



Transtibial Amputations

Successes and Challenges

by Douglas G. Smith, MD, ACA Medical Director

Transtibial amputations, also known as “below-knee” or “BK” amputations, are among the most frequently performed major limb amputations. Statistically, about half of all major lower-limb amputations are transtibial, and, in the past several decades, this amputation level has been emphasized in education and training for surgery, prosthetics and rehabilitation. Because of this, many individuals with transtibial amputations successfully achieve rehabilitation at or near their preamputation levels.

Losing a limb is never easy, and the challenges are different for different people at different stages of their lives. Though healthcare professionals can deservedly take pride in the fantastic levels of success in the majority of transtibial amputation cases, we shouldn’t forget that a small number of people don’t recover well. Despite the advancements in surgical techniques and prosthetics, more work still needs to be done. This article reviews the importance of the knee joint and then highlights some of the major issues involved in transtibial amputations.



Knee Power

A person who has undergone a transtibial amputation retains the knee joint – that wonderfully powerful mechanism that lifts them up and lowers them down. This is a huge benefit. It is thus important for both transtibial and transfemoral (above-knee, or AK) amputees to understand the impact of having or not having a knee. Whenever possible, a surgeon wants to preserve a healthy knee joint because it provides a transtibial amputee with many functional advantages not available to those who have undergone a transfemoral amputation or a knee disarticulation (amputation through the knee joint). Not only does a healthy knee provide the power to lift and lower, it is also helpful in maintaining overall balance. The knee is very important in transfers, such as on and off the toilet, in and out of bed, and up and down stairs, and it also gives us greater ability to push forward, slow down, and walk on slopes and stairs.

For amputees who have lost their knee, the prosthesis contains a knee unit that is helpful. Unfortunately, it only replaces the bending motion of a natural knee, not the power. A practical knee unit with the power to provide and dissipate energy and to raise and lower an individual has yet to be built. One of my patients who had mastered the use of a transtibial prosthesis subsequently lost his knee to a severe infection. As he relearned prosthetic use as a transfemoral amputee, he told me, “Doc, it’s not twice as hard going from a BK to an AK. It’s 10 times as hard.”

A prosthetic knee is basically a swinging hinge. When you walk, this hinge effect makes the foot rise up in back. This bending at the knee “shortens” the overall length of the limb so that the toes clear the ground as the leg swings forward. If the knee didn’t bend, you’d stub your toe every time. Then, as you pull your hip forward, the hinge motion swings the leg ahead so that it’s straight and doesn’t cave in when weight is applied.

Prosthetic knees have evolved over time, going from ones that were basically simple pendulums to those that were regulated by rubber bands and springs to those that are moderated by hydraulic or pneumatic components. Now, some knee units have advanced control where the motion is modulated through microprocessors. But we still don’t have one capable of giving “the big push.” While we can create a powered knee in the lab with a large motor and energy source, it’s not practical in the real world. Right now, there isn’t a motor that’s both small enough to fit in a prosthesis and strong enough to do the pushing job. Nor is there an energy source to run it. We can’t put a lawn mower engine inside a prosthesis. In the knee, power is super important and we haven’t been able to replace that. Someday, we will. Fortunately, the transtibial amputee has his own knee.

Foot and Ankle: Accommodation, Balance and a Little Bit of Push

For the transtibial amputee, the major challenge is replacing the foot and ankle, which are filled with many bones and small joints that work together in a unique fashion. We typically think of our ankles as pushing down and pulling up – jobs they do quite well! But their major roles are accommodation, shock absorption and motion. Our foot adjusts to uneven and different



surfaces. We can move from concrete to gravel and still stand or walk steadily, and the foot lets us know when there’s a change in the surface and responds rapidly to nerve signals to accommodate it. This ability of the foot to feel position and surface is called proprioception. It’s the sensation that tells us the foot’s relation to the ground, whether the ground slopes up or down, and whether it’s hard or soft, slippery or dry, rough or smooth.

The foot is not locked into a single mode. It adjusts and adapts. When we’re walking, the foot is at first soft and conforms to the shape of the surface beneath it. As the foot touches down to the surface, it absorbs the shock of impact and assumes the shape needed to be stable as we begin to put our weight on it. Once we start getting our weight over the foot, it begins to become solid so that our calf muscles can push against it. They can’t push against something soft and yielding. They must push against something that is solid and will support us through rollover and pushoff. At the end of the step, the foot provides a solid lever arm to magnify the forces of the calf muscles. Healthy feet and ankles are capable of doing these functions thousands of times a day, every day. Without a foot and ankle, we lose the feeling, the sense of positioning, and shock absorption. Our feet give us amazing instantaneous feedback about the surface beneath us. The partial foot amputation preserves a small bit of this ability, but all of it is lost with a transtibial amputation.

Prosthetic feet generally can be designed to be soft and accommodating or firm and spring-like, but

not both. A prosthetic foot that's soft and accommodating usually remains that way, while a prosthetic foot that's made to provide the firmer foundation needed for pushoff and the spring-like propulsion of stored energy is often described as too "stiff" for less vigorous uses. We have not yet met the challenge of creating a prosthetic foot that's soft and accommodating through the first part of the gait cycle, then more spring-like in the second part to give a little push off at the end.

Good Surgery Is All About Anatomy

There are two major bones in the lower leg. The larger of the two is the tibia. It's the bone in front of the leg – the one we can easily feel through our shin because there's very little padding there. That lack of padding is why it really smarts when we bang our shin against something. The smaller bone on the outside and a bit back is called the fibula. The tibia and fibula are joined at the top

and bottom by joints at the knee and the ankle. When the tibia and fibula have been surgically divided in transtibial amputation, they remain joined near the knee but are no longer jointed below. The two bones can scissor toward each other, sometimes causing pinching and stress in the lower leg. While some transtibial amputees find this bothersome, fortunately many do not. Some reconstructive surgical techniques call for using a bone graft to build a bone bridge to connect the tibia and fibula, creating a kind of joint at the bottom of the lower limb to replace some of the function lost with the removal of the ankle. Other reconstructive surgical techniques focus on muscle padding or the design of the tissue to cover the end of the amputation flap. We'll explore these reconstructive surgical concepts and others in my next column.

The lower leg has four muscle compartments: the anterior, lateral, deep posterior, and superficial posterior. Most

surgeons use the superficial posterior compartment – the big muscles in your calf, called the gastrocnemius and soleus – as the main sources of padding in transtibial amputations. Others use the anterior muscles. It's very rare to use the deep posterior compartment – those muscles that help make your toes curl – for this purpose. One of the challenges in a transtibial amputation is the lack of padding on the front of the lower leg. Surgically, we really can't add a lot of padding to that area. We can bring some muscle over the end of the residual limb from the back and sides, and some newer reconstructive techniques extend the posterior flap to provide even more padding. But even with these efforts, the front of the lower leg remains exposed and is often sensitive.

The lower leg also contains five major nerves: the tibial, the superficial peroneal, the deep peroneal, the saphenous, and the sural. One of the objectives of reconstructive amputation surgery is to find all five major nerves, draw them down gently, divide them and allow them to retract away from the amputation site and into soft tissues. When a nerve is severed during amputation, it will form an ending of nerve fibers called a neuroma. We want to position the nerve ending in well-cushioned soft tissue that's away from the incision, any scar tissue, areas of pressure and throbbing vessels. There, the nerve ending will not be irritated by traction, pressure from the prosthetic socket or any other unwanted sources of contact. Knowledge of prosthetic designs and areas of contact or pressure will aid the surgeon in nerve placement. The surgeon's goal is to retain as much of the useful remaining nerve function in the residual limb as possible, while also carefully managing the nerves to minimize nerve scarring and painful neuromas.

The surgeon should make an effort to preserve as much bone length as possible between the top of the tibia and the junction of the middle and lower third of the tibia, based on the available healthy soft tissues. Amputations in the bottom



third of the tibia generally should be avoided. There's no muscle in that part of the leg to provide padding for the bone so we often shorten the bone to obtain the needed padding. Areas with poor soft tissue padding are more difficult to fit comfortably with a prosthesis. The surgical objective is a cylindrically shaped residual limb with stable muscles, good distal tibia padding, and a nontender and nonadherent scar.

Postoperative management techniques vary widely. Some surgeons apply a simple soft dressing and delay prosthetic rehabilitation until full healing, sometimes waiting months after surgery. At the other end of the spectrum, other surgeons apply an immediate casting system with a prosthetic foot attachment and will then begin partial weight-bearing on the very first day. Options also exist to prescribe and apply various prefabricated air limbs or air bag prosthetic systems. Many surgeons believe that wounds heal fastest when we start actively using the leg shortly after surgery. Some surgeons, on the other hand, fear that walking on a fresh amputation would be horribly painful and harmful to the healing process. But studies have shown that because postoperative prosthetic casting techniques allow for early activity and load-bearing, the residual limb can actually have less swelling and less pain. I believe that the transtibial amputation is especially well-suited to rigid dressings and aggressive immediate postoperative prosthetic (IPOP) management. The biggest benefit of IPOP management can be psychological and emotional. The person often becomes less focused on the loss of a limb and switches to a mind-set of recovering and regaining an active life.

Sockets, Suspension, Sleeves and Into the Future

A wide variety of socket designs are available for the transtibial amputee. It must be noted, however, that an exact mold of the residual limb does not make a good socket. The socket must be indented where people can

take extra weight and relieved or pulled out over sensitive areas. Typically, the region around the patellar tendon just below the kneecap can take weight so we indent there, and we indent the sides of the tibia to push this bone up in back to protect the very distal tip. The top end of the fibula and the very distal (lower) tip of the tibia are sensitive areas where relief regions are added. Fine-tuning the shape of the socket – sculpting its subtle modifications – is the real art of prosthetics.

Sockets can incorporate foam or silicone gel liners to provide better comfort and accommodate minor changes in the size of the residual limb. Disadvantages include increased perspiration and a less comfortable and clean feeling in hot, humid weather. Hard sockets have cotton or wool socks between the leg and the socket and are more durable and easier to clean than liners. Another type of socket is made of soft material inside that is supported by a rigid outside frame. These flexible sockets change shape

to accommodate contractions of the underlying muscles and can be useful for limbs that are scarred or difficult to fit. Open-ended sockets with side joints and a thigh corset are not used much today, except by those who have worn them successfully in the past and by individuals with limited access to prosthetic care.

Suspension is the term used to describe the way a prosthesis is attached to a residual limb. Surgically, while we try for a cylindrically shaped limb, most frequently the result of a transtibial amputation is an overall conical shape that just isn't perfect for suspension. It's good for donning a prosthesis, but it's harder to hold it on. On the plus side, the transtibial procedure occurs farther up the limb than the ankle-level or partial foot amputation so the surgical and prosthetics team has more room to better shape the residual limb. They also can provide for an artificial limb with shock absorbers, rotators and other components that reduce motion stresses and help with bending, movement and suspension.



There are many suspension devices for the transtibial prosthesis. The simplest is a suprapatellar strap, which wraps above the femoral condyles and patella (kneecap). Sockets can be designed to incorporate a supracondylar mold or wedge to grip the above rounded lower end of the femur (the femoral condyles). But this type of suspension has a higher profile, which is bulkier and less cosmetic when sitting. The fork strap and waist belt are useful for the person who has a very short residual limb. These devices help decrease pistoning in the socket and keep the prosthetic limb from falling off. They are also helpful for people whose activities require a secondary suspension system. If the person has a limb with poor soft tissue or intrinsic knee pain, side hinges and a thigh corset can help relieve the burden on the knee joint and shift some of the weight up to the thigh. Historically, these side hinges and thigh corsets are the oldest suspension method for transtibial amputees, and their use began to taper off in the late 1950s and throughout the '60s and '70s as other types of suspension devices emerged and gained wider acceptance.

There are both "outside" and "inside" suspension sleeves. The older

versions were outside sleeves made of latex or neoprene, and they fit on top of the prosthesis, then up and over the knee and thigh areas. They do not actually contact the amputation stump. Latex outside sleeves advanced suspension beyond the strap systems and were seen as an improvement by many people. However, they can be restricting, especially while sitting, and sometimes cause contact dermatitis on the thigh.

Inside, or roll-on, sleeves were developed after the outside sleeves. The inside models are usually silicone based and have a locking mechanism or pin. They roll onto the amputation stump itself, then fit inside the prosthesis, providing an extra gel or elastomeric cushion between the residual limb and the socket. Typically, a small metal post at the far end of the liner slides into a catch-lock to suspend the socket to the liner. Some users of these inside sleeves say they like the secure suspension and feeling of improved prosthetic control. They also say they have an improved sense of where their foot is in space.

But other individuals have not had success with the locking pin because of the way suspension occurs at one fixed point. This direct pulling on the end of

the amputation site can be painful and may lead to a tender, swollen circle of tissue at the end of the limb. Alternative methods to secure the inner sleeve to the socket include a ski buckle-type clamp on the sides of the liner or a prosthesis with a small pump that creates a vacuum between the inner sleeve and socket so that suspension occurs around the entire liner, not just at one point.

Inside sleeves are not as durable as we would like and require fairly frequent replacement. It's not unusual for them to last only two to three months. And the silicone gel sleeves can be expensive. A significant number of inner sleeve users (up to 30 percent) decide they do better with other systems. Some data indicate that people might actually walk less using an inside sleeve than an outside liner. This may be because of the distal lock mechanism or because of the "wet suit" effect caused by wearing an inside sleeve with a very intimate fit. Several amputees have told me, "It's like a wet suit, and after awhile you simply need to peel it off."

Looking ahead, the next evolution may be osseointegration – direct attachment of the prosthetic limb to the bone. While we have learned much from the successes with dental implants, several hurdles still remain for prosthetic limbs. The interface between the implant and the bone has improved, but still can loosen over time. The interface between the implant and the skin where the post comes out of the amputation site is the biggest problem, however. The skin does not directly adhere to the post, and fluid drainage problems and bacterial infection are common. As science continues to improve both the bone-implant interface and the skin-implant interface, however, these devices may be applicable to more people, and we may have an expectation that they can be implanted safely and last long enough to make the extra surgery worthwhile.

In the future, we may also see prosthetic feet containing microprocessors that allow the person to push off and decelerate more readily and to better

accommodate to different surfaces. Perhaps these devices of the future will be controlled bioelectrically, with our own muscles, or through some combination of both. The evolution of transtibial prostheses has already brought us running legs that have large, curved carbon fiber springs, and although they typically provide too much spring for most regular, everyday use, they're terrific for running and could point us in the direction of different prosthetic devices or attachments for different activities.

Great care and consideration should go into choosing the best prosthesis for each individual with a transtibial amputation. One common error is to prescribe a foot that is either too stiff or does not get to the foot flat position quickly enough for that person, especially in the first 12 to 18 months following surgery. Just as function can vary with different feet, so can the cost. Some people assume that the most expensive foot must be the best for them, but while the costly foot may be capable of some noteworthy things, it may not be the best foot for every person. Individuals can value accommodation and power differently at various stages of their lives. We should match foot function with the person's primary needs. A person who enjoys life with mostly household activity may be happier using a foot that's soft and accommodating rather than one made for running, jumping and higher impact activities.

Coping and Mastering

Of all the amputation levels, the transtibial is the one where we see an incredibly vast spectrum of outcomes, ranging from individuals who learn to run and jump to other people who are unable to successfully wear a leg and, instead, use a wheelchair for mobility. How people deal with their loss, master it to varying degrees and move on with their lives is as individual as each person. Our goal is to get everybody farther along in the spectrum. Physical fitness plays an important part. A person who has maintained overall good health generally has an improved chance of overcoming limb loss. He or she already has a head start. Emotional factors and social support are also extremely important, and those with the best hope for recovery often have family and friends nudging them in the right way and helping them when they need help. This doesn't mean doing it for them, but helping when it's called for and pushing them when they need a push. It also means giving them time to be alone when they need it.

Support needs to be tailored to each individual. Some people deal with amputation and recovery with resolve and a sense of purpose. They tell me, "It's tough, doc, but I know what needs to be done." Some people master it to an extraordinarily high degree like Carl Brashear, a Navy diver whose story was depicted in the film *Men of Honor*. Brashear first overcame tremendous racial prejudice to enroll and train as a Navy diver. Then, after losing his leg in a shipboard accident, he had to fight again to continue diving for his country. His courage and motivation are truly amazing. For other people, the loss can derail their entire life. It can take them years to get back

on track. Some never do. Many things make a difference – strength, balance, motivation, depression, family support – and they're all measured differently and to varying degrees for every person.

Despite the advancements in surgical techniques and prostheses, much still needs to be done. Many surgeries could be performed better. Ill-fitting sockets could be adjusted for greater comfort. Alignment and suspension can be improved. Muscles can be strengthened with better training and reconditioning. While we want to applaud our successes and take satisfaction that a majority of transtibial amputees recover well, sometimes we may underestimate just how difficult this loss and recovery can be. We shouldn't let the difficulties faced by some amputees fall below the radar screen. Each amputee and the different members of the surgical and rehabilitation team have specific jobs, and they all must work in tandem so that everybody benefits as much as possible from recent advancements in surgical, prosthetic and rehabilitation technology and techniques. ■

"Nothing splendid has ever been achieved except by those who dared believe that something inside them was superior to circumstances."

- Bruce Barton, author