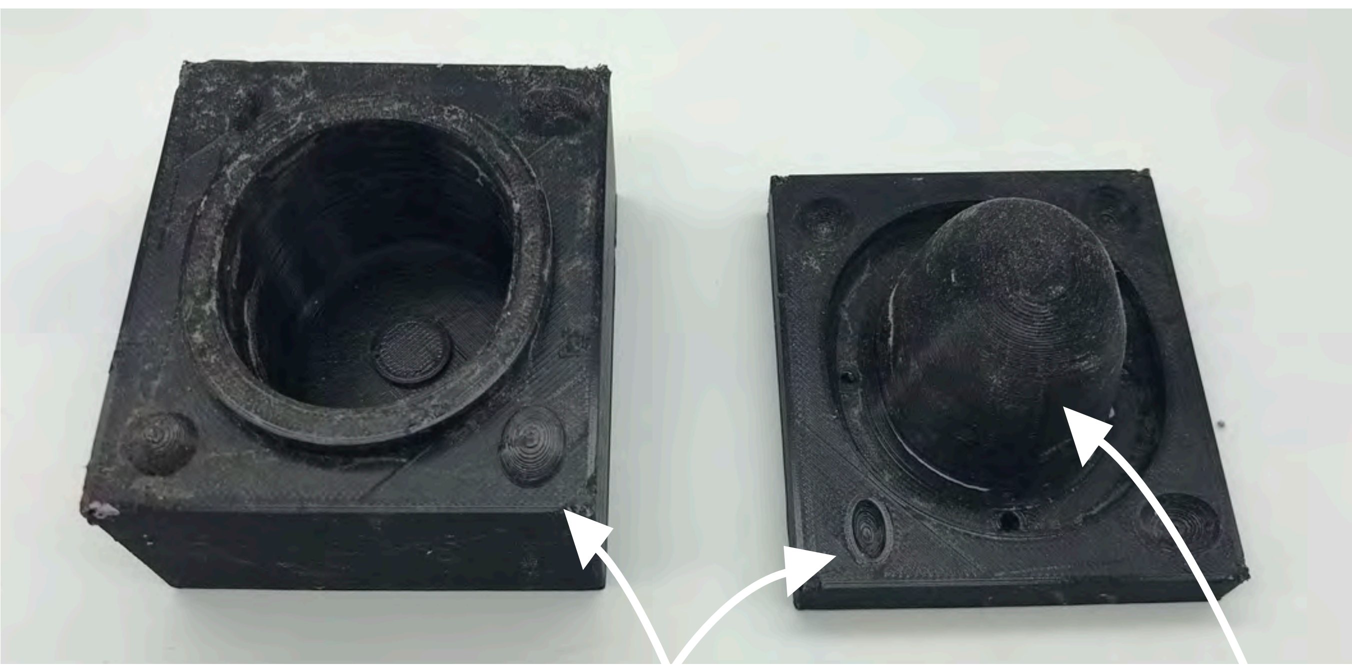


In our testing, **the silicone was created separately from the cup.** In production, the cup will be inserted into the silicone mold. When the silicone is cast, it will permanently adhere to the cup.

Mold Replacement System

Creating molds each time a customized part needs to be replaced is **extremely wasteful of materials.** The prosthetic's goal is to **reduce the amount of replacements needed**, and this is true for both the prosthetic itself, and the molds needed to produce the prosthetic.

Bottom Mold **Top Mold**

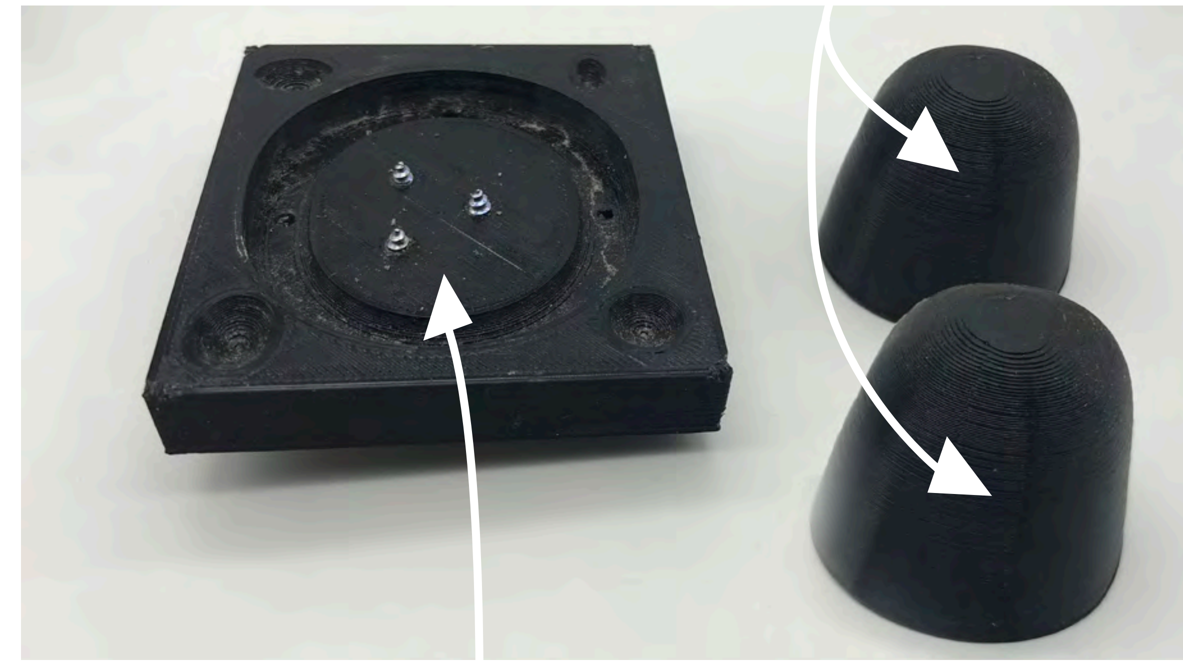


keys for proper alignment **amputated limb scan**

The mold we printed to test out the casting process for the socket insert is a **two part mold**. The mold itself is very small, since we are **casting silicone that is no larger than a few inches in all directions, and hollow.**

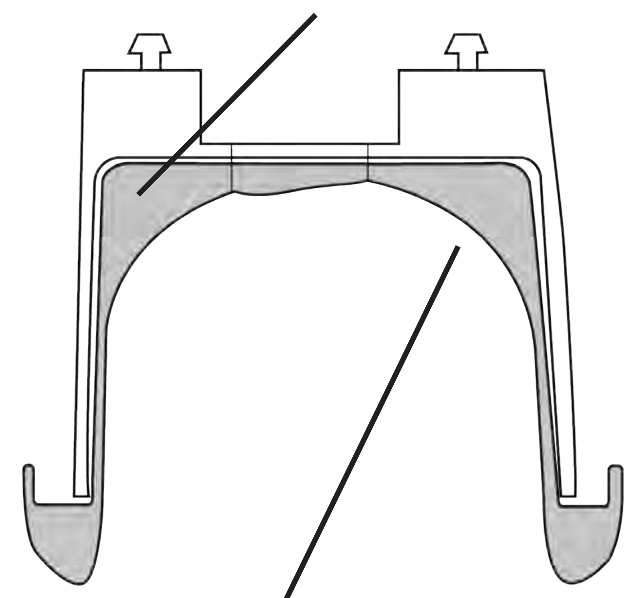
Top Mold Separated from the Scanned Print

replacement scans



screws to hold in replacement scans

the external shape is the same.

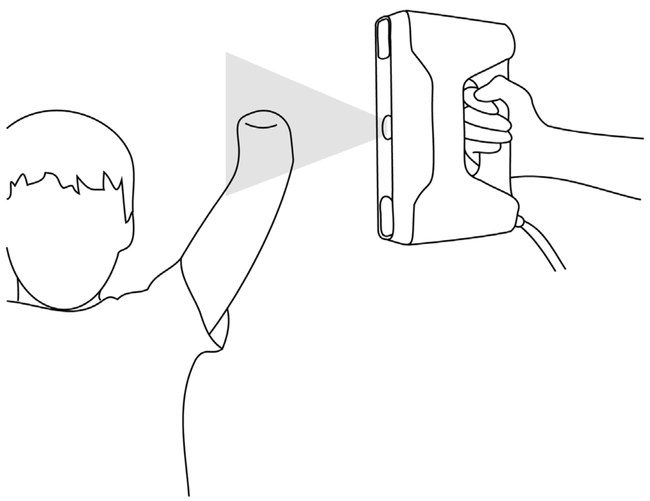


the internal shape changes

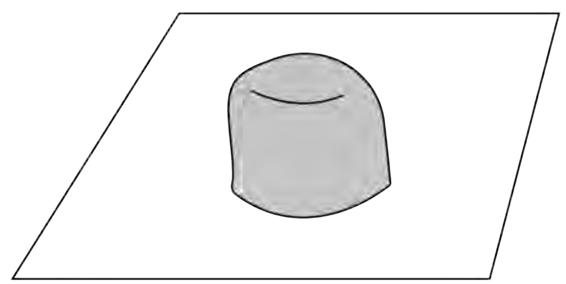
To reduce the amount of molds that are produced, **we standardized the shape of the silicone that fits within the insert cup**. The only part of the silicone that changes is the part that is touching the amputated limb. **The mold has replaceable inserts that take the form of the limb, to cast customized sockets with a minimal amount of material waste.**

Making the Socket Insert

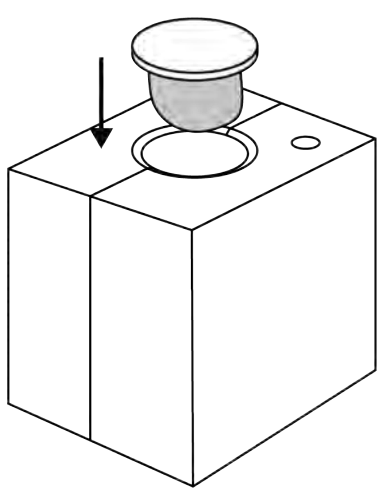
Prosthetics are very expensive because there are **many custom parts** involved. The **socket insert will be replaced frequently, and will be custom fit each time** it is replaced. There needs to be a manufacting method that a **prosthetic specialist can do in the office space and will not significantly increase the cost of the prosthetic**.



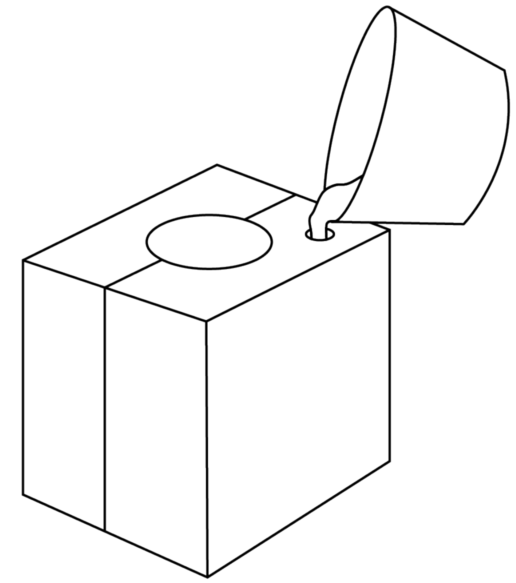
1. Scan the limb



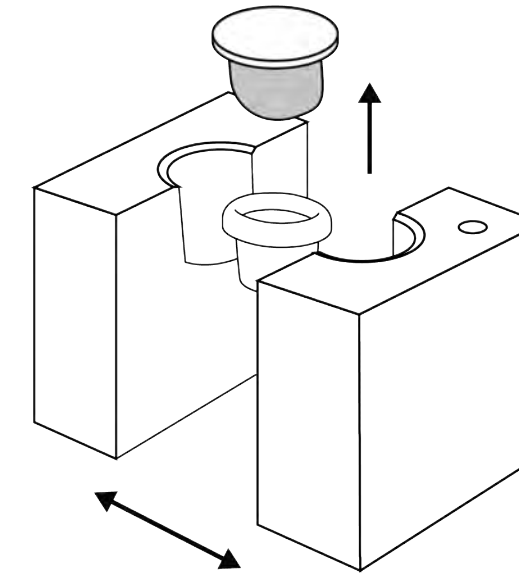
2. 3D print the scan



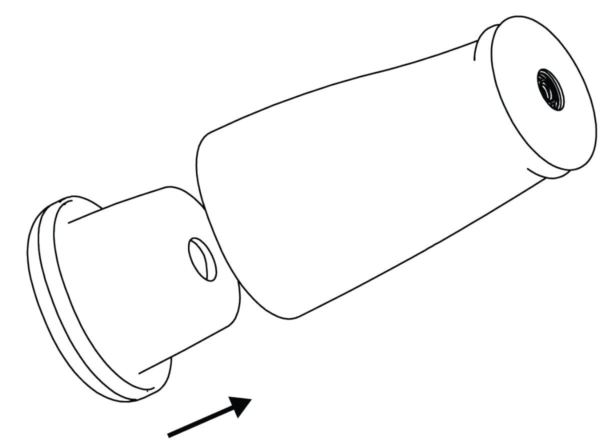
3. Insert the print into a mold



4. Pour in silicone



5. Remove from mold

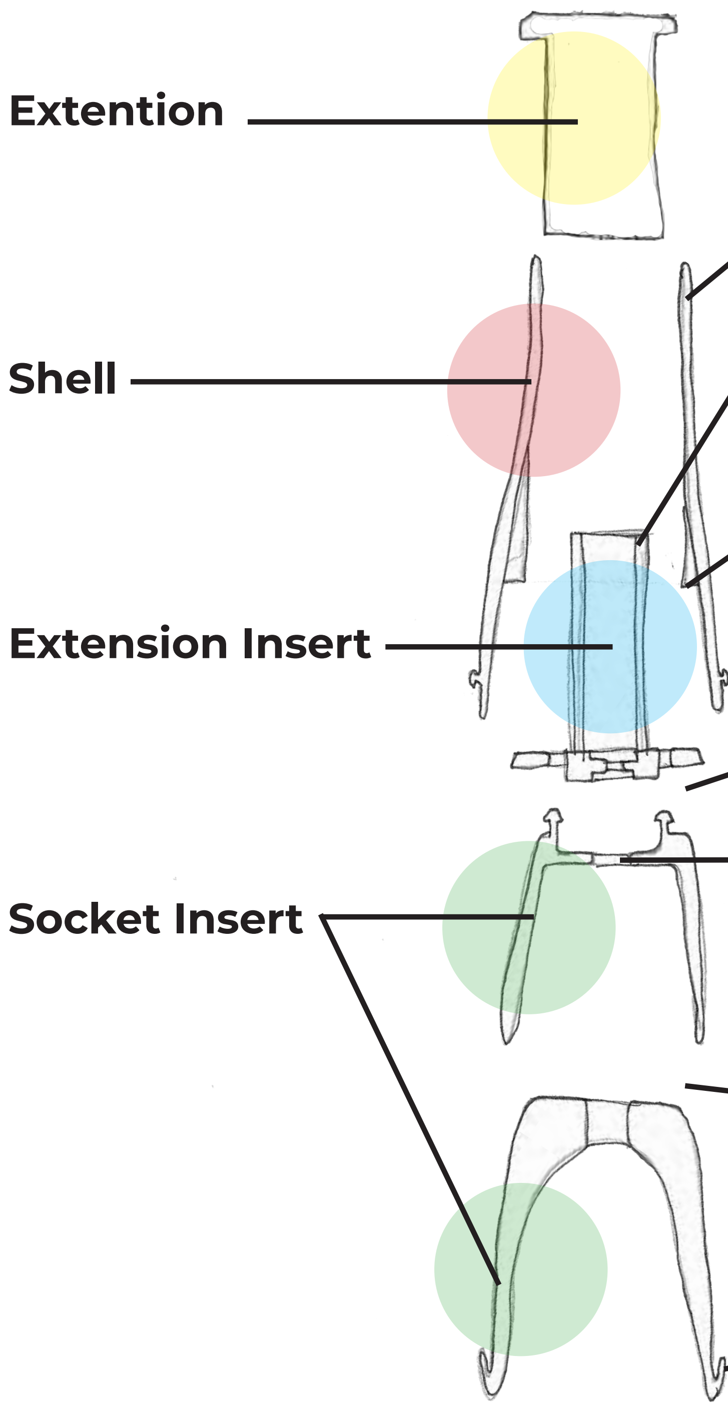


6. Insert socket into forearm

By using **3D scanning technology**, we can avoid physically casting the limb, which **reduces cost**. By having a set mold, where the only interchangable part is the print, we **reduce the amount of replacements** in the casting process.

Manufacturing Considerations

Manufacturing considerations **affected the design** of the forearm significantly.



The internal extension mechanism needed to be **separated into two components** for ease of manufacturing.

The ribs **guide the sliding extension** as well as remain **easily manufactured** in a mold.

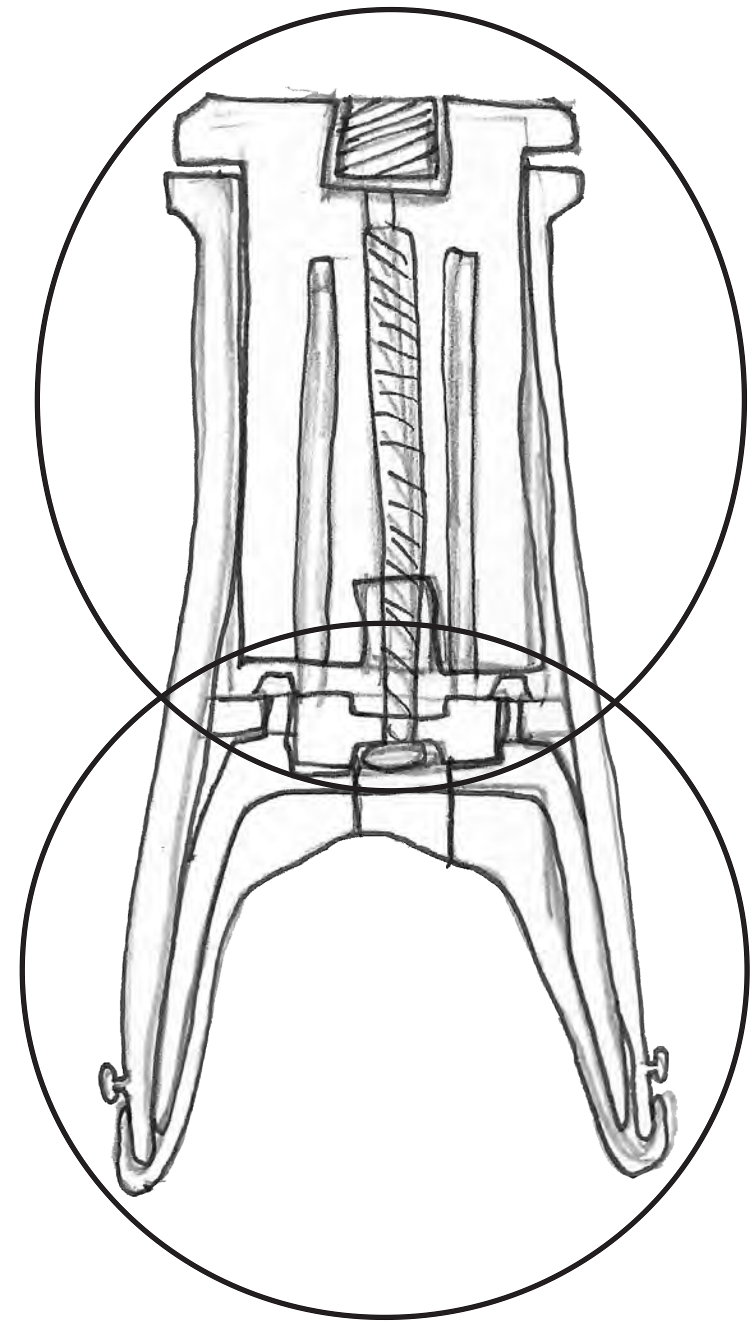
The socket insert **snaps into the forearm**.

A hole in the socket insert allows for **access to the adjustment bolt**.

The silicone is **overmolded** into the cup.

Flaps on the silicone **secure it to the forearm**.

The components that make up the forearm overall allow for the prosthetic to **adjust in length and replace the socket.**



Extension mechanism: **provides the means for extending the length**

Components utilized:

- Shell
- Extension Insert
- Extension

Replaceable socket: provides a **way to replace a small part of the prosthetic.**

Components utilized:

- Extension Insert
- Socket Insert

These solutions **prevent entire prosthetics from being discarded** after the child grows and develops.

Manufacturing Considerations

The **two** components of the internal extention mechanism are the **external shell and the internal extension insert**.

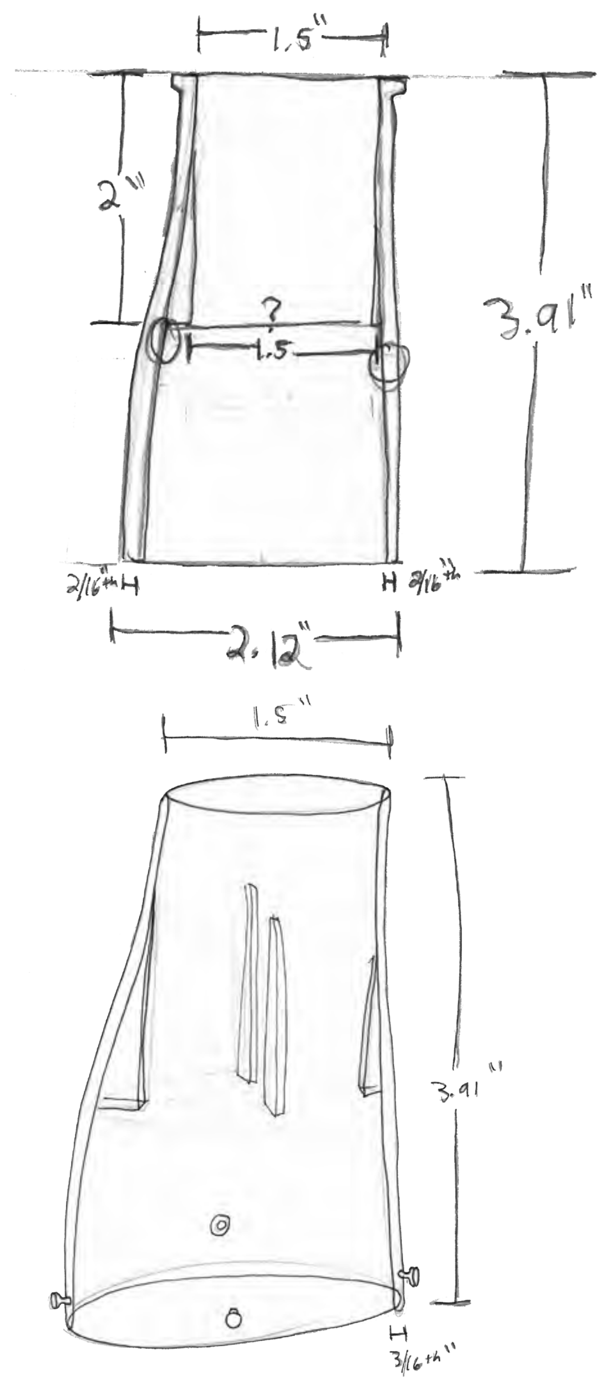
Our manufacturing considerations were developed **with help from Eric Schneider**, our materials and processes expert.

The shell of the forearm **contains all the components.** There is **very little structural support** from this part.

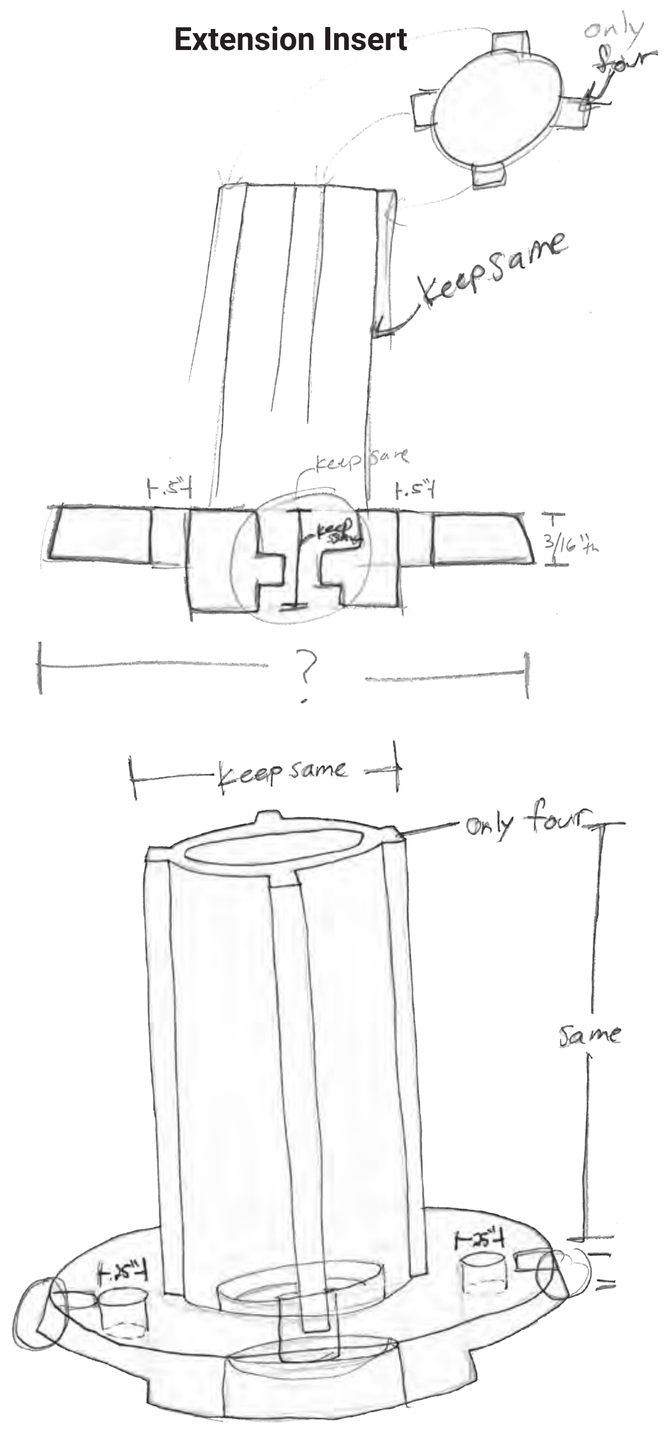
The shell **acts as protection** for the internal components. This is also what is seen as the **form of the forearm.**

These ribs, as mentioned in the previous page, **support the extension, giving it a vertical wall.** The ribbing shape **reduces weight and allows for the shell to be injection molded.**

Shell



Extension Insert



We decided to include **four ribs** on the side of the mechanism because this number is the **easiest to injection mold.**

The extension insert component is **attached to the shell** and is **responsible for the extension mechanism.**

The extension insert **connects all the components of the forearm together**. This is explained futher on the next few pages.

Materials and Color Choices

We explored various material choices for this prosthetic, determining the **most durable**, and most sensible for the size of production. We looked into having the prosthetic produced as an **SLS print.**

SLS, or Selective Laser Sintering, is a form of 3D printing. **It uses a laser to turn powered nylon into the object being printed.** There are many benefits of SLS printing:

The powered nylon **acts as it's own support,** so there is no need to include supports. This means **complex forms can be printed very easily.**

It is **completely solid,** as compared to filament printing, which is not solid. This means the **structure is much stronger.**

It is very **porous,** which means that it is extremely **lightweight.**

Using **Injection Molded Polypropelene** had more advantages than the SLS printing.

Polypropelene is:

Lightweight

Scratch-resistant

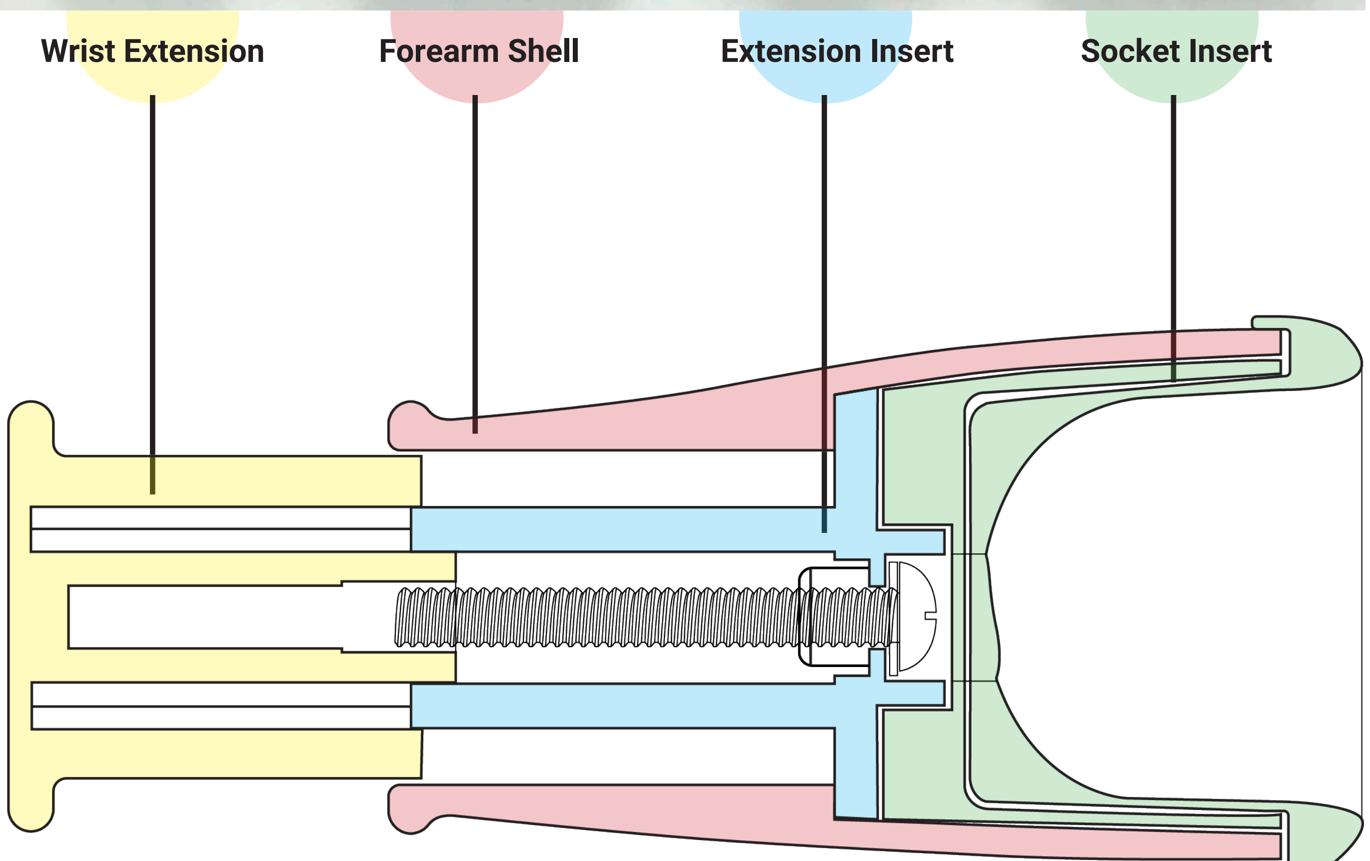
Inexpensive

It is also injection moldable, which allows for a **larger production scale. SLS printing is not capable of this.**

We wanted a saturated, gender-neutral color for the forearm, as this would be universal for children. Red was a great fit.

How It All Fits Together

Overall, the forearm is broken up into **four components**:



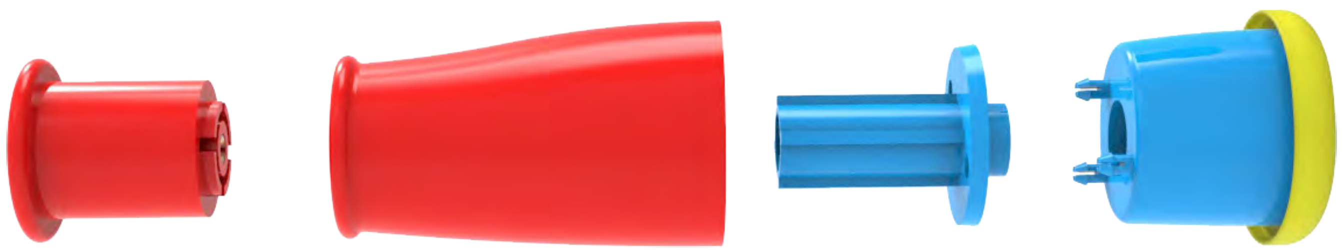
Components Without Shell

Components With Shell

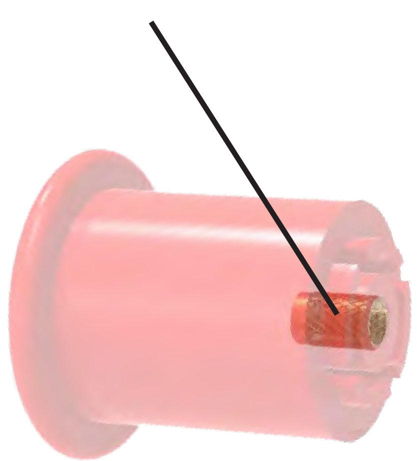
This component based system makes the forearm prosthetic **capable of replacing small parts** within the system, **rather than replacing the entire prosthetic.**

How It All Fits Together

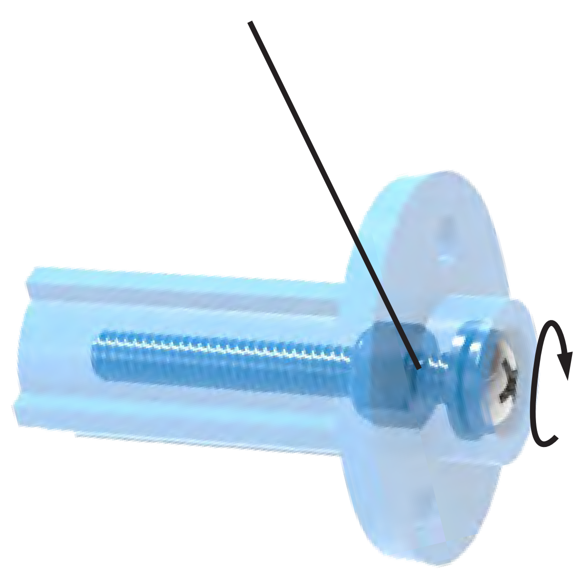
Wrist Extension **Forearm Shell** **Extension Insert** **Socket Insert**



The **threaded insert fits inside** the wrist extension.



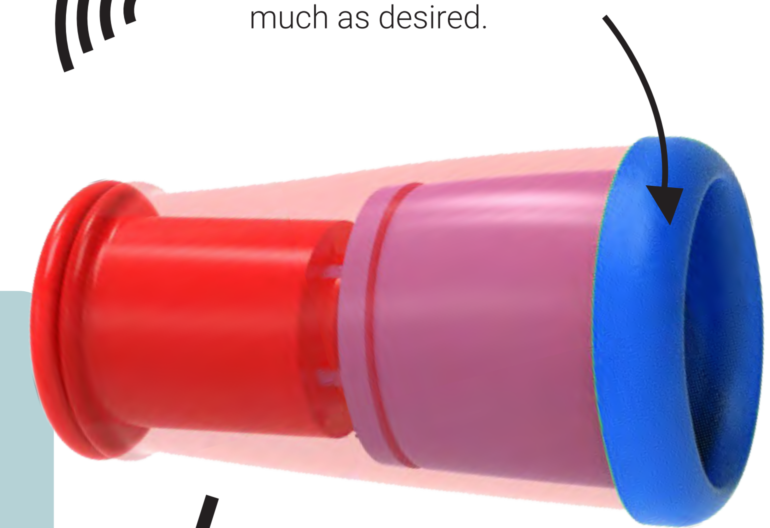
Self-locking nut, bolt and washer **all fit securly inside the extension insert,** yet loose enough to **allow for it to rotate.**



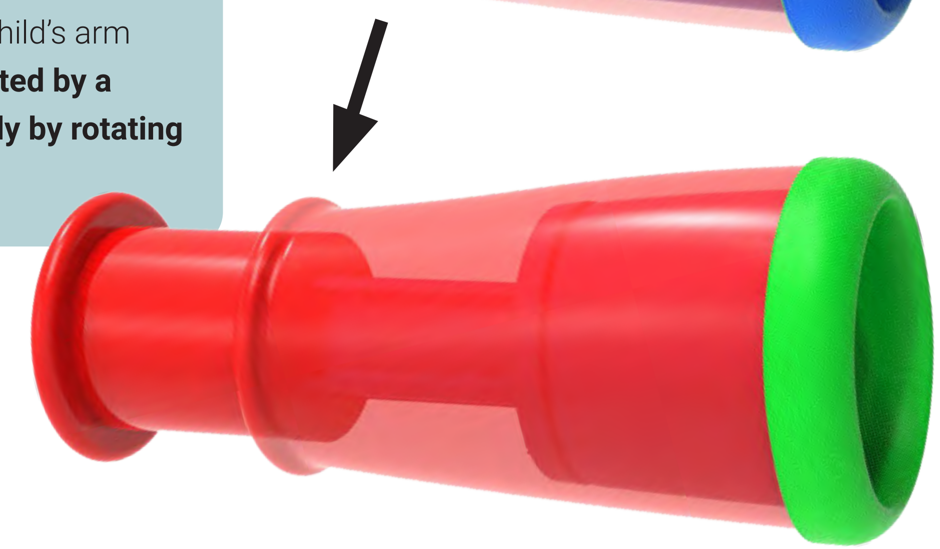
All the hardware is **responsible for the extension** aspect of the forearm.

The shell is attached to the inside components by being **ultrasonically welded** to the extension insert.

The socket color can change as much as desired.



All components inside the shell are **completely replaceable**, but the only part that is **frequently replaced is the socket insert.** As the child's arm lengthens, the bolt is **adjusted by a prosthetic specialist simply by rotating the bolt on the inside.**



Socket Development

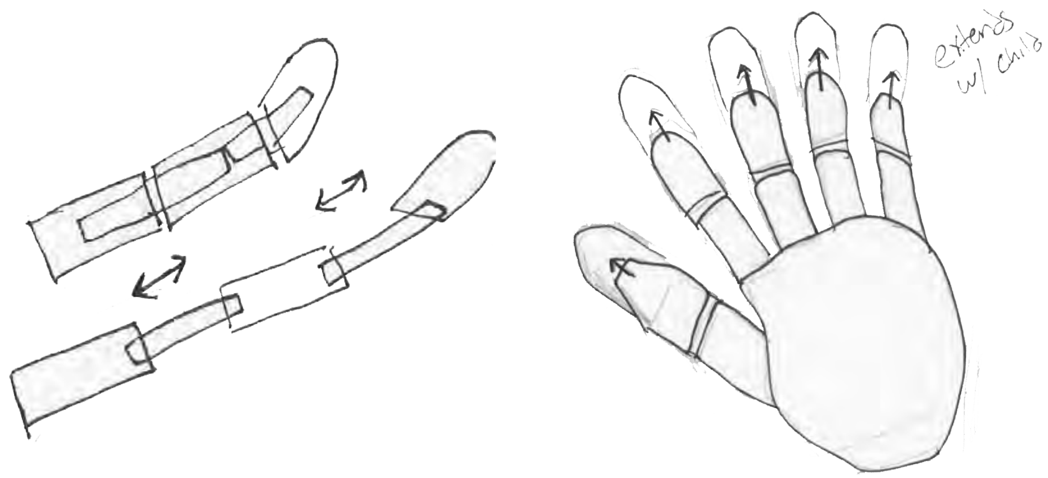
Hand Development

Armband Development

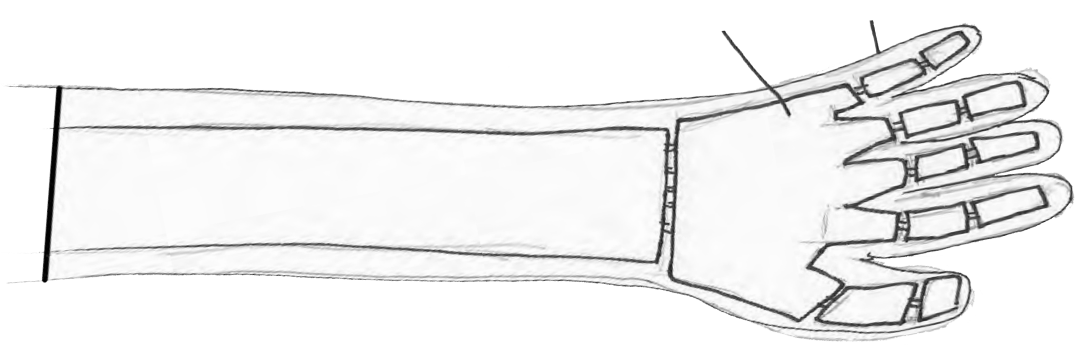
Forearm Development

Growing the Hand

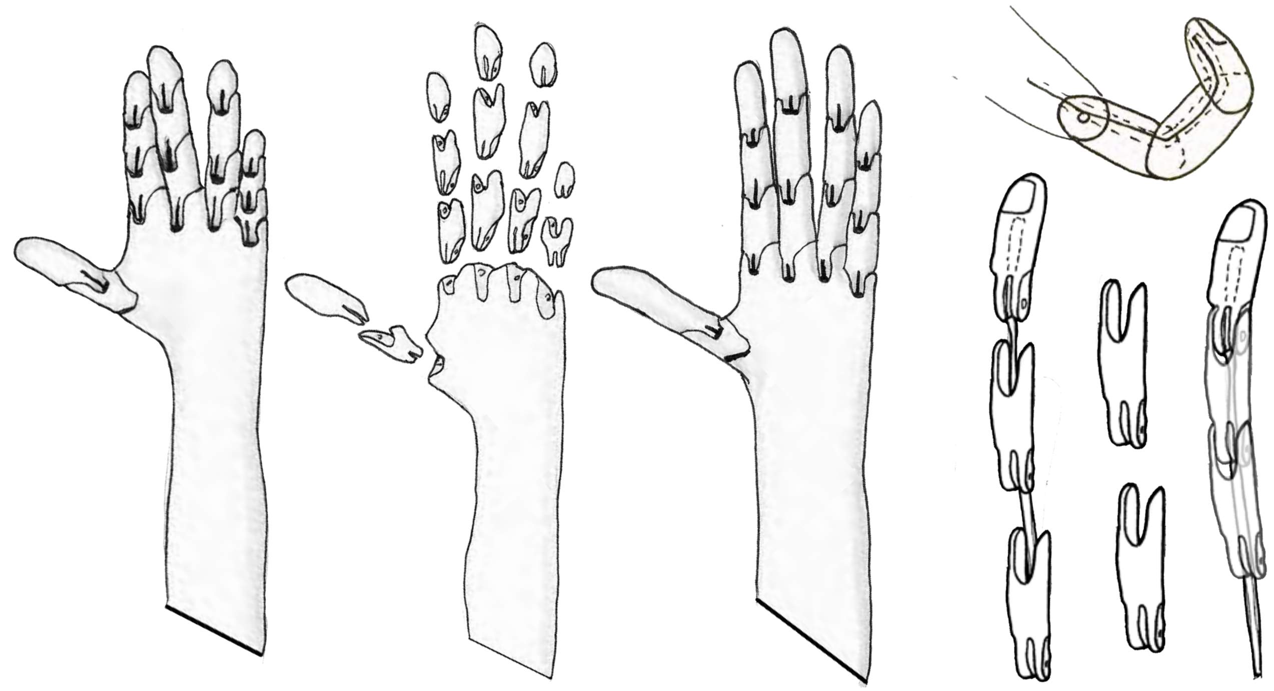
As the forearm extends, there needs to be a way to have the **hand grow as well.** We started to ideate and develop sketches for concepts that could **increase hand size and fuctionability as the child increases in size and mental capacity.**



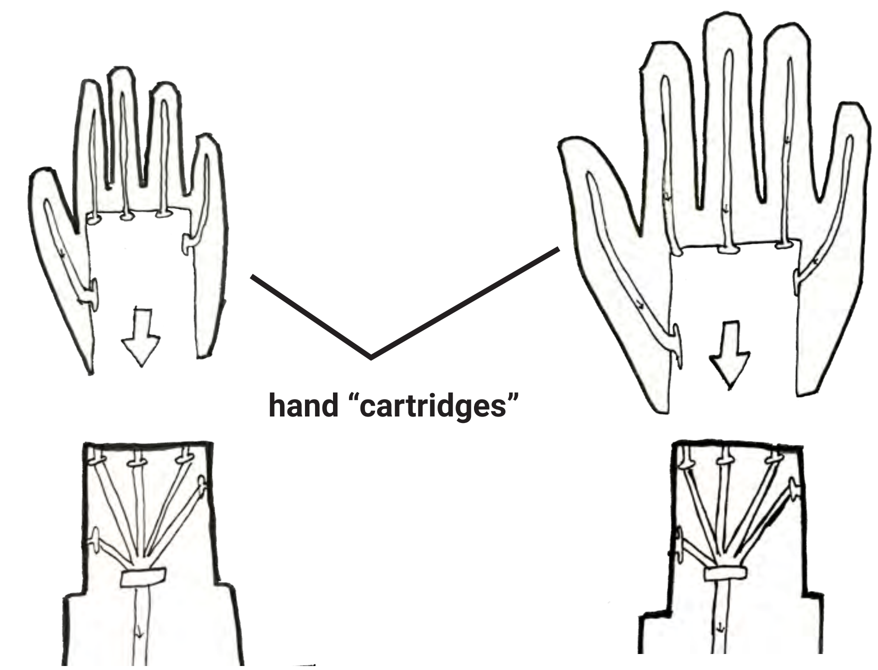
We explored ideas where the **fingers would simply extend** as the child requires a larger hand.



A **replaceable silicone skin would be able to cover the hand** as the child grows. This is not very ideal and would create a lot of waste.



We also looked at ideas where the **fingers would be replaecable and could snap in place**. A wire in the middle would allow for the fingers to remain in place when adjusted.

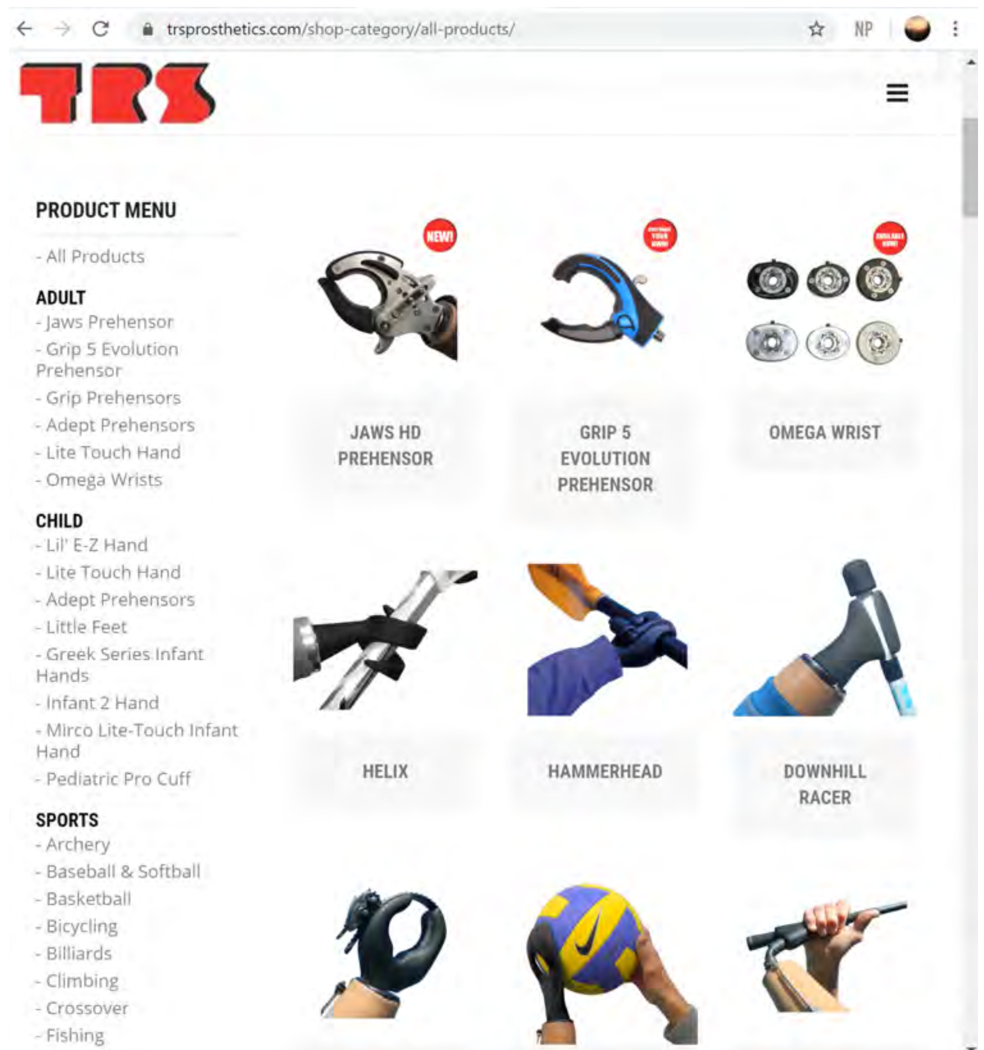


Only adjusting the fingers does not accommodate for the overall growth of the child. **The entire hand will need to be replaced,** which unfortunately creates waste, but is the most beneficial to the child.

TRS Prosthetics

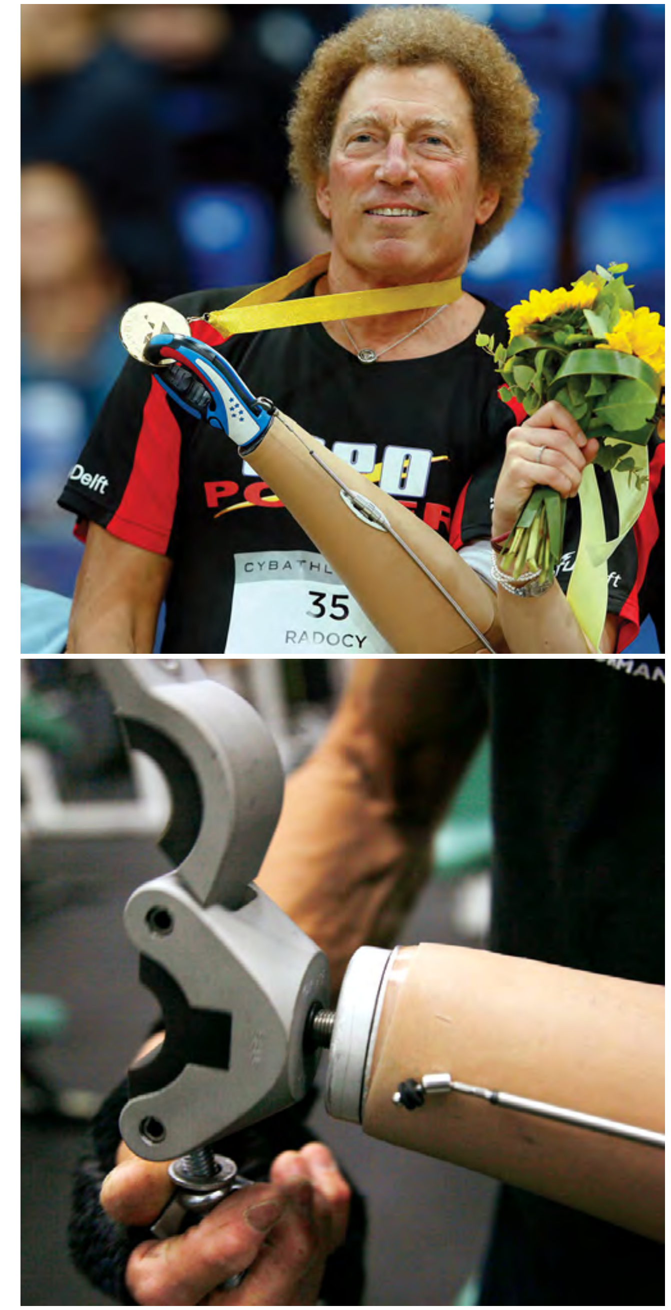
The **hand structure is much more complicated** and would require a lot more time than what we have to develop it. Struggling with how to continue with this part of the project, **we reached out to Hanger Clinic**, and talked with prosthetic specialist Joe Kersh.

Joe directed us to **TRS Prosthetics.**

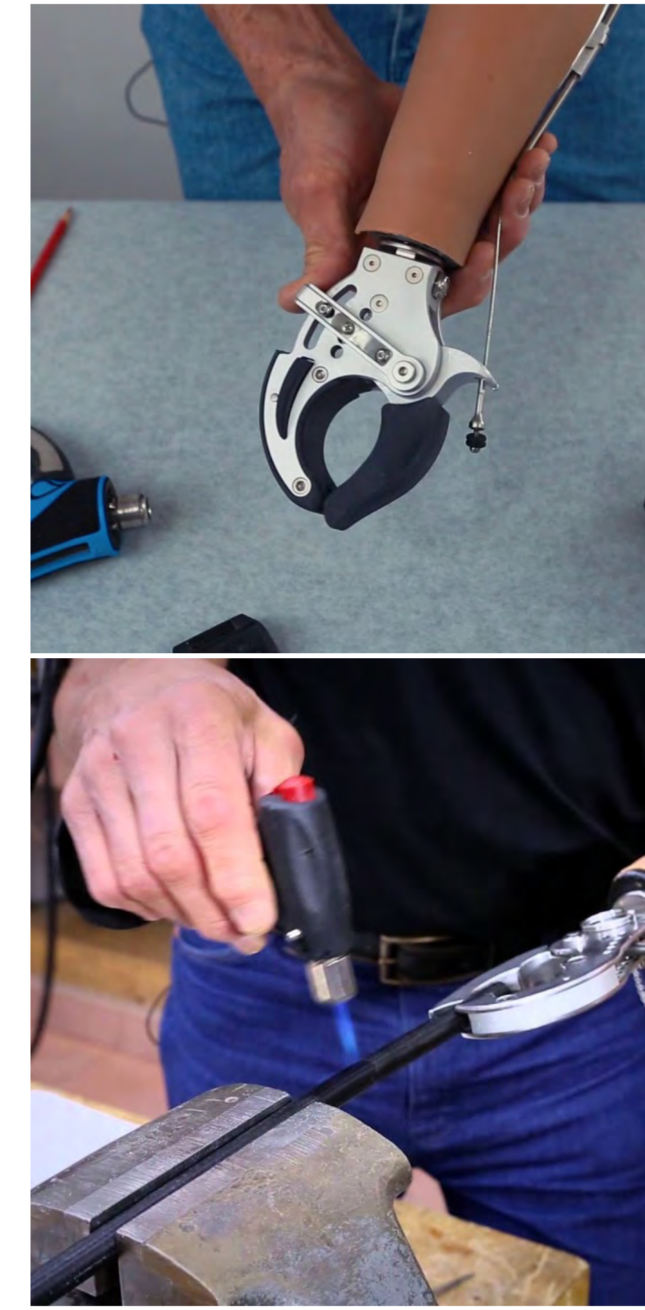


TRS Prosthetics is a Colorado based company that **specializes in prosthetic appendages.** They create prosthetics for **hundreds of different uses** for people of all ages.

Althetic Use



Workshop Use



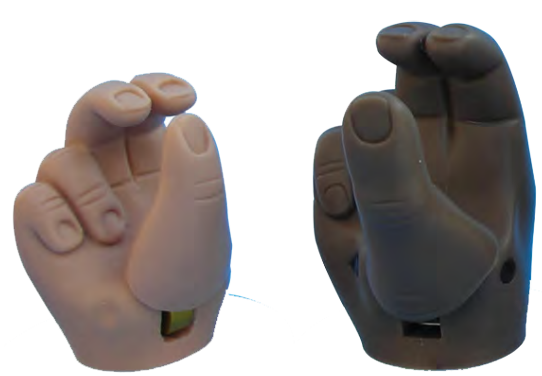
These prosthetic appendages **secure to any prosthetic** that utilizes it's standard attachement. They are designed for specific purposes that allow for a **variety of different activites without needing to change out an entire prosthetic**. Althetic and workshop use are just a few examples.

TRS Pediatric Prosthetic Appendages

Rather than redesigning a system that already exists, **we can incorporate this existing line of products to fit our needs**.

Greek Series Hands

A stationary hand intended for **cosmetic purposes.**



Micro Like Touch Hands

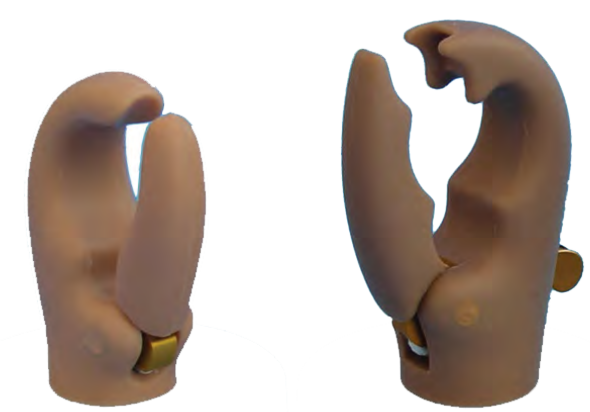
The thumb can open and close to **allow for grip.**

Lite Touch Hands

The thumb can open and close to allow for **grip for larger children.**

Infant 2 Hands

A stationary hand that allows the child to **hold items easily in the palm.**



Adept Prehensors

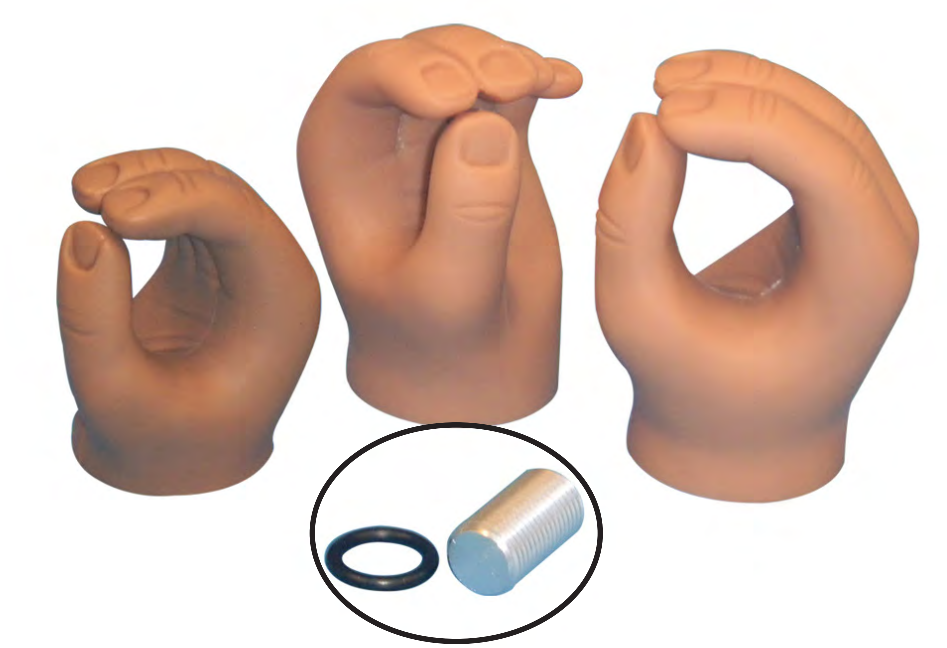
A hand that allows the child to **grip items such as pencils.**

We can utilize this company's product with our design in order to **reduce the amount of waste produced,** and allow for as many uses as prosthetic appendages available.

TRS Prosthetic Attachments

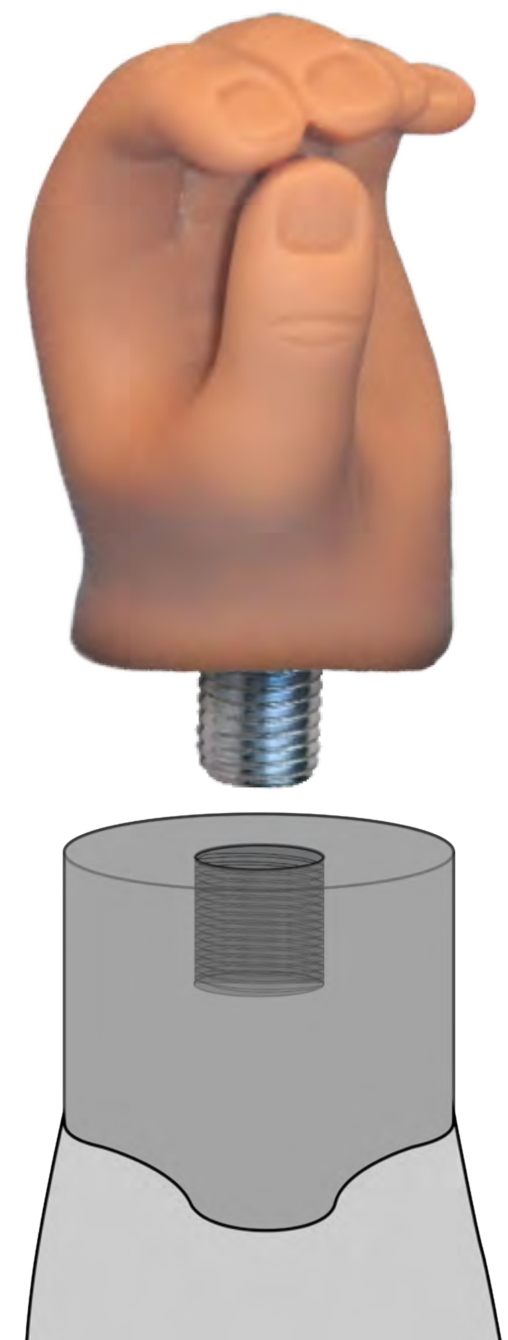
TRS Prosthetic appendages are intended to function exactly as we had planned for our system. **By utilzing the pediatric appendage catalog, we can incorporate this attachment mechanism to our forearm.**

These pediatric prosthetics attach to standard prosthetics with a **1/2" bolt to create a simple attachment.**



This **bolt comes with the prosthetic** when ordered from TRS.

We can easily **adapt our prosthetic to fit with this attachment** in order to use these appendages.

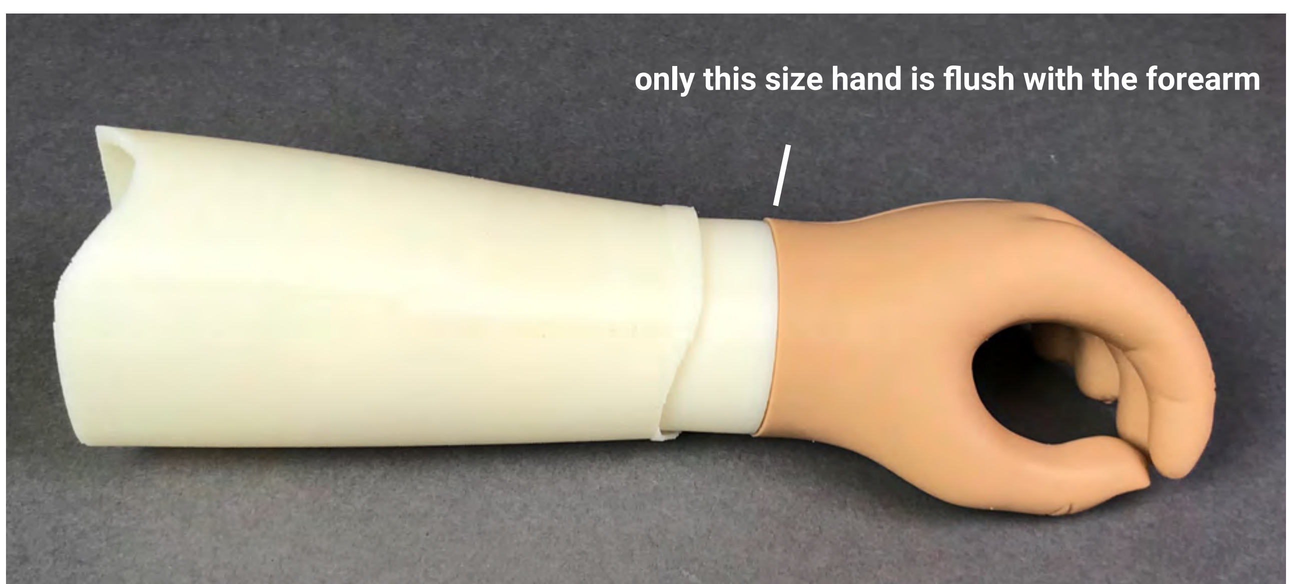


The **receiving end** of the attachment only needs to fit this 1/2" bolt.

The prosthetic can get **screwed into the extension** component of the forearm.

Adapting the Forearm

We tested to see how the hand fits with the forearm, and it worked as we expected. In this test, we printed the bolt, testing out how it would work if the bolt is permanently attached instead of being screwed in.



What we realized during this testing was that **as the hand is changed out for larger more sophisticated hands, the diameter will start to look strange** if they are not lined up properly.

The simplest way to prevent the prosthetic from looking awkward is to **break up the space intentionally.**

Through sketchings, we explored various ways we can **intentionally create a break in the prosthetic** between the forearm and the hand.

Connecting the Components

After exploring various forms of how to break up the space, **we settled on a concept that has a playful feel.** This is intended for young children, so creating it to be **round, without any sharp corners or shapes,** works well with the prosthetic.

Round playful division in the prosthetic helps **appeal to children.**

We did **not want the prosthetic to look exactly like a forearm.**

Children with these challenges should feel **empowered from the prosthetic** and want to stand out.

Prosthetic forearm with various other hands that are **capable of screwing into the prosthetic.**

Socket Development

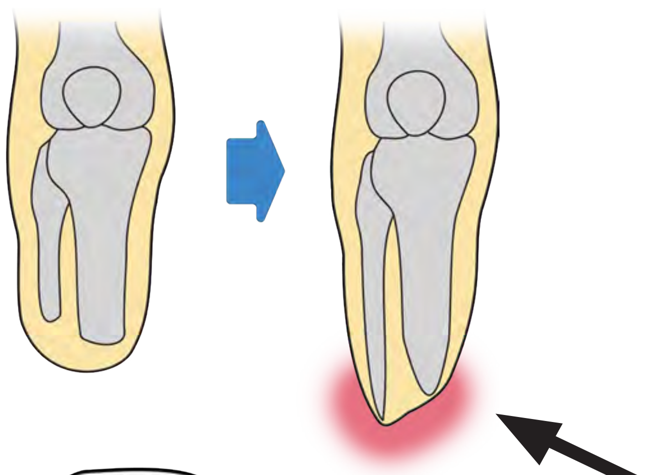
Hand Development

Armband Development

Forearm Development

Overgrowth

Dr. Ranade is a **Pediatric Orthopedic Surgeon** at Mount Sinai Hospital in New York City.

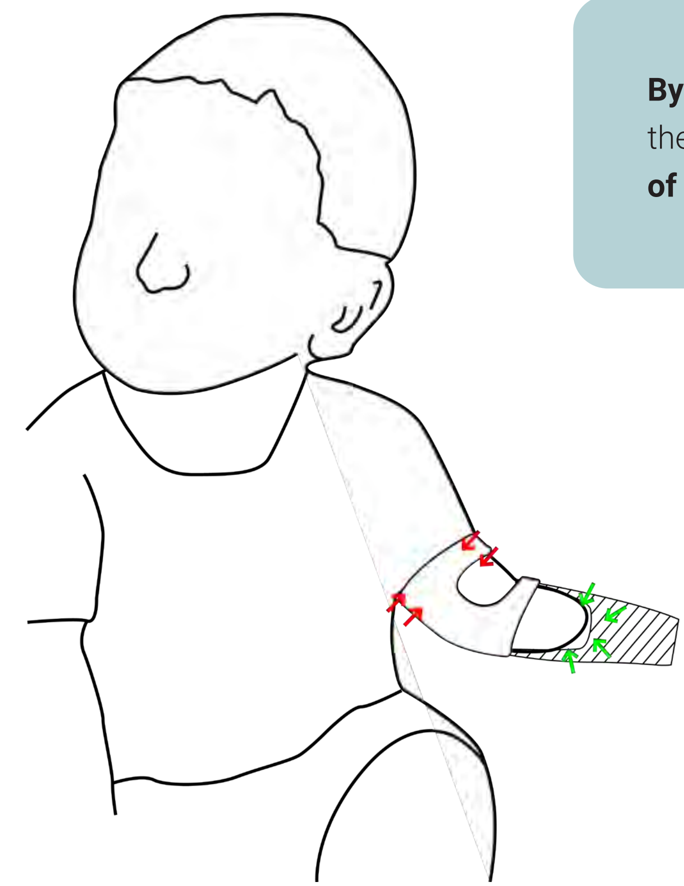


She pointed out an opportunity to **combat overgrowth** when designing a transradial child prosthetic.

Overgrowth is caused by **too much pressure on the limb** during growth.

"Using the upper extremity is smart because the forces are less."

By transferring the pressure from the limb to the bicep, we are able to **reduce the changes of overgrowth** with this prosthetic.



Armband Inspiration

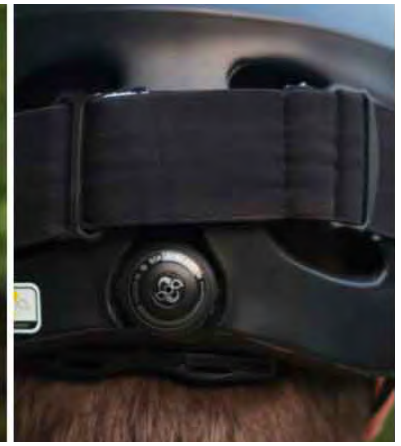
We started to look at armbands that currently exist to learn about how they are **secured to the body.**

A lot of arm bands use **velcro as a securing method, but we may need a more secure method to attach a prosthetic.**

A very **common securing** fastener on these armbands are **boa fasteners.**

Many products use boa fasteners as **replacement for other tightening mechansism.**

Shoes are one of the most common product that use boa fasteners.



They are also used in **helmets** as a way to tighten to the head.

Many products that need to be **secured to the body** are great for this use.

Boa Fastener

Boa fasteners work by **turning the dial** to to either **pull in or push out a wire** with an internal ratcheting effect.

Boa fasteners are devices that **secure many soft good products to a person.** Some of its features include:

Easy to tighten by rotating the dial.

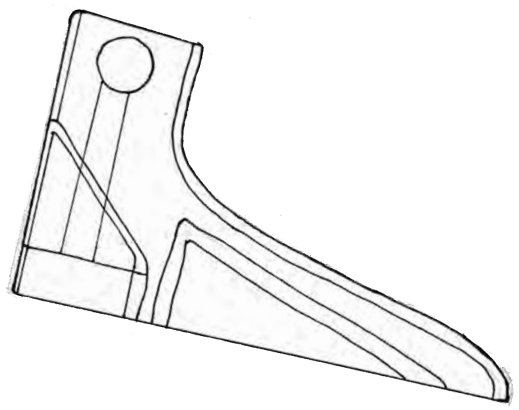
Compact and fit in small spaces.

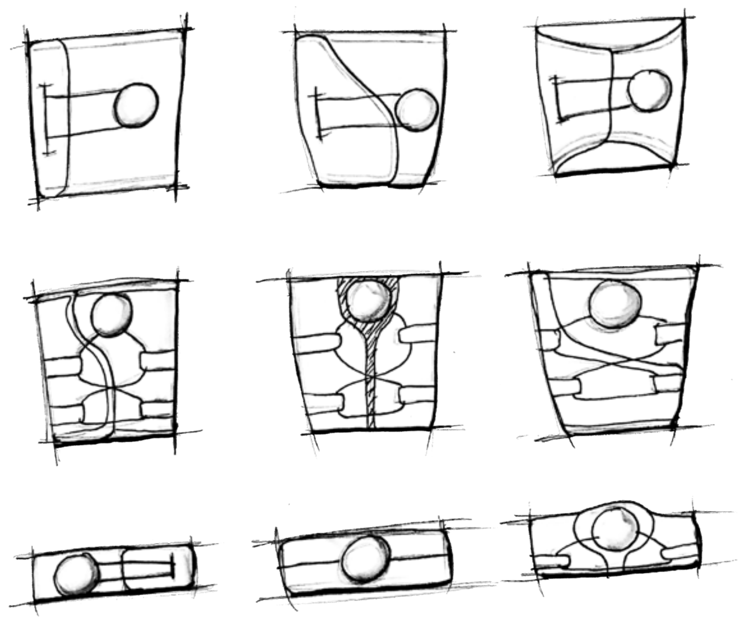
Tight fit on many products.

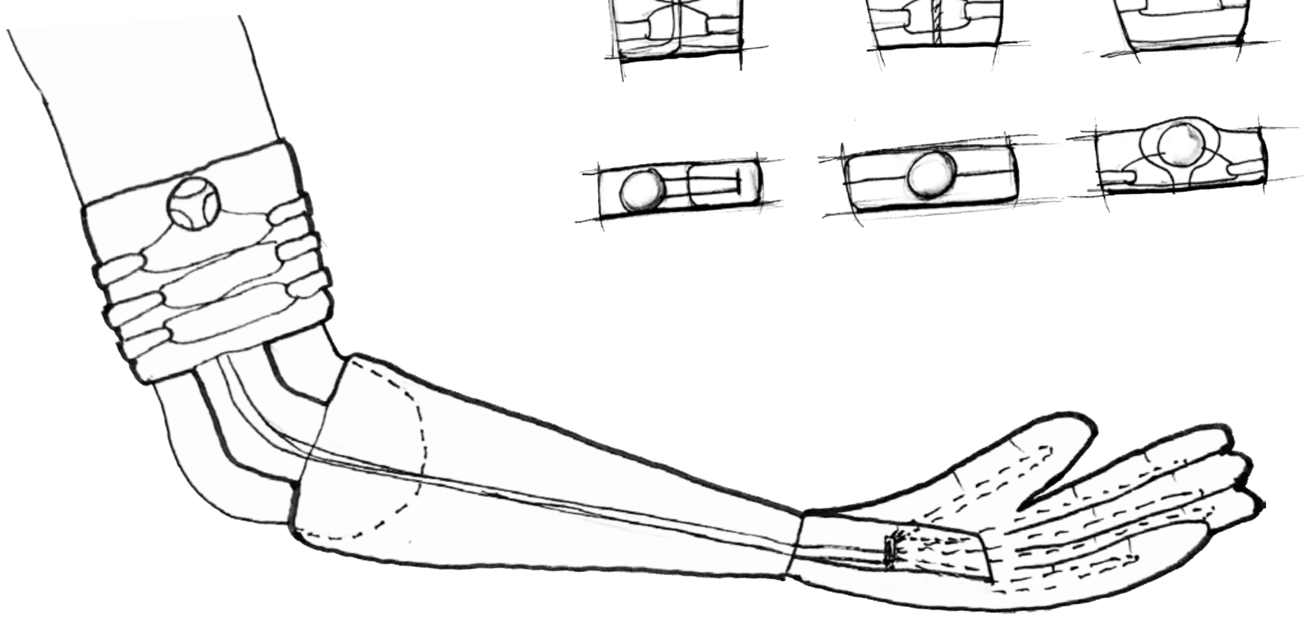
These features make boa fasteners **great for securing a prosthetic on a person**, as confirmed by Joe Kersh.

Developing the Armband

We started to sketch armbands that would **incorporate the boa fastener**, as this is a good way to **secure the prosthetic to the body.**

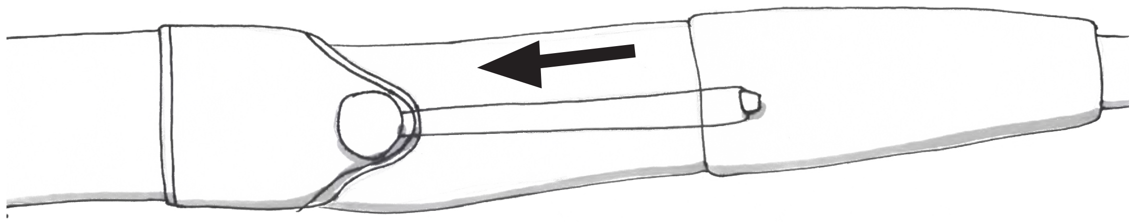


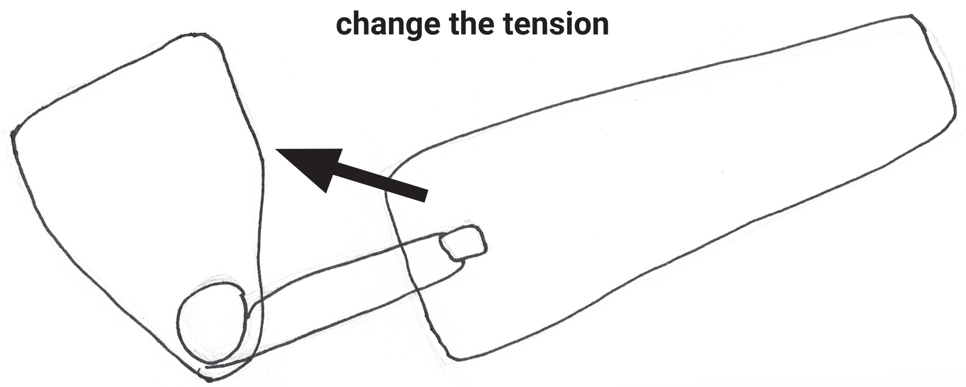


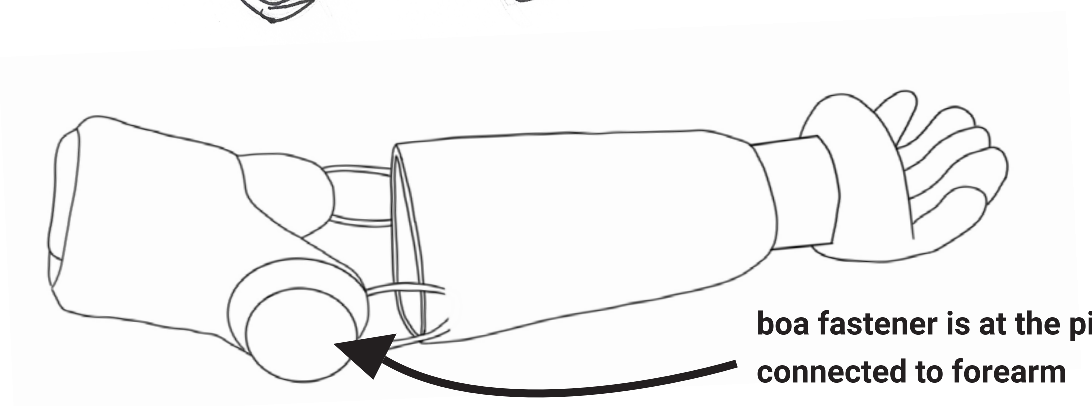


These current ideas utilize the boa fasteners to **tighten around the bicep**. We chose not to use simple velcro because **the boa fastener is better at tightening.**

Keeping the tension between the armband and the forearm is very important because it is keeping the forearm securly attached to the patient. We need to accommodate for the bend in the elbow and to make sure the tension does not change.



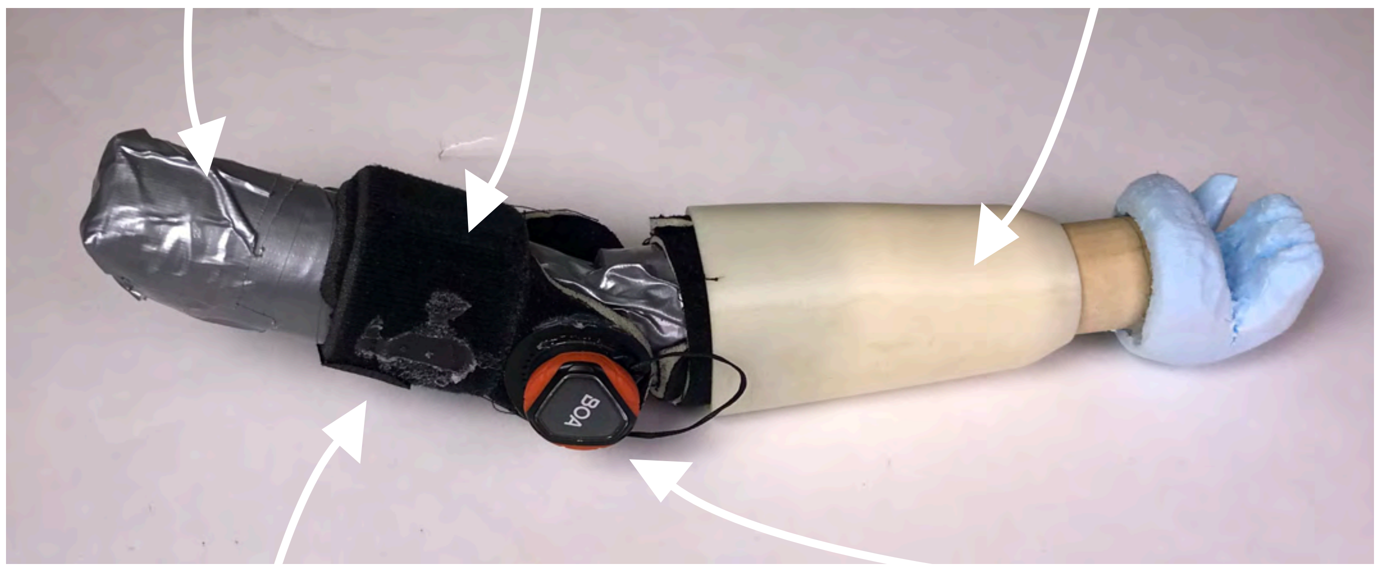




Our first concept that we believe might solve this problem was having the **boa fastener itself connect to the forearm, and putting the fastener at the pivot point** of the elbow. This could protentially prevent the tension from changing around the elbow.

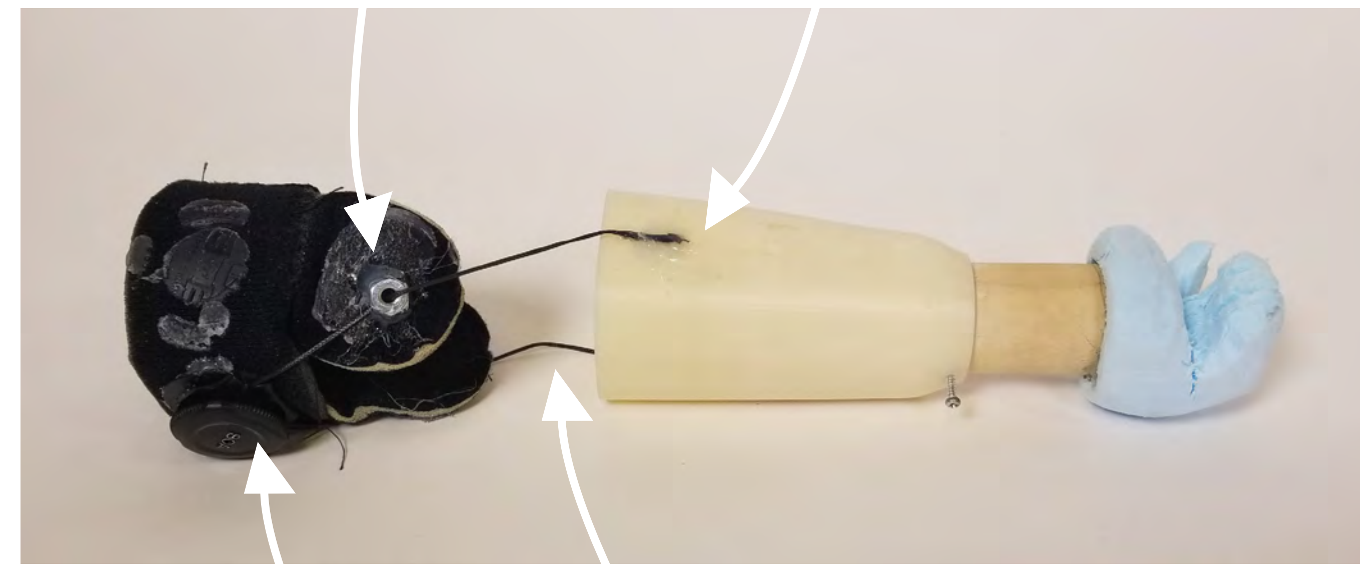
Testing the Armband

We tested this concept with a rough mock-up to see if **having the fastener at the pivot point would help with the tension,** and to test the overall bulk that this would create.



After testing, **the tension was not really working**. The armband connection seemed **too loose and the armband itself was bulky** with two boa fasteners around the elbows

Based on our previous test, we **updated the armband** to test the changes.

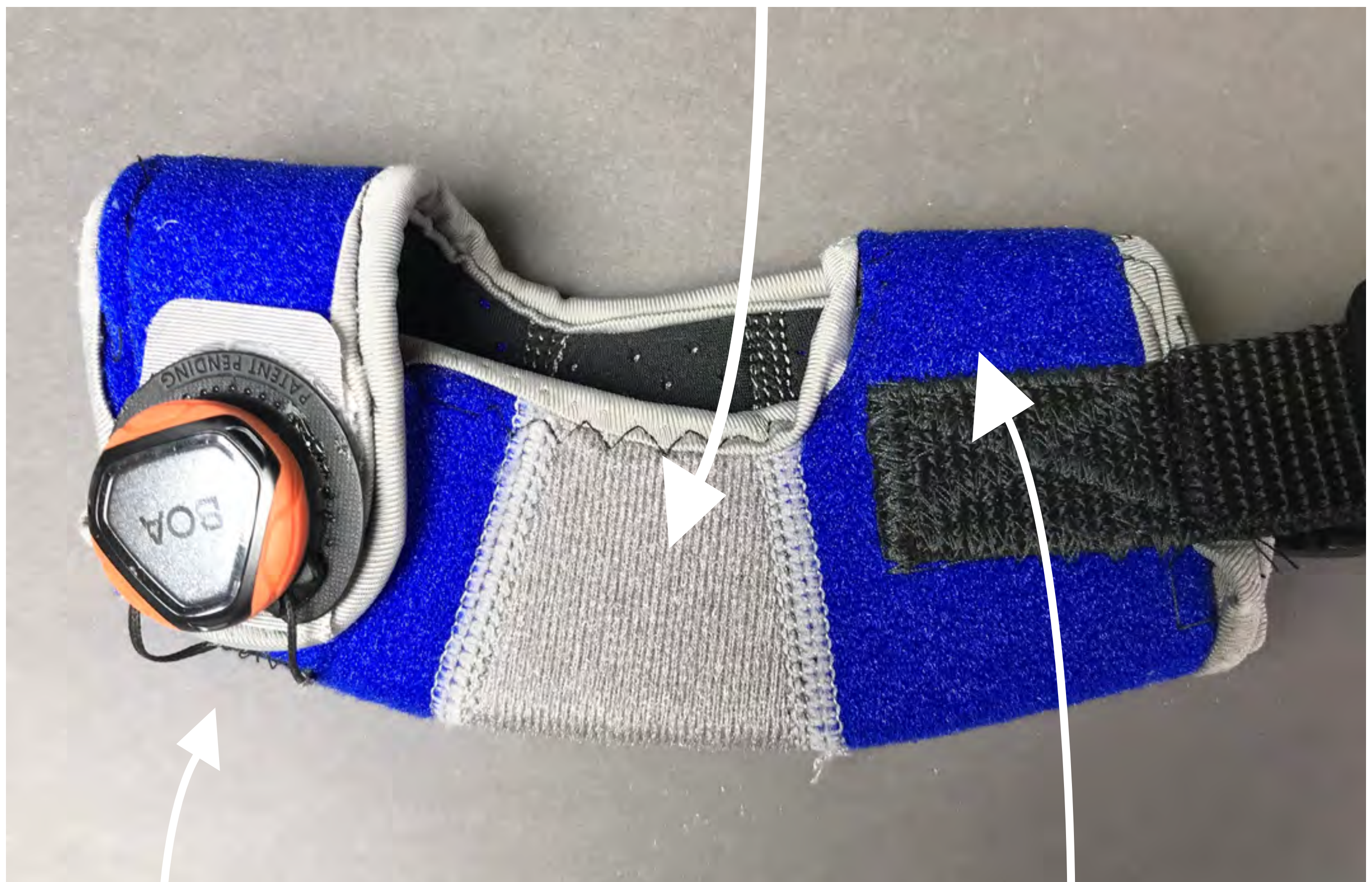


We then tested our concept with a single boa fastener in the back. The **wires would fit around the armband** to create a joint at the elbow bend. **This also did not work correctly.**

Testing the Armband

We learned from the previous tests that the **bend in the elbow is important.** After doing more research, we realized that **elbow braces might be good inspiration** for having a band that can be **both flexible and supportive.**

elbow fits here



boa secures the back

velcro secures front on other side

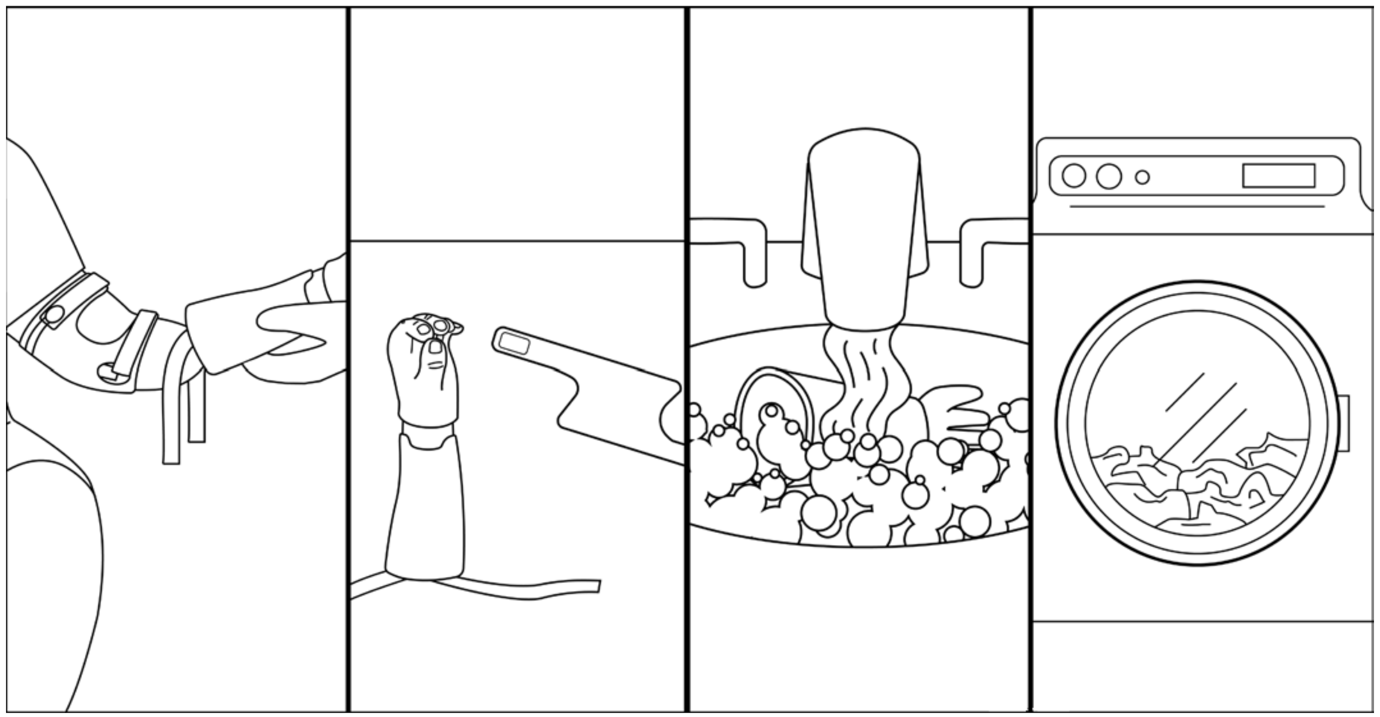
This concept worked well, as there was **easy flex around the elbow,** as well as **two points of connection on the armband**. A boa fastener is used at the end by the bicep and the lower part can simply be held in place with velcro.

Whole System

Proper Sized Armband

Connecting the Armband

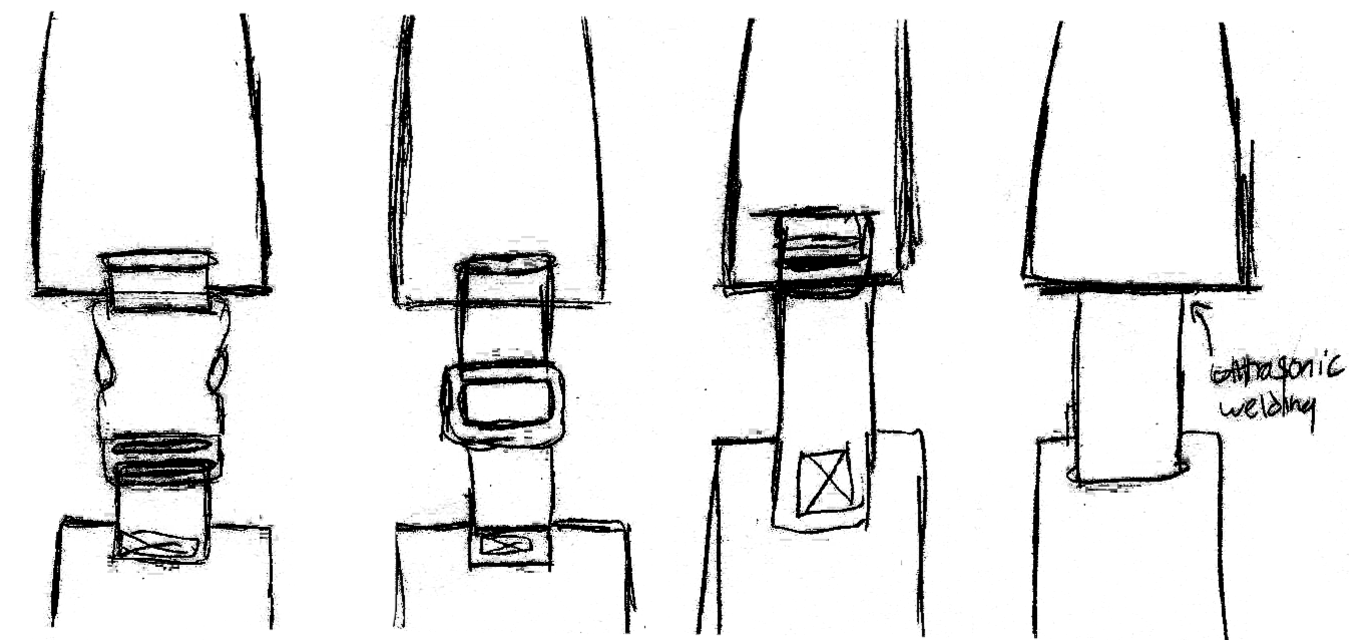
The elbow brace concept solved many of our concerns with the first few ideas. Since we are able to get the joint in the eblow to rotate well while also securing the armband to the arm, **we needed a way to connect the armband to the forearm.**

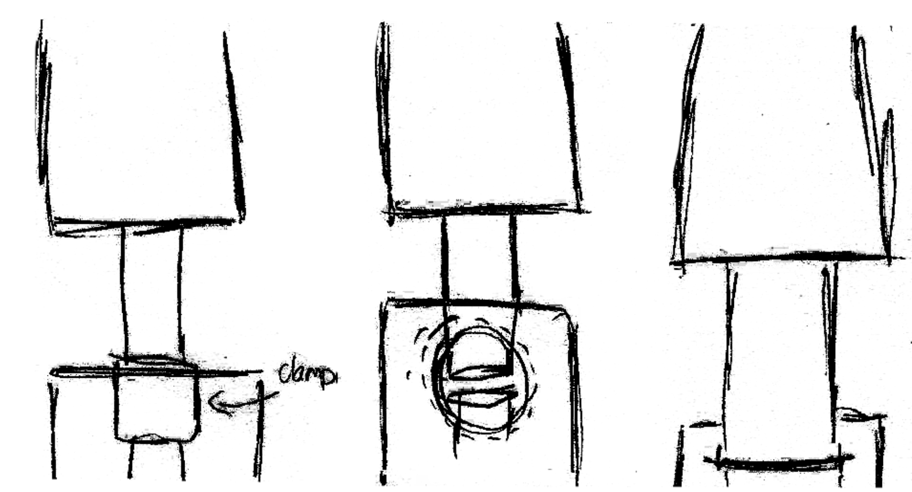


Remove Prosthetic | **Separate Components** | **Wash Forearm with Soap and Water** | **Wash Armband in Washing Machine**

Prosthetic Specialist **Lauren Rossi informed us that the hygeine of the prosthetic is extremely important.** The prosthetic should be removed by a parent every night. The **forearm of our prosthetic needs to be washed in soap and water every night,** while the armband needs to be washed occasionally.

Separating the forearm from the armband must be **as simple as possible because parents need to remove it every day and attach it every morning.** We explored a variety of different mechanism that would connect the forearm and armband together with **straps.**



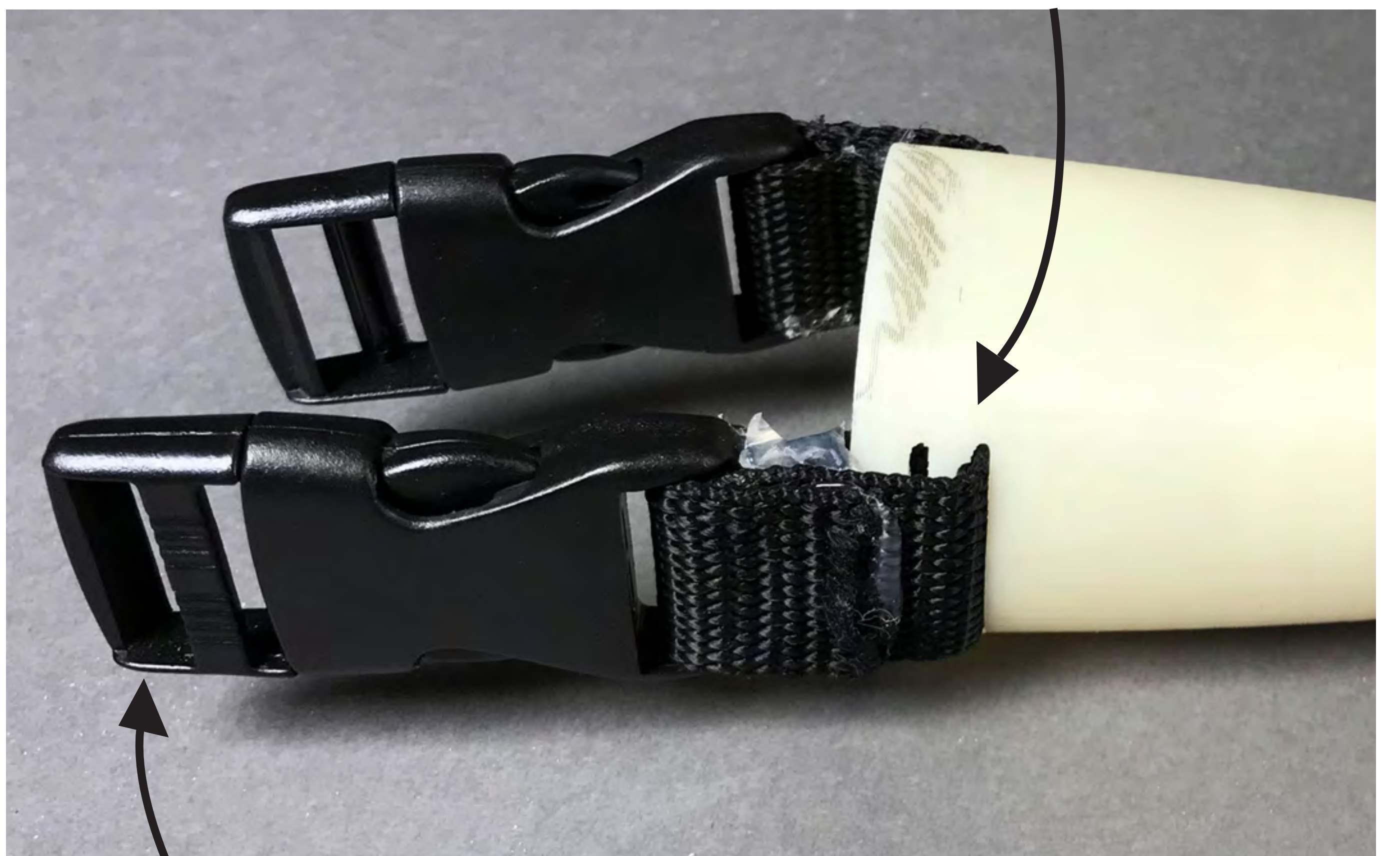


We explored concepts such as **buckles, straps and holes** in the prosthetic to wrap around and tighten.

Connecting the Armband

We first tested the **side release buckle concept**, which is a **common method to secure straps.**

These buckles would attach to straps that **loop through holes** in the forearm.



We specifically chose buckles that have the capability to **adjust the length** of straps on their own.

Buckles Attached Together

strap is sewn onto the armband

Buckles Separated

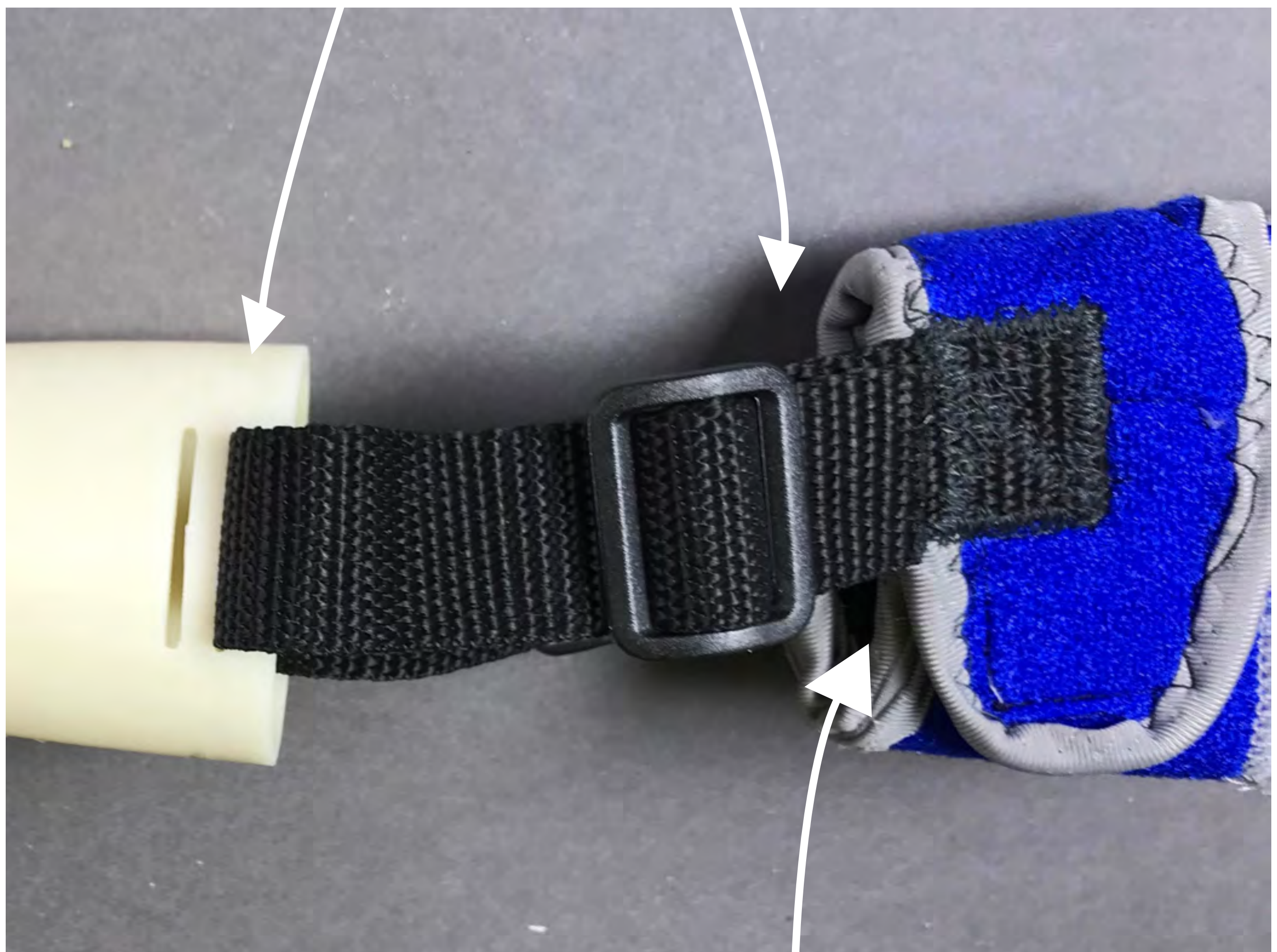
There is a lot of **leftover strap. This is necessary to be able to make length adjustments,** but might be distracting if dangling.

Overall the side release buckles were **functional, but tended to be too bulky** and do not really allow for any aesthetic exploration.

Connecting the Armband

We tested a slide buckle that could potentially **reduce the amount of bulk** and hold any leftover strap that is sticking out.

The strap wraps around a hole in the prosthetic and **loops back to the hardware.**



The hardware holds the **extra strap.**

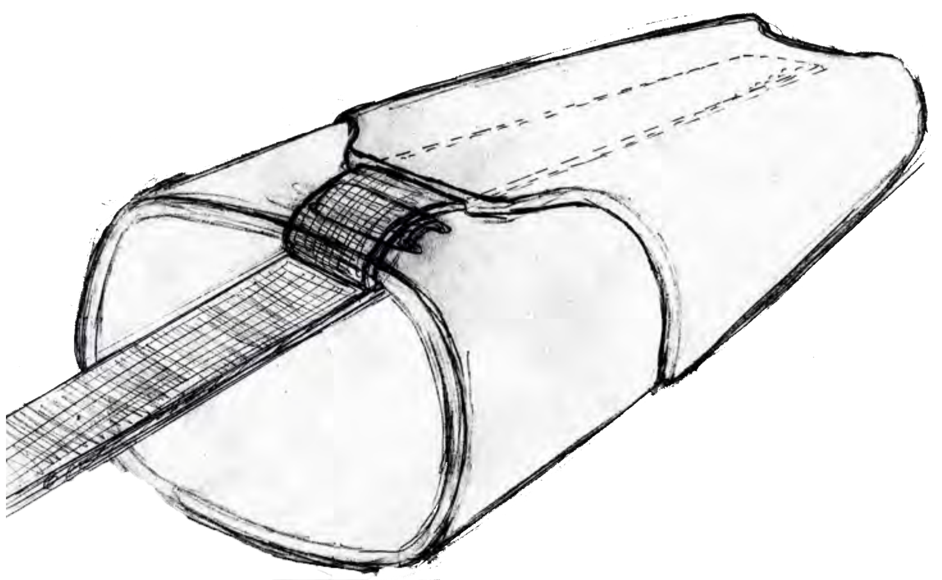
Top View of How the Straps all Connect

Side View of Prosthetic

This type of connection worked better than the previous buckles but is **not as intuitive to use as the side release buckles.**

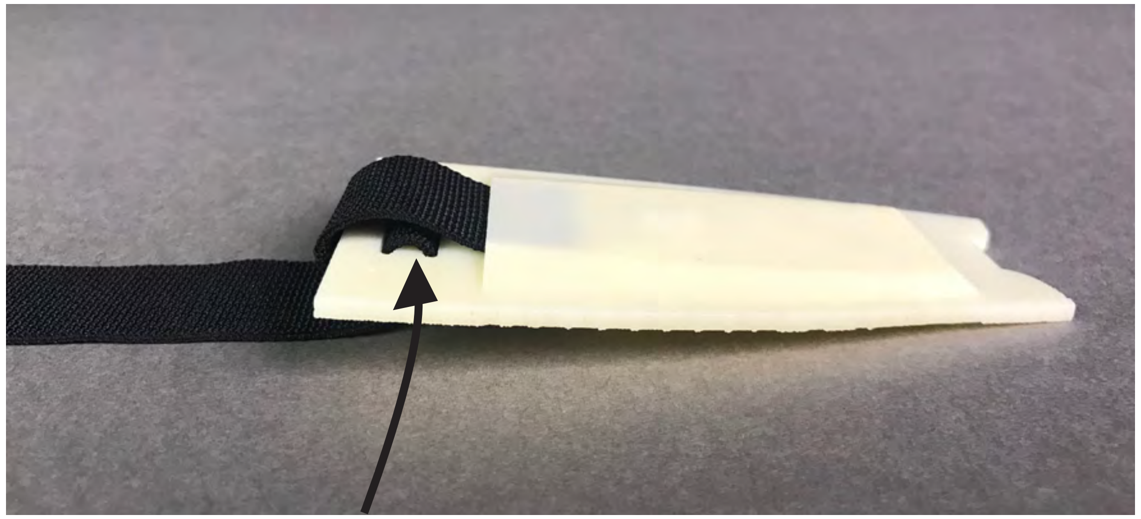
Connecting the Armband

We then explored the concept of the **holes in the forearm** that we included in the previous exploration concepts. The two holes that are in the prosthetic act as a **securing and tightening mechanism** similar to the previous concepts.



We **printed a test** to see how this idea would function.

This proved to be very **secure and tight fitting**. The **pocket that we included on the prosthetic test helped to prevent extra straps from being intrusive** on the child's movement.



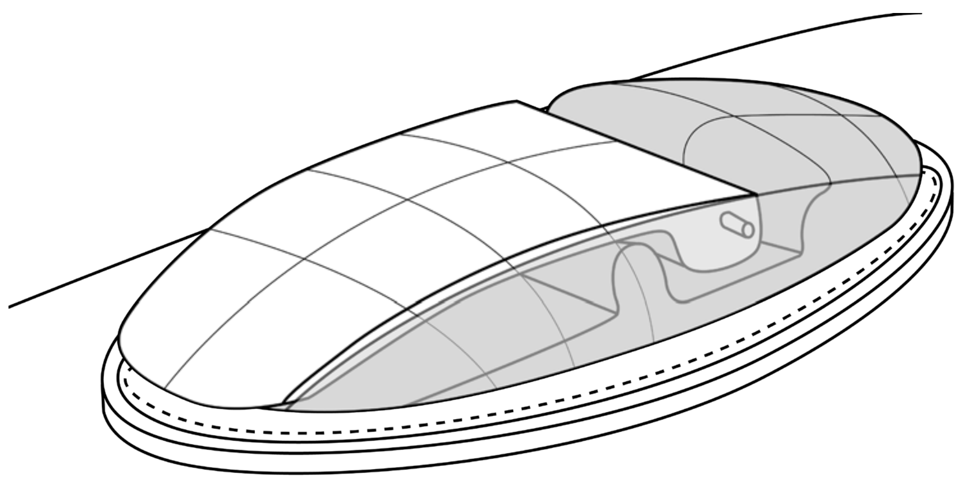
The strap loops around the holes and can **get tightened or loosened.**

Extra strap can get held in printed pocket

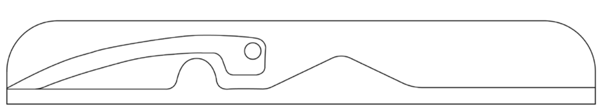
The drawback of this concept was that the **straps are still very bulky on the inside** of the prosthetic, and would **affect the fit** on the child.

Connecting the Armband

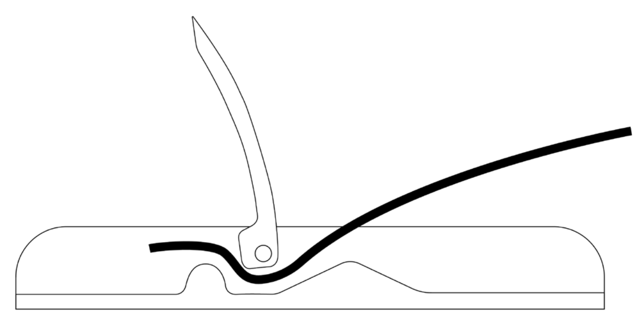
We tested a concept that would **reduce the amount of bulk in the straps**. This concept involved designing a clip that can secure the strap. Instead of the strap being sewn to the armband, it is attached permanantly to the forearm and straps into the armband.



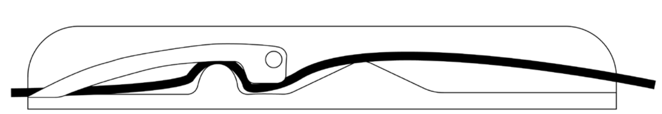
Snap Clip



Closed

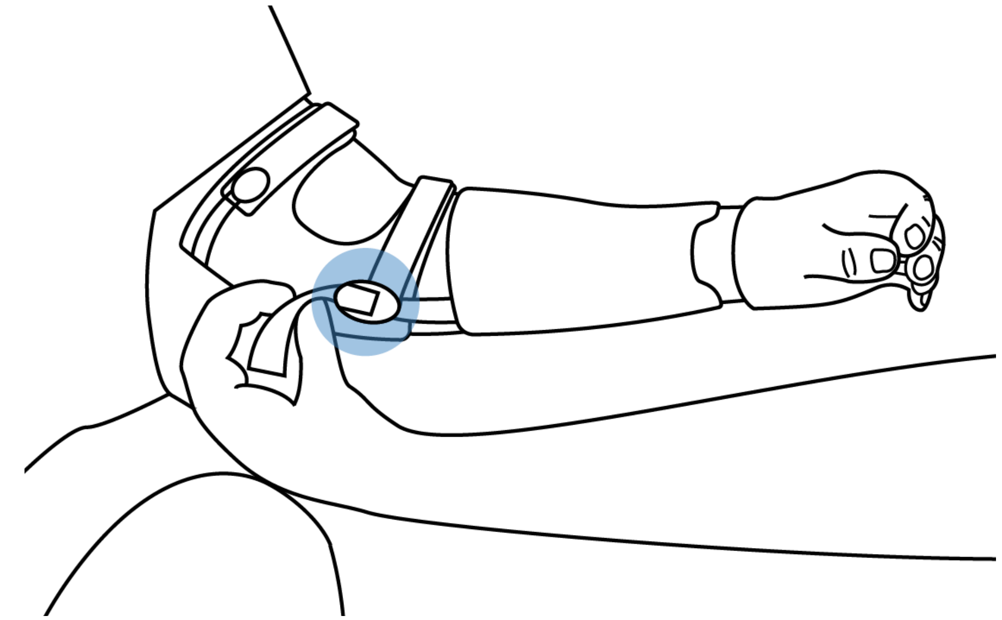


Open and Insert Strap

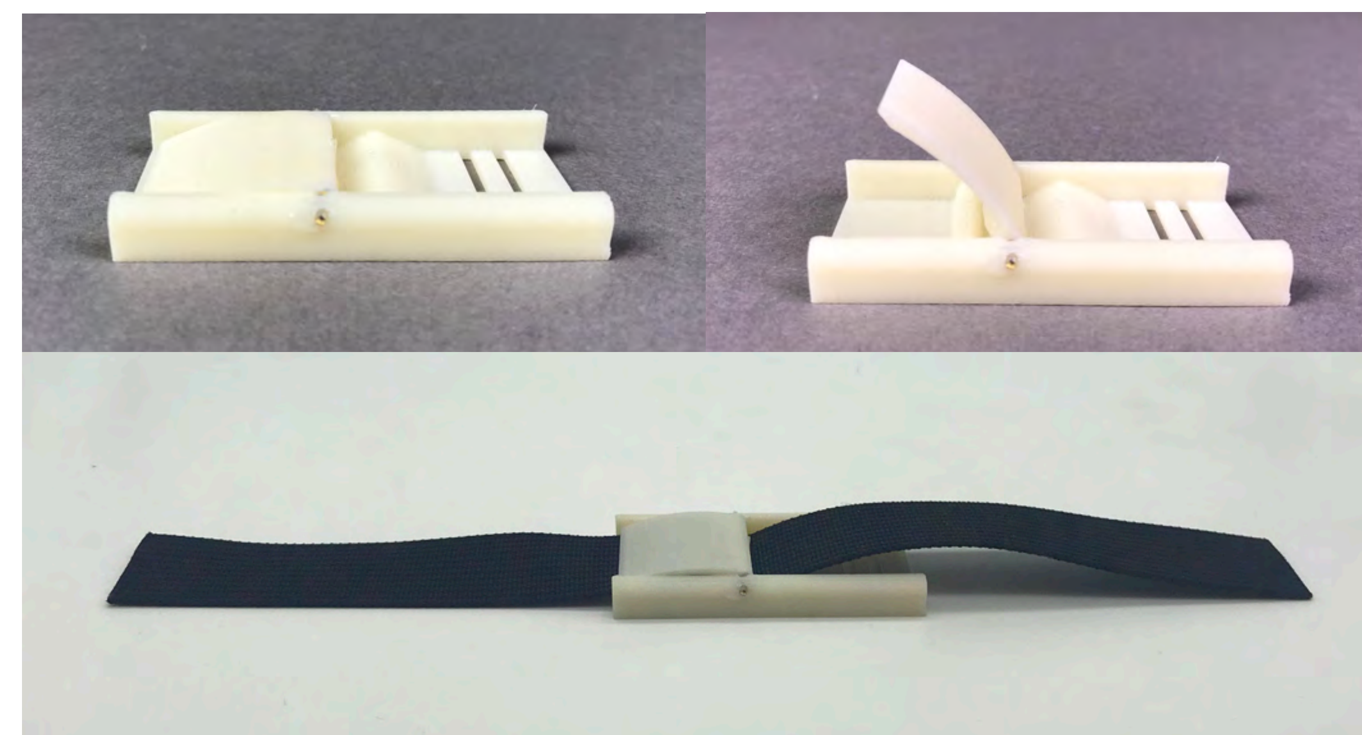


Close and Secure

The Clip is Sewn Directly onto the Armband



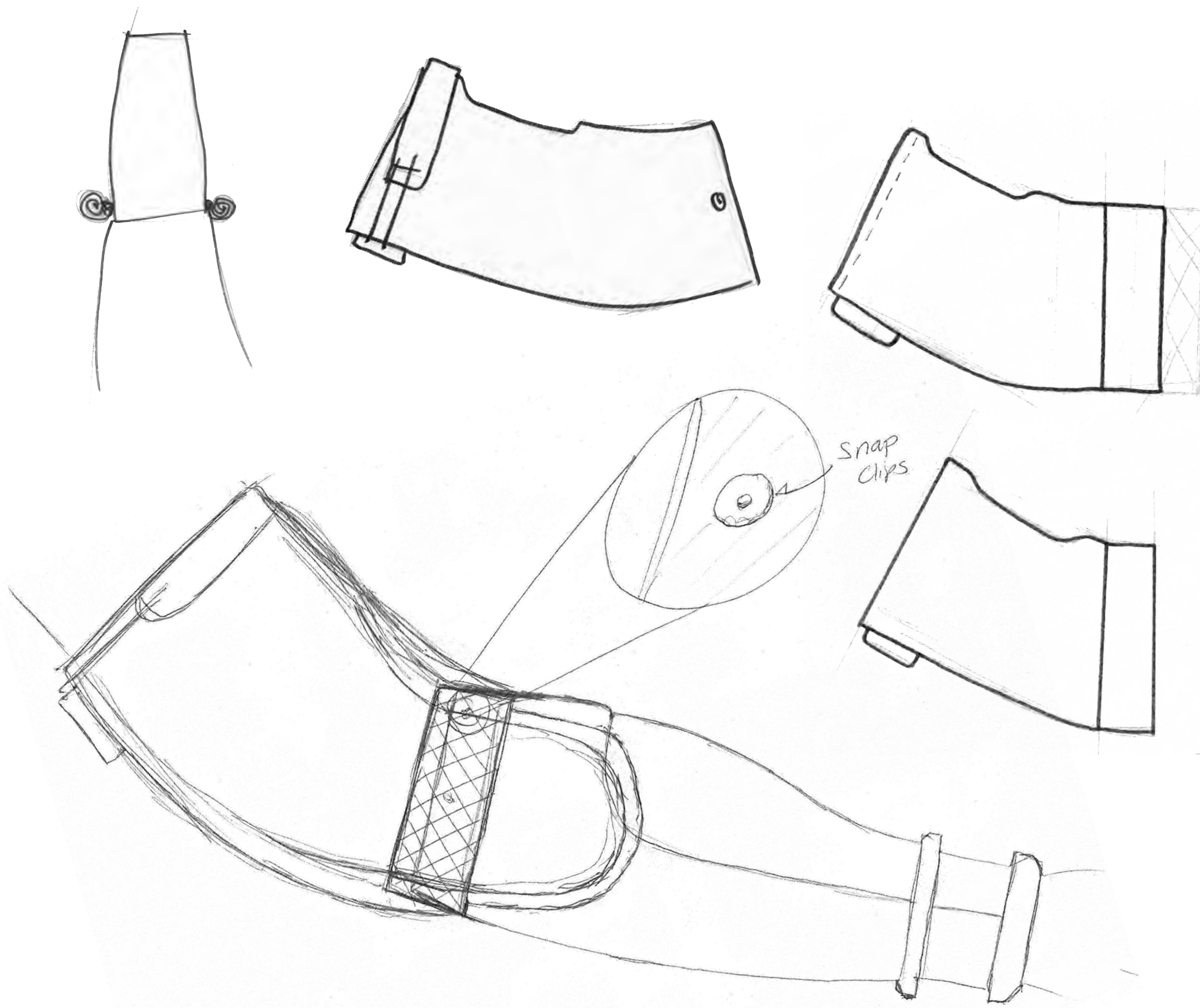
Testing the Clip



The snap clip worked well in concept, but it was at this point that we decided to **move away from using straps**. They did not add much benefit to the prosthetic and **only made connecting the two components more complicated.**

Connecting the Armband

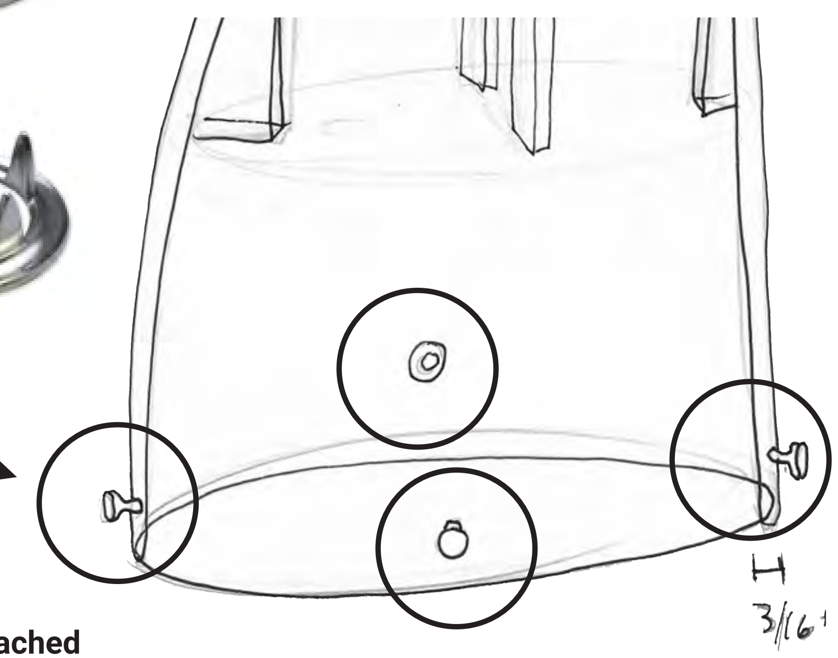
Moving away from straps, we sketched concepts that would be able to **connect the armband and the forearm together in a simple way.**



We discovered the armband **would be able to attach directly to the forearm by possibly snapping it together** with metal snaps.

Snaps would **not introduce any additional bulk** into the armband, and can connect to fabric.

This component would be attached to the armband.



This component would be attached to the forearm.

We can incorporate the **design of these snaps into the forearm** so that one metal snap can conenct directly to the forearm.

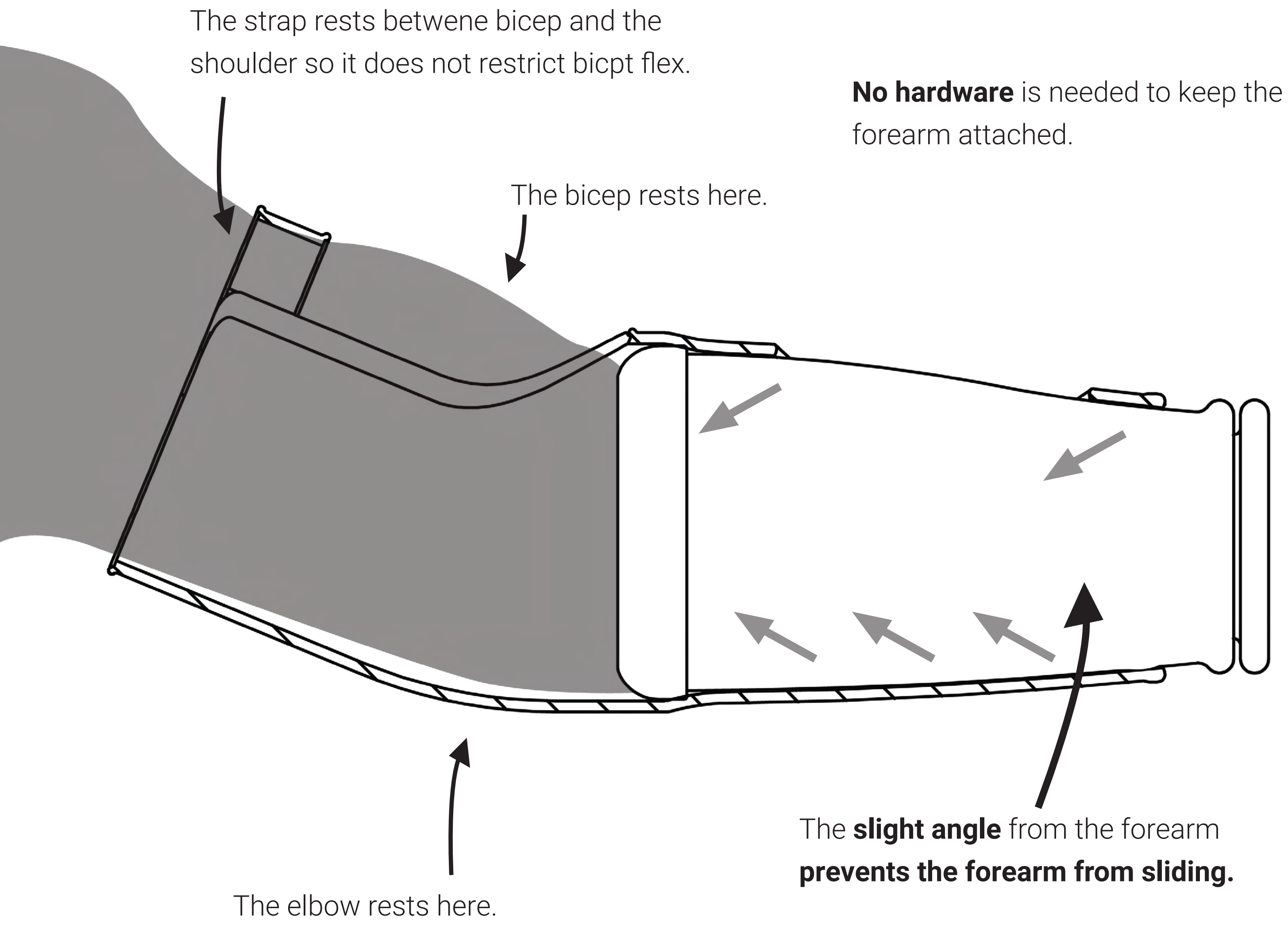
Connecting the Armband

We tested a variety of **different forms of armbands incorporating the snaps with the design.**

Using snaps **still added extra amount of bulk**, and our goal was to make this **as smooth of a transition as possible betweem the two components.**

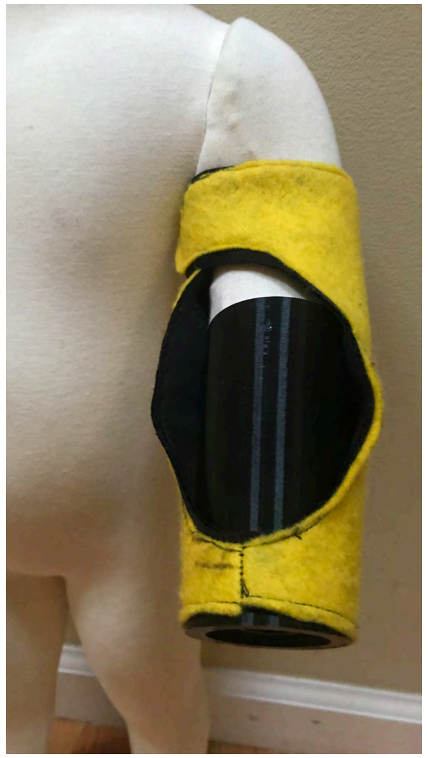
Connecting the Armband

After testing snaps, we realized that we could **utilize the slope of the forearm** and create a **tightly fitted armband** that covers the forearm as well.



This seemed really promising, as it would **incorporate no hardware, and seamlessly transition between the forearm and the armband.**

tight fitted to secure



wrap around band

This concept **worked well**, and was secure when testing it. This was very promising and seemed to show the correct path for connecting the armband and the forearm together with **as little hardware as possible.**

Final Armband Form

We created a prototype for the **armband in it's final form**. The result **satisfied all the requirements** we made to support the design.

boa fastener

boa fastener pulls strap to tighten

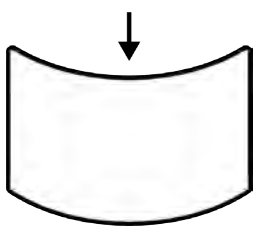
forearm fits here

armband secures the forearm well

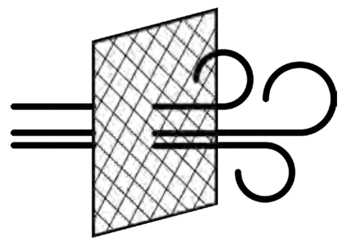
Here is the **whole system put together**, with the hand attached to the forearm and the forearm secured into the armband.

Material Choice

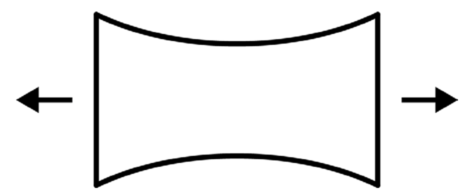
After understanding how the armband would attach to the prosthetic, we needed to understand **what materials would be best**. The material choice needs to be:



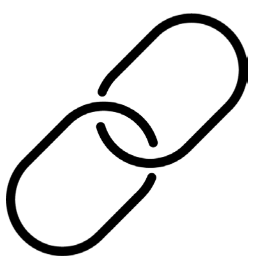
Flexible



Breathable

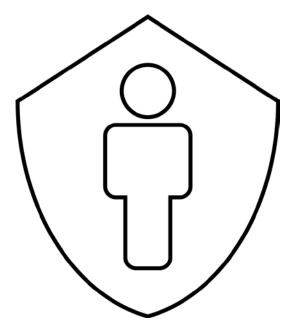


Stretchable

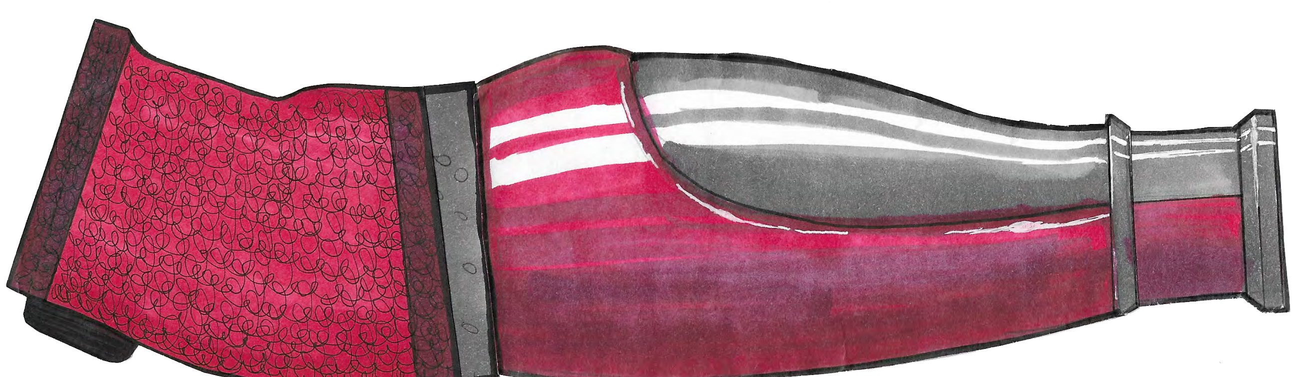


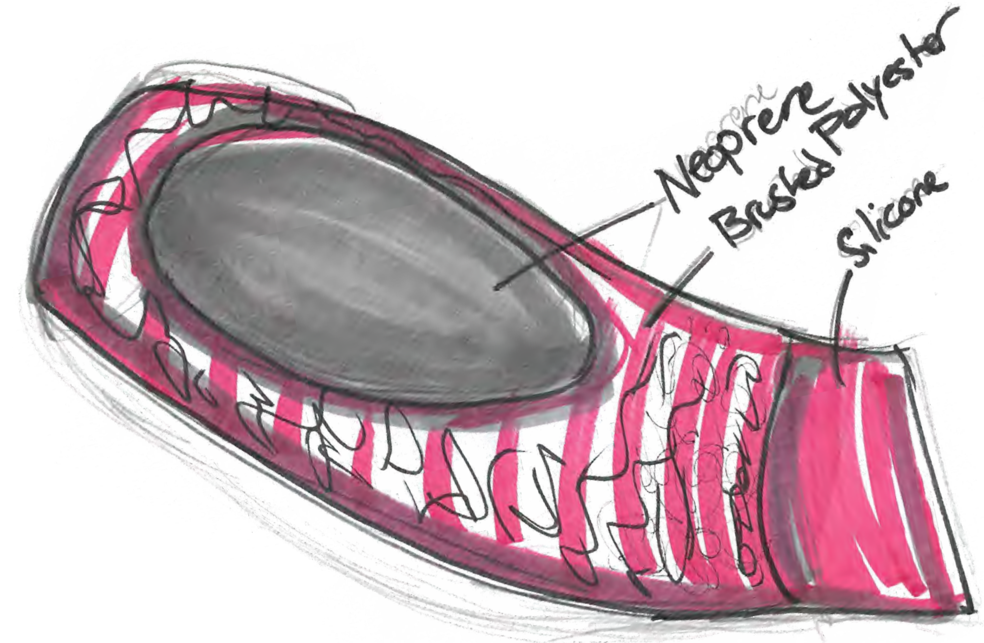
Durable

Comfortable

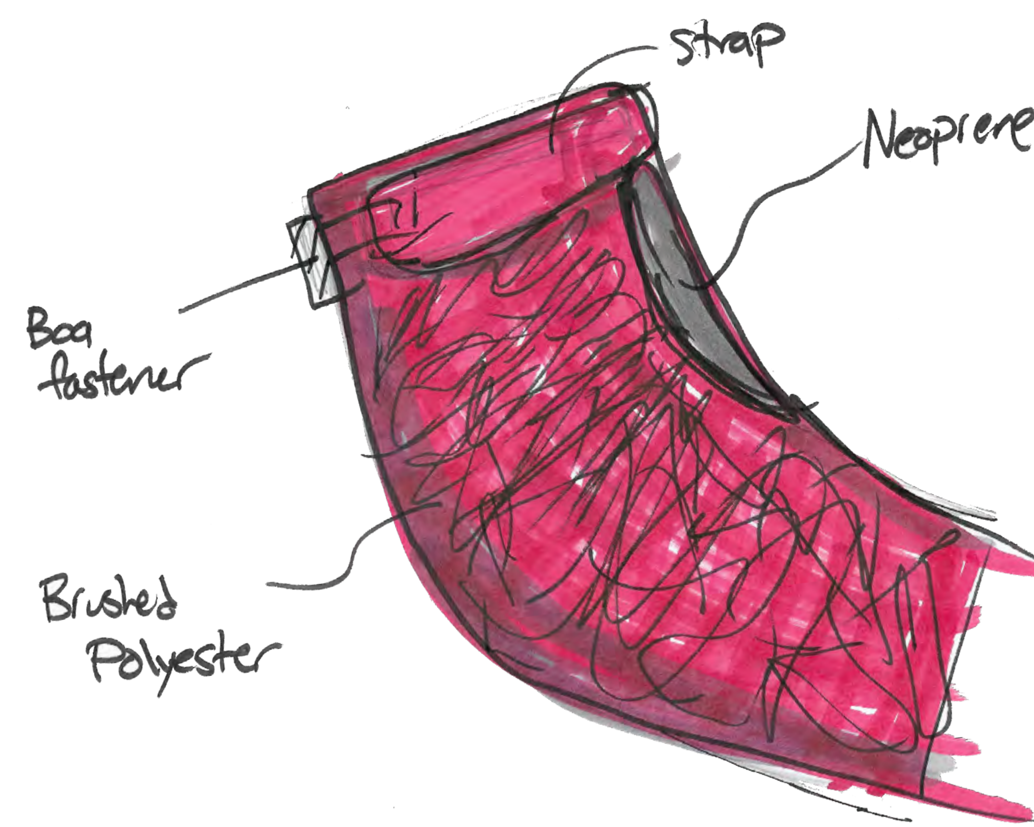


Child-safe





Neoprene is a great choice for the armband material, as it has the exact qualities that we need.



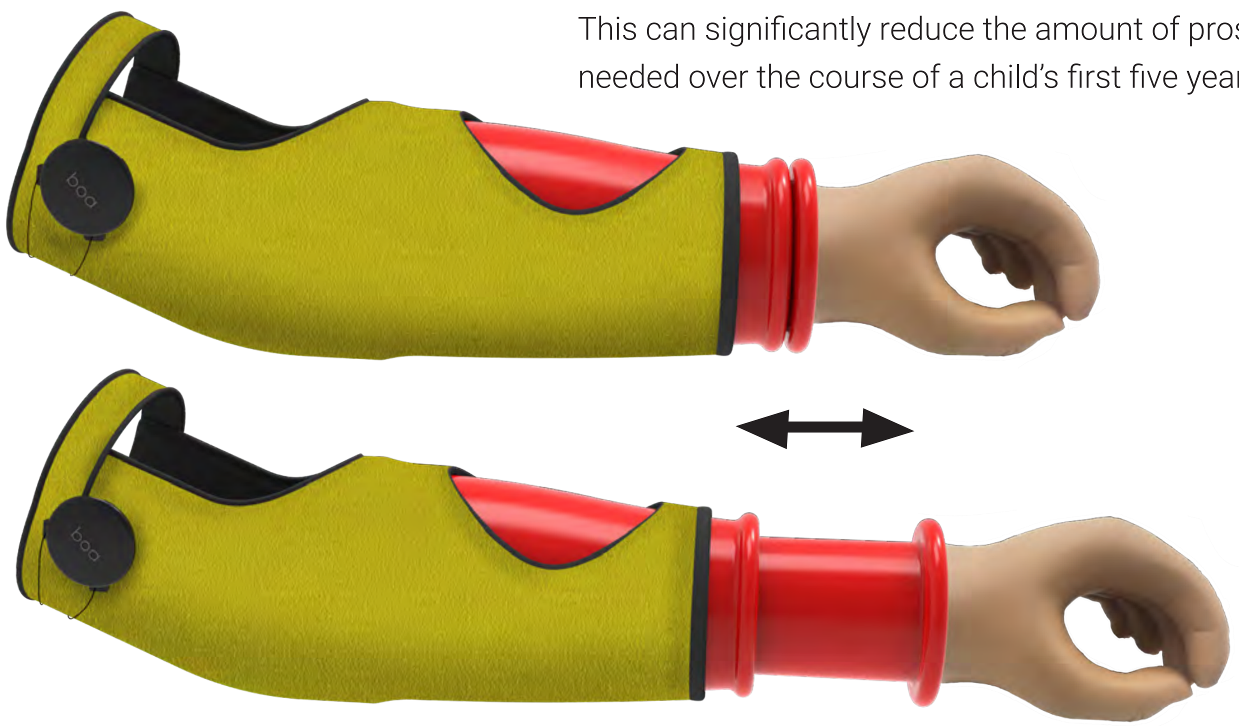
We have the opportunity to **customize the outside of the armband** with a fabric that will be **personal to each patient.**

Overview

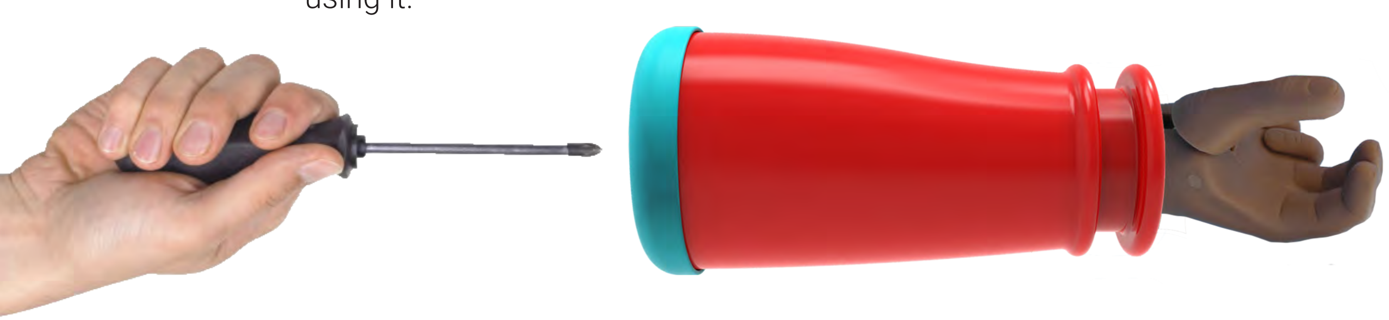
The Forearm and Hand

The prosthetic's **length can adjust based on the child's needs**. As the child grows up, a prosthetic specialist can use a tool to fine-tune adjust the length appropriately.

This can significantly reduce the amount of prosthetics needed over the course of a child's first five years.



The adjustment access is in the socket, which **prevents parents from adjusting the prosthetic** on their own while the child is using it.



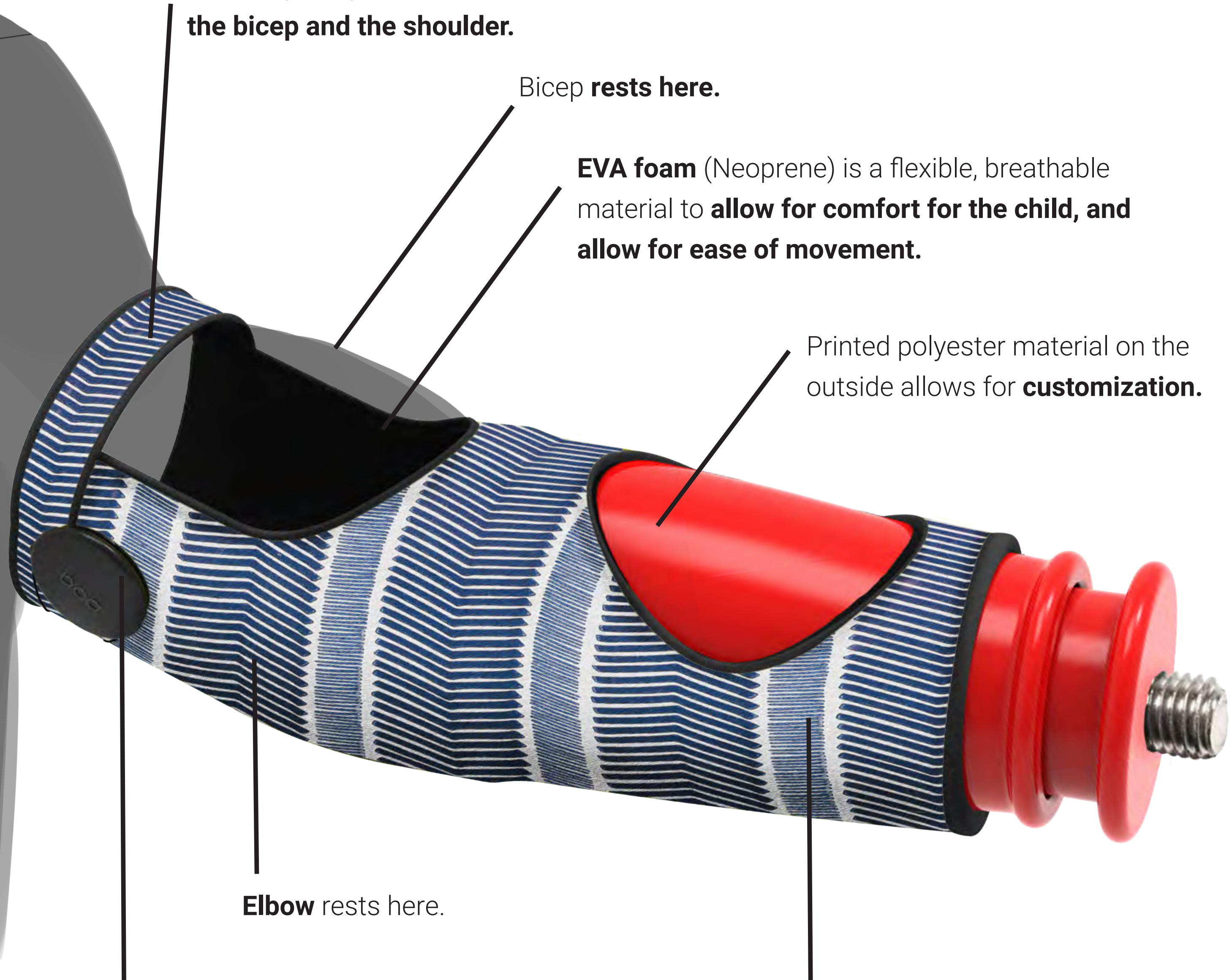
Adjustments can only be made by the prosthetic specialist with a screwdriver. The bolt and tool used can be an uncommon shape, further preventing potential adjustments made by the parents.

Using TRS Prosthetics, a patient can have a **variety of different functions** with their hands, and able to have a hand grow with them as they grow up.

By using TRS Prosthetics' standard attachement, the prosthetic can be **adapted to any hand.**

The Arm Band and Customization

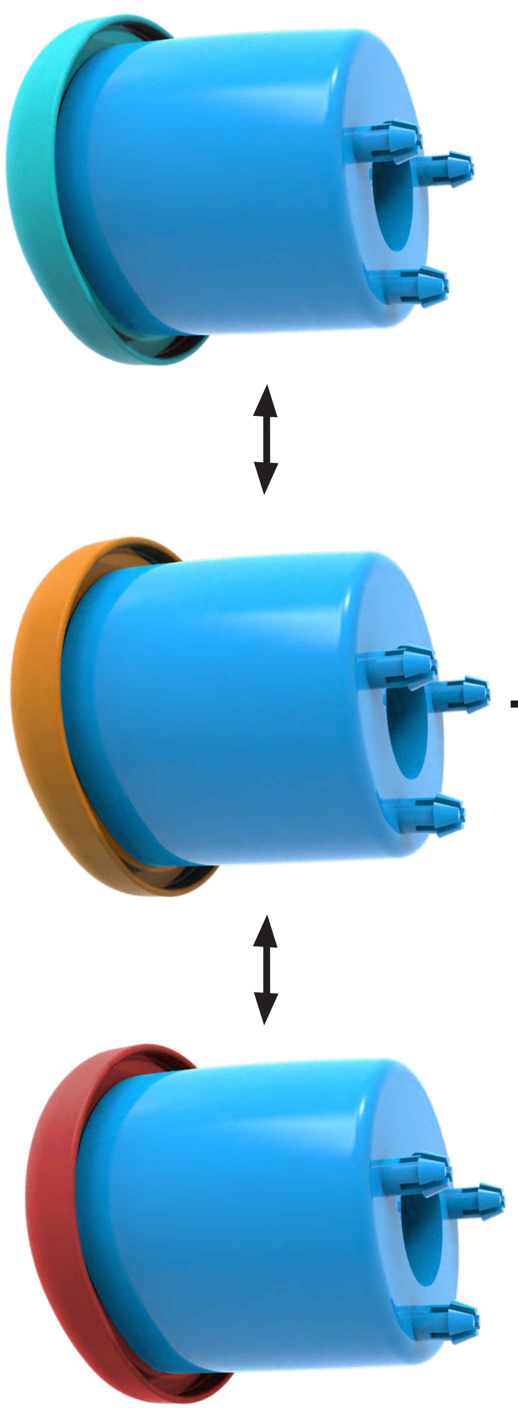
The armband provides **extra support for the prosthetic** and reduces the chance for overgrowth.



The patient and family are able to **customize the outside of the armband** with fabric that can be tailored to the child. This is relatively **easy to produce, as the only change is the fabric pattern.**

The Replaceable Components

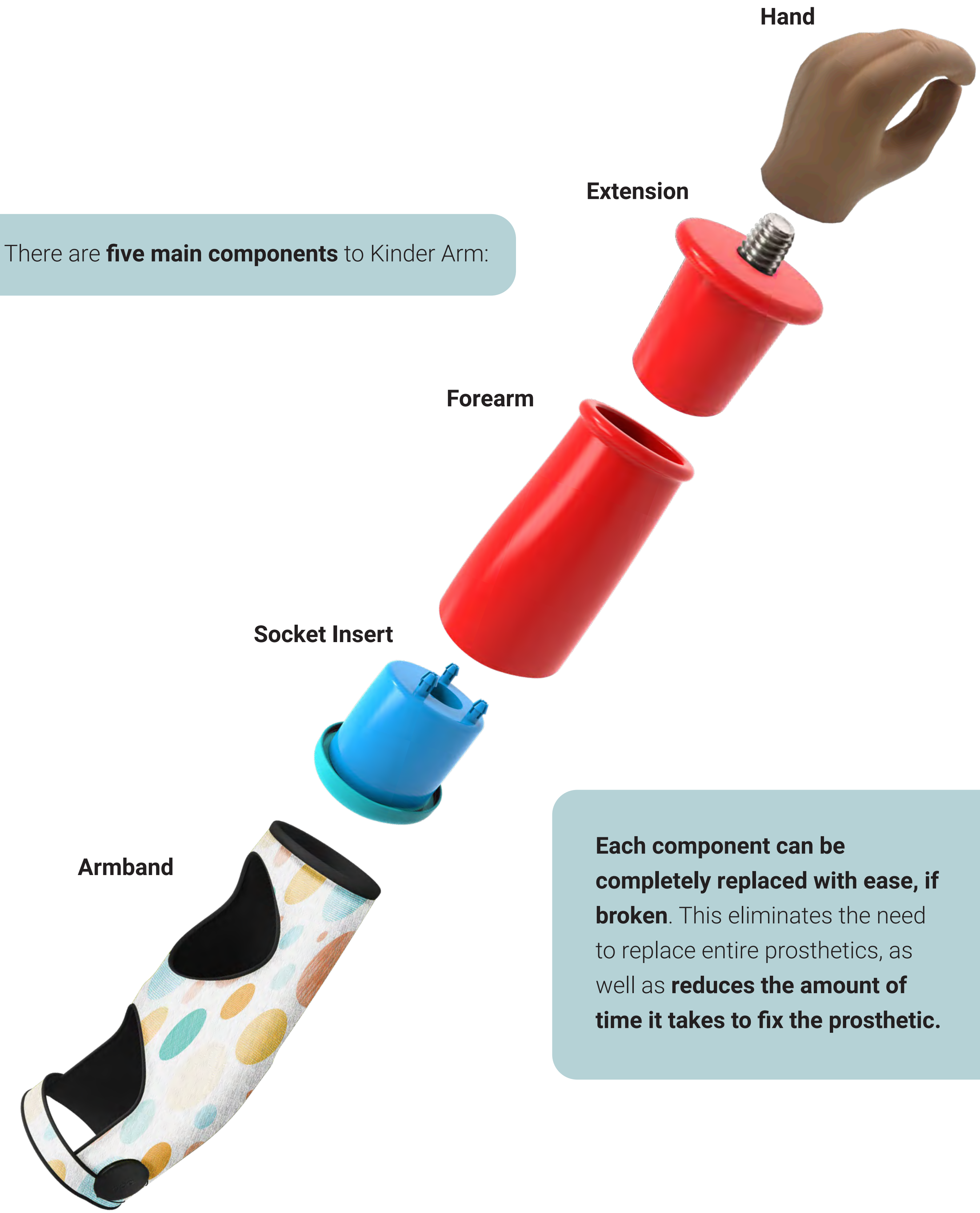
The socket is the only regularly replaced part, because the socket should fit as accurately as possible to the child.



Using snaps, the socket can be **securly inserted and removed to change out** an outgrown socket.

Each time the child grows, a **new socket is molded to fit the child perfectly,** until the next time it is needs to be replaced.

There are **five main components** to Kinder Arm:



Each component can be completely replaced with ease, if broken. This eliminates the need to replace entire prosthetics, as well as **reduces the amount of time it takes to fix the prosthetic.**

"Children & Prosthetics." Children & Prosthetics ' News - Kenney Orthopedics - Orthotics & Prosthetics, www.kenneyorthopedics.com/about/news/view/556/children-prosthetics.

Development, Web. "Prostheses for Children With Limb Differences." Amputee Coalition, 1 Apr. 2009, www.amputee-coalition.org/resources/prostheses-for-children.

Dynamics, Arm. "Prosthetics for Children." Arm Dynamics, www.armdynamics.com/our-care/prosthetics-for-children.

Khan, Muhammad Adil Abbas, et al. "Pediatric Traumatic Limb Amputation: The Principles of Management and Optimal Residual Limb Lengths." World Journal of Plastic Surgery, Iranian Society for Plastic Surgeons, Jan. 2016, www.ncbi.nlm.nih.

Maduri, Prathusha. "Upper Limb Amputation." StatPearls [Internet]., U.S. National Library of Medicine, 18 May 2019, www.ncbi.nlm.nih.gov/books/NBK540962/.

"Pediatric Prosthetics." Hanger Clinic, www.hangerclinic.com/pediatrics/pediatric-prosthetics/Pages/default.aspx.

"The True Cost of Prosthetic Limbs: What It Means For Families." Jordan Thomas Foundation, 29 June 2017, jordanthomasfoundation.org/true-cost-prosthetic-limbs/.

Sources