

TRANSFEMORAL AMPUTATION: *The Basics and Beyond*

Prosthetics Research Study

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1. Introduction

Amputation at the transfemoral level can be very challenging for the amputee as well for the surgeon, the prosthetist, the physical therapist, and every member of the health care team. In the United States, this amputation level is most commonly known as an above-knee amputation, or AKA, whereas elsewhere it is referred to as a transfemoral amputation because the amputation occurs in the thigh, through the femur. The term transfemoral amputation is gaining favor in the United States because it more accurately describes the amputation level involved. Many of the same issues are faced by amputees with knee disarticulations. Except where noted, the information provided in this monograph applies to both transfemoral amputations and knee disarticulations.

Transfemoral amputations are performed less often than in the past because of new understandings of the importance of preserving the knee joint. As recently as 30 years ago, transfemoral amputations were performed frequently in patients with foot infections that required amputation. At that time, the impact of amputation level on rehabilitation and function was not fully understood. Also, the prevailing belief was that a thigh-level amputation was significantly more likely to heal than an amputation at the calf (called a transtibial amputation) or foot because amputations in the calf and foot had very poor healing rates. Thanks to better amputation surgical technique, vascular reconstruction, patient selection, and improved antibiotic treatment, amputations at the calf and foot now have an excellent chance of resulting in a well-healed, functional limb.

Despite the current emphasis on performing amputations that preserve limb length, many transfemoral amputations are still required. Of the more than 1.2 million people in the United States living with limb loss, 18.5 % are transfemoral amputees, according to the latest figures provided by the National Center for Health Statistics.¹ Dillingham and associates² reported that 266,465 transfemoral amputations were performed in the United States between 1988 and 1996 (the most recent years available), an average of 29,607 annually.

Although transfemoral amputations are fairly common, adjusting to life after this surgery is not simple. The transfemoral amputee must deal with increased energy consumption for ambulation, balance, and stability; a more complicated prosthetic device; difficulty rising from sitting

to standing; and, unlike amputation levels in the tibia and the foot, prosthetic discomfort while sitting. The cost of a transfemoral prosthesis is also significantly higher than for a transtibial prosthesis.

Learning to walk after a transfemoral amputation is many times harder than learning to walk after a transtibial amputation. The transfemoral amputee not only has to learn to use a prosthetic knee but also must learn to coordinate the interaction of the foot componentry with the prosthetic knee, which requires more mental energy. In addition, achieving a comfortable socket fit is more challenging. Skills such as coming to a stand, standing balance, ambulation, and negotiating hills, stairs, and uneven terrain are more difficult. The transfemoral amputee has more difficulty with balance and decreased proprioception and therefore has both a greater risk and greater fear of falling. For these reasons, the rehabilitation process is much more difficult for the transfemoral amputee than for the transtibial amputee. Physical therapy is more prolonged (usually at least twice as long as for the transtibial amputee), and a better understanding of prosthetic components is required on the part of the physical therapist.

For the transfemoral amputee to achieve the best possible outcome, it is necessary for the physical therapist to understand the prosthetic components and how they work. The physical therapist must also know how to train the patient to function in all mobility situations, and must also be familiar with issues that are relevant specifically to amputees, such as phantom pain, residual limb skin issues, and the importance of the trained peer visitor.

Physical therapists generally receive little formal training specific to working with amputees, and once in practice, most physical therapists may see one amputee a year, if that. In addition, prostheses continually change as new components become available. For many therapists, keeping up with the constantly changing world of prosthetic components is the most challenging aspect of working with amputees, especially if the basic mechanics of the prostheses are not understood. The purpose of this monograph is to provide a resource of the basic medical and prosthetic issues involved in transfemoral amputation so that with this understanding, the physical therapist is better able to treat the transfemoral amputee in such a way that a positive experience results for both the amputee and the therapist.

2. Amputation Surgery

Amputation at the transfemoral level demonstrates the importance of muscle reconstruction and balance between residual muscle groups. After a transfemoral amputation, very little, if any, weight can be borne directly on the end of the residual limb. In addition, transection of the femur creates thigh muscles that are out of balance as the residual flexor and abductor muscle groups overpower the residual extensors and adductors. The goal of surgery is to try to regain muscle balance and to properly position the femur for weight bearing and ambulation.

The term for the surgical technique by which muscles are reattached to bone following amputation is myodesis (Figure 1). There are two main methods for performing a myodesis. One is to drill holes through the bone and suture the muscle directly to the bone. In the other method, the surgeon secures the muscle over the bone and sutures to the periosteum, the thick tissue covering the bone. For the transfemoral amputation, in which a more secure attachment is required, the first method is usually indicated.

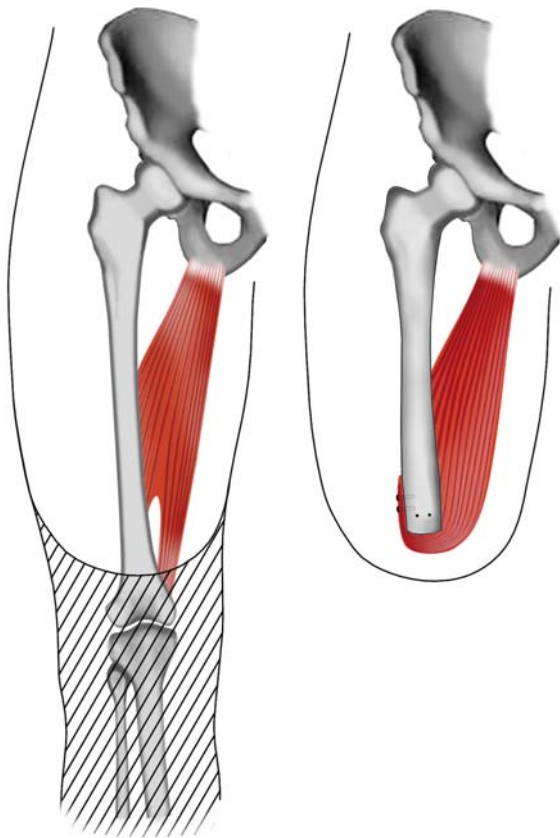


Figure 1 – Myodesis

The primary hip abductor and flexor muscles are attached on the greater and lesser trochanter on the proximal femur, near the hip. Because they are above the surgical division in all transfemoral amputations, they are not affected by the amputation. The adductor and extensor muscles are, however, attached at the lower end of the femur and will be divided in a transfemoral amputation surgery. This results in weakness and a limited ability to adduct and extend the hip.

Without the normal attachment of the adductor and extensor muscles, the leg tends to go into simultaneous flexion and abduction. Therefore, to counterbalance flexion and abduction forces, the surgeon must reattach muscles to the femur or its periosteum. This myodesis makes the residual limb stronger and more balanced and keeps the femur centered in the muscle mass.

Unlike a knee disarticulation, a transfemoral amputation results in a residual limb that cannot bear the body's weight directly on the transected end. Therefore, as noted earlier, one of the goals of transfemoral amputation surgery is to balance the muscles so that some weight can be borne on the sides of the thigh. The adductor muscles are secured to the residual femur to prevent the femur from drifting outward (abducting). If the femur abducts, weight cannot be loaded as easily onto the side, and the bone end may press painfully against the socket. By surgically balancing the muscles, the leg can be positioned in slight adduction in the socket so that most of the weight-bearing force is on the sides of the leg and not on the distal end.

Myodesis also may help to reduce “the adductor roll,” a collection of tissue that sometimes forms high on the inner thigh above the socket line (Figure 2) and which can be quite bothersome. While this roll is commonly caused by issues such as weight gain, mismatched socket geometry, or improper donning of the residual limb, some also believe that this adductor roll is caused in part by the retraction of muscles that have been transected and are no longer held in place. This tissue then spills out over the top of the socket, and before long a significant roll of soft tissue has accumulated in that area. The prosthetic socket may dig painfully into this extra tissue. Myodesis helps secure the adductor muscles and the soft tissue over these muscles. This secure attachment of the adductor muscles appears to restrict the development of a large adductor roll.



Figure 2 – Adductor roll

Myodesis does have a major drawback: Muscle tissue does not hold sutures very well. Think of the tissues of the muscles as

being like a string mop that is encased in a plastic wrapper. The plastic wrapper is like the fascia, which is the tissue that covers the muscle. Suturing muscle is like sewing through the plastic bag and the strings of the mop. The fascia provides some reinforcement, but the individual strands of muscle do not hold suture well. A suture inserted at midthigh will drift downward in the muscle tissue because there is nothing to which it can be securely attached. If the surgeon tries to suture across the strands and loop them together, blood flow is cut off to the end of the muscle. Tendon and skin hold sutures well; muscle does not; and the fascia at midthigh is quite thin and tears easily. So while myodesis is important, it may not always be successful at this level. Occasionally the myodesis will stretch out or even pull free in the postoperative period. Patients will usually say they “felt something give.”

Some surgeons do not use myodesis as part of transfemoral amputation surgery, and sometimes, even with good surgical technique, the myodesis fails or the distal attachment stretches out gradually over time. In these situations, the end of the femur may be very prominent, the patient may have pain at the distal lateral aspect of the residual limb, the prosthetic socket may not fit well, and the patient may walk poorly. The first approach to managing these problems is to modify and realign the prosthetic socket. One modification is to pad

the inside of the socket on the lateral side at the midthigh, above the painful end of the femur. This pad helps to push the femur into adduction. By applying pressure over a broad area over the middle of the femur, it avoids increasing contact and pressure on the painful distal end of the femur. The second adjustment is to aggressively align the socket into adduction. This may even require changing the point where the socket attaches to the knee unit. This alignment change will pre-position the entire thigh, including the femur, into adduction to both improve loading on the lateral side of the femur and maximize the abductors. If the pain and femoral position cannot be managed by socket modification or by aggressive adduction of the socket to preposition the femur in adduction, then surgical revision can be considered. Myodesis is harder to perform during a revision procedure than during the initial amputation, but it can be done.

The thoughtful surgeon must understand the entire course of the amputation process, from the initial emergency department visit to the selection of the final prosthesis. Amputation is both devastating for the patient and challenging for the surgeon. The surgeon capable of achieving a successful amputation can indeed help improve healing, rehabilitation, and quality of life.

3. The Mechanics of Able-Bodied Gait

Locomotion, or gait, is the progressive motion of the human body while walking. Able-bodied, or “normal,” gait refers to the typical motion of the healthy human body during walking. Able-bodied gait is commonly used as the reference when assessing a pathologic gait or an intervention designed to restore function. A firm understanding of able-bodied gait is important before attempting to evaluate, quantify, or record pathologic gait.

Several clinicians and researchers have defined locomotion in terms of basic, functional tasks. Inman and associates³ defined the two basic requisites for bipedal walking: (1) sustained ground reaction forces (GRFs) that support the body, and (2) periodic movement of the feet to transfer support from one limb to the next in the direction of travel. Winter⁴ defines the three main tasks of walking gait to be (1) support of the head, arms, and torso (HAT) against gravity; (2) maintenance of upright posture and balance; and (3) foot trajectory control to achieve adequate ground clearance and a gentle heel contact. Similarly, Perry and associates⁵ at the Rancho Los Amigos Medical Center defined the three functional tasks of locomotion to be (1) rapid loading of the body’s weight onto the outstretched limb (weight acceptance), (2) progression of the body over the single support limb (single-limb support), and (3) unloading of the limb and movement of the limb through swing in preparation for the subsequent weight acceptance (swing limb advancement). All three methods of describing gait offer similar assessments of the functional tasks required for locomotion, including the need for body weight support and the transfer of support from one limb to the other.

One primary objective of locomotion is the efficient movement of the body through space. The rhythmic, periodic motion of the limbs and body propels the body forward with a minimal expenditure of physiologic energy. Any change to the patterns of able-bodied gait usually result in less optimal patterns and a higher rate of energy consumption. Observing and documenting such changes helps the clinician assess progress, report diagnoses, or evaluate interventions.

Although the functional tasks and objectives of locomotion may appear to be relatively straightforward, the analysis of gait is a complex task. To assist in this analysis, gait is commonly evaluated over a short period known as the gait cycle, which is further subdivided into functional segments known as phases. A methodical analysis of the phases of the gait cycle often yields useful clinical information.

The Gait Cycle

The gait cycle is defined from the moment one extremity contacts the ground (initial contact) until the next contact by the same extremity. The gait cycle is grossly subdivided into stance and swing phases, each occupying approximately 60% and 40% of the overall cycle, respectively. Stance phase begins when an extremity touches the ground and lasts as long as that same extremity is in contact with the ground. Swing phase begins when an extremity leaves the ground and lasts until the same extremity again contacts the ground. At standard walking speeds, there is a short period of double-limb support when both limbs are in contact with the ground. This period of double-limb support occurs twice in the gait cycle, once from the perspective of the reference limb, and once from the perspective of the contralateral limb. Each period of double-limb support occupies approximately 11% of the normal gait cycle.⁶

Phases of gait

For more detailed analysis, the gait cycle is often subdivided into eight phases that define the major activities and motions that occur. Traditional evaluation of normal gait defined the eight phases to be heel strike, foot flat, midstance, heel-off, toe-off, acceleration, midswing, and deceleration.⁶ Because this terminology is insufficient to describe select pathologies such as ankle equinus,⁷ an alternate nomenclature was developed by Perry⁸ and is now commonly accepted. This terminology divides the gait cycle into the following phases: initial contact (Table 1), loading response (Table 2), midstance (Table 3), terminal stance (Table 4), preswing (Table 5), initial swing (Table 6), midswing (Table 7), and terminal swing (Table 8).

Table 1 – Detailed description of able-bodied initial contact

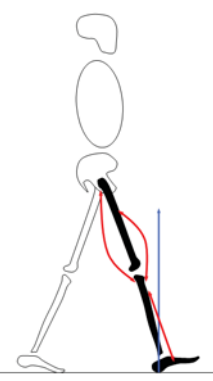
INITIAL CONTACT	
 <p>Primary Goals Knee fully extended Position limb for step</p>	<p>Description: The moment at which the foot touches the ground.</p>
	<p>Ankle: The ankle joint is positioned at neutral (90°) at ground contact. The ground reaction force lies posterior to the ankle, creating a small plantar flexion moment. The pretibial muscles (tibialis anterior, extensor digitorum longus, extensor hallucis longus) are contracted to support the weight of the foot and control plantar flexion of the foot.</p>
	<p>Knee: The knee joint is positioned at neutral (0°) or slightly flexed at ground contact. The ground reaction force lies anterior to the knee joint, creating an extension moment. The quadriceps muscles remain contracted in preparation for loading response. The hamstrings briefly contract to counter the knee extension moment and stabilize the knee.</p>
	<p>Hip: The femur is flexed 25° with respect to the vertical at ground contact. The ground reaction force lies anterior to the hip joint, creating a large flexion moment. The hip extensors contract to resist the flexion moment.</p>
	<p>Pelvis: The pelvis is in 5° of forward rotation at ground contact.</p>

Table 2 – Detailed description of able-bodied loading response

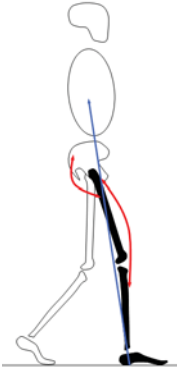
LOADING RESPONSE	
 <p>Primary Goals Knee remains stable Foot remains in line of progression</p>	<p>Description: The impact of the body weight is absorbed by the musculoskeletal structures of the lower limb. The foot reaches a position flat on the ground.</p> <p>Ankle: The ankle rapidly plantar flexes to 10° before returning to neutral by the end of loading response. The ground reaction force lies posterior to the ankle, creating a plantar flexion moment. The pretibial muscles eccentrically contract to provide controlled plantar flexion and initiate tibial progression. This motion is known as the “heel rocker.”⁸</p> <p>Knee: The knee flexes to 15° throughout loading response. The ground reaction force passes behind the knee to create a flexion moment. The quadriceps eccentrically contract to provide controlled flexion and absorb shock. The hamstrings concentrically contract to extend the femur and pull the body forward over the stance leg.</p> <p>Hip: The femur extends slightly throughout loading response to reach 20° flexion. The ground reaction force vector moves posterior and approaches, but remains anterior to the hip joint. A hip flexion moment is maintained through loading response. The hamstrings concentrically contract to extend the femur and pull the body forward over the stance leg.</p> <p>Pelvis: The pelvis remains in forward rotation throughout loading response. The hamstrings contract to stabilize the pelvis.</p>

Table 3 – Detailed description of able-bodied midstance

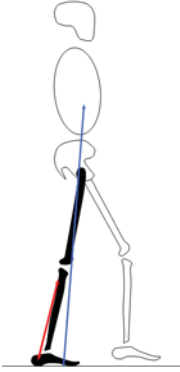
MIDSTANCE	
 <p>Primary Goals Vertical shank 2-4” gait base Trunk erect</p>	<p>Description: The body moves over the stance limb in a controlled progression while the opposing limb swings through, providing momentum.</p> <p>Ankle: The ankle dorsiflexes from neutral to 5°. The ground reaction force moves forward through the ankle joint, creating an increasing dorsiflexion moment. The ankle plantar flexors eccentrically contract to provide controlled motion of the tibia. This motion is sometimes referred to as an “ankle rocker.”⁸</p> <p>Knee: The knee extends to approximately full extension (5°) by the end of midstance. The ground reaction force passes across the knee joint from posterior to anterior, changing the knee flexion moment to a knee extension moment. The quadriceps remain active while the knee flexion moment is in effect. The knee is stabilized by the ankle plantar flexors and knee extension moment in the latter half of midstance.</p> <p>Hip: The femur extends throughout midstance to approximately 10° of extension. The ground reaction force moves to the hip joint throughout midstance. By the end of midstance, the small hip flexion moment is eliminated. No hip flexor/extensor muscle activity is present.</p> <p>Pelvis: The pelvis rotates to neutral (0°) by the end of midstance. The hip abductors contract concentrically to stabilize the hip.</p>

Table 4 – Detailed description of able-bodied terminal stance

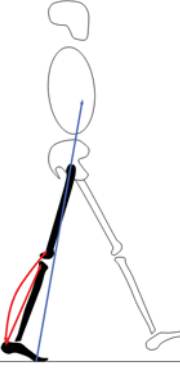
TERMINAL STANCE	
 <p>Primary Goals Equal step length Level pelvis</p>	<p>Description: The body passes over the stance limb and the contralateral limb stretches out to prepare for contralateral initial contact.</p> <p>Ankle: The ankle continues to dorsiflex to 10°. As the ground reaction force vector moves to the toes, the metatarsophalangeal joint extends to 30° to provide a smooth rollover. The dorsiflexion moment reaches a maximum by the end of terminal stance. The ankle dorsiflexors concentrically contract to lift the heel off the ground. This motion is referred to as the “forefoot rocker.”</p> <p>Knee: The knee remains at maximal extension (5° flexed) throughout most of terminal stance then flexes slightly (15°) prior to preswing. The ground reaction force vector remains anterior to the knee joint throughout most of terminal stance, moving posterior as the knee begins to flex. The knee extension moment peaks in the middle of terminal stance, before decreasing and changing to a flexion moment just before preswing. Ankle dorsiflexors concentrically contract to stabilize the knee throughout this phase.</p> <p>Hip: The femur extends to a maximum of 20° hyperextension with respect to the vertical. Pelvic rotation (below) contributes. The ground reaction force vector moves posterior to the hip joint, creating a small hip extension moment that peaks and begins to diminish as the limb is unloaded. Weak action of the hamstrings may act to control hyperextension.</p> <p>Pelvis: The pelvis rotates 5° backward as the contralateral stance limb extends forward, contributing to the apparent hyperextension of the femur.</p>

Table 5 – Detailed description of able-bodied preswing

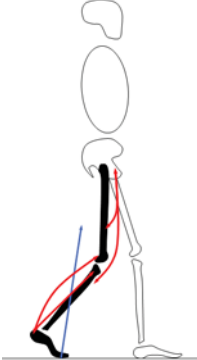
PRESWING	
 <p>Primary Goals Smooth hip flexion Smooth knee flexion Socket remains secure on residual limb Foot tracks in line of progression</p>	<p>Description: The stance limb begins to unload and the knee flexes in preparation for swing as the body weight passes to the contralateral foot.</p> <p>Ankle: The ankle plantar flexes through preswing and moves into 20° of flexion. The MTP joint continues to extend, reaching 60° of extension by the end of preswing. The ground reaction force vector lies anterior to the ankle joint, but the dorsiflexion moment rapidly decreases as the foot is unloaded. The ankle plantar flexor muscles cease contraction early in preswing and the pretibial muscles concentrically contract late in preswing in preparation for lifting the foot.</p> <p>Knee: Knee flexion continues, reaching 40° by the end of the phase. The ground reaction force vector remains posterior, but decreases in magnitude as weight is transferred to the contralateral limb. The knee flexion moment peaks and then diminishes as the foot unloads.</p> <p>Hip: The femur reverses direction and flexes to approximately 10° of hyperextension. The hip extension moment fades as weight is unloaded. The quadriceps are concentrically contracted to assist the thigh momentum in pulling the femur forward.</p> <p>Pelvis: The pelvis begins in 5° of backward rotation and begins to rotate forward.</p>

Table 6 – Detailed description of able-bodied initial swing

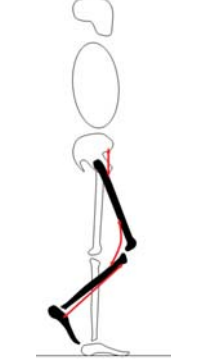
INITIAL SWING	
 <p>Primary Goals Maintain level pelvis Control heel rise</p>	<p>Description: The knee flexes and the thigh rotates forward as the foot lifts off the floor and clears the ground.</p> <p>Ankle: The ankle dorsiflexes throughout preswing to clear the foot, reaching 10° of plantar flexion by the end of the phase. The pretibial muscles remain active throughout preswing to dorsiflex the ankle joint.</p> <p>Knee: The rapid knee flexion continues to a maximum of 60° during initial swing, then begins to flex slightly ending the phase at about 55° of flexion. The hamstrings concentrically contract to flex the knee.</p> <p>Hip: The femur moves from slight hyperextension to 15° of flexion throughout initial swing. The hip flexors concentrically contract to assist in lifting the swing leg.</p> <p>Pelvis: The pelvis continues to rotate forward toward neutral.</p>

Table 7 – Detailed description of able-bodied midswing



MIDSWING	
 <p>Primary Goals Toe clearance Knee and foot track line of progression</p>	<p>Description: The thigh continues forward and the knee extends to bring the foot out from underneath the swing leg.</p> <p>Ankle: The ankle continues to dorsiflex to the neutral position (0°) as the foot swings underneath the body. The pretibial muscles remain concentrically contracted to clear the foot.</p> <p>Knee: The knee joint continues to rapidly extend to about 20° of flexion by the end of the midswing. The momentum of the swinging leg powers the extension and no knee muscles are actively contracting to power this motion, although slight muscle activity in the hamstrings may be present to control the momentum.</p> <p>Hip: The femur continues to flex, reaching a maximum of 25° flexion by the end of this phase. Hip flexors remain concentrically contracted aid in the progression and control of the femur in early midswing. The hamstrings contract concentrically late in the phase to begin decelerating the femur.</p> <p>Pelvis: The pelvis rotates forward through the neutral position.</p>

Table 8 – Detailed description of able-bodied terminal swing

TERMINAL SWING	
 <p>Primary Goals Smooth deceleration to full extension Equal step length</p>	<p>Description: The leg extends in preparation for initial contact.</p>
	<p>Ankle: The ankle remains fixed at neutral (0°) throughout terminal swing. The pretibial muscles remain concentrically contracted to position the foot for initial contact.</p>
	<p>Knee: The knee fully extends, then flexes slightly (5°) before initial contact. The quadriceps contract concentrically to extend the knee and the hamstrings contract to slow the limb and prepare for ground contact.</p>
	<p>Hip: The femur extends slightly from full flexion (20°). The hamstrings and quadriceps concentrically co-contract to position the femur for initial contact.</p>
	<p>Pelvis: The pelvis rotates forward 5° as the lower limb extends into the step.</p>

Gait Analysis

Gait analysis is a broad term that describes the evaluation of walking motion and patterns. This evaluation ranges in complexity from the simple observational gait analysis that might be conducted in a clinic or hallway to an instrumented gait analysis performed in a gait laboratory. The parameters used to assess gait commonly fall into several broad categories, including temporal, spatial, kinetic, kinematic, energy expenditure, and muscle activity. Examples of key parameters from each category are included in Table 9.

Observational gait analysis often includes such qualitative outcomes as “too narrow a base of support” or “reduced range of motion,” whereas instrumented gait analysis produces a quantitative assessment of those parameters (eg, 12.0 cm and 15°). Selection of the proper gait parameters and depth of analysis is an important task. Using inappropriate or too few parameters may result in inaccurate assessment, whereas selection of too many may be redundant or costly. In most cases, it is prudent to perform only the tasks needed to achieve the required assessment.

Stride Analysis

Even the most elementary gait analysis usually includes several sagittal-plane temporal and spatial measures, the most common being velocity, stride length, and cadence. These parameters are relatively easy to measure and are often used to diagnose a variety of pathologies. Values for the normal population have been well documented in the literature (Table 10).

Table 10 – Temporal-spatial characteristics of the able-bodied population⁸

Characteristic	Stride Length (m)	Velocity (m/s)	Cadence (steps/min)
Mean Value	1.41	1.37	113
Mean (Men)	1.46	1.43	111
Mean (Women)	1.28	1.28	117

Stride characteristics in transfemoral amputees may be influenced by such factors as patient age, residual limb length, pathology, and amputation etiology. For example, Perry⁸ reported a decrease in mean walking velocity of 3%

Table 9 – Typical biomechanical parameters

Temporal (Time)	Spatial (Distance/Length)	Energy Expenditure
Stance time Swing time Double-support time Single-limb support time Velocity Cadence	Stride length Step length Foot angle Base-of-support width	Oxygen consumption Oxygen cost Relative energy cost (%VO ₂ Max) Heart rate Muscle work
Kinetic (Force)	Kinematic Motion	Muscular Activity
Ground reaction force Center-of-pressure Joint moments	Joint range-of-motion Joint moments	Contraction magnitudes Muscle activation time

in the 60- to 65-year-old group, 9% in the 60- to 80-year-old group, and 11% in the 60- to 87-year-old group. The effect of pathology and etiology on walking speed is even more marked. Vascular transfemoral amputees exhibit a mean walking velocity of 0.6 m/s, only 56% of the mean velocity for able-bodied individuals.⁸

In normal gait, the step length is usually assumed to be one half of the stride length because there is only minimal asymmetry between the right and left feet. Many types of pathology, including transfemoral amputation, will affect the gait symmetry. In these cases, step length symmetry cannot be assumed. The degree of the asymmetry and its impact on the patient vary greatly, depending on the patient's physiology and pathology.

Detailed stride analysis may also incorporate several coronal-plane parameters, including base-of-support width and foot angle with respect to the direction of motion. Such variables are important when assessing the patient's balance and coordination. Sample coronal and sagittal measures are shown in Figure 3.

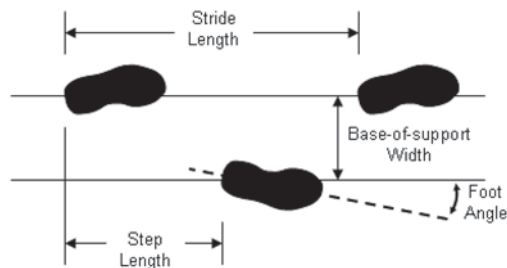


Figure 3 – Coronal and sagittal stride characteristics

Observational gait analysis does not quantify temporal or spatial parameters, but numerous methods exist for measuring temporal-spatial parameters, ranging from the simple (eg, a stopwatch) to the sophisticated (eg, motion analysis systems and instrumented walkways). Velocity may be easily measured by timing how long it takes the amputee to walk a known distance. Similarly, cadence can be calculated by dividing the number of steps by the time elapsed. Note that both collection methods assume the patient walks at a consistent velocity/cadence and are therefore more indicative of a mean velocity/cadence. One additional drawback of observational gait analysis is that this type of simple analysis cannot quantify asymmetries in these stride characteristics. To obtain such data, more sophisticated equipment (such as a gait analysis laboratory) is recommended.

Force Analysis

The ground reaction force (GRF) is the resultant force that opposes the weight of the body as it strikes and moves across the ground during gait. The GRF is equal in magnitude and opposite in direction to the force being supported by the stance limb(s). GRF is commonly resolved into three independent force components: the vertical ground reaction force (the VGRF), the medial-lateral (ML) force, and the anterior-posterior (AP) force (Figure 4).

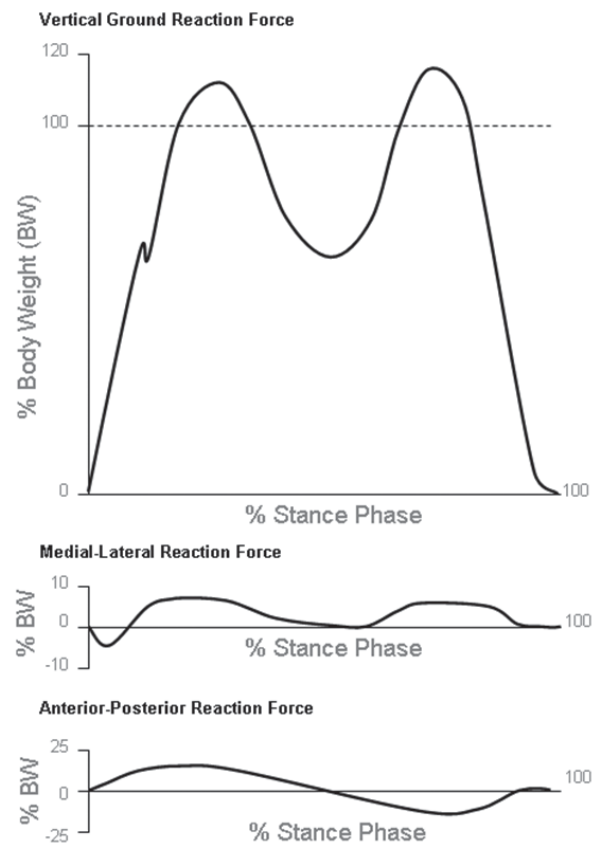


Figure 4 – Components of the ground reaction force

The VGRF is commonly identified by the characteristic “M” shape that occurs when force during normal walking gait is plotted. The first major peak is often named the weight-acceptance peak because it occurs as the support limb is loaded in early stance. The second major peak is often called the propulsive peak; it occurs as the body is propelled into the next step and weight is unloaded off the stance limb. The two large peaks of the “M” oscillate about full body weight (BW), reaching a maximum of about 110% BW and a minimum between peaks of approximately 80% BW.⁸ The small spike in the VGRF that occurs early in stance is called the impact peak or impact spike. It is thought to represent the change in moment of body segments as the body strikes the ground in loading response. This impact peak is often not present in the VGRF profile of various pathologies (such as amputee gait) and high-speed activities (such as running).

The ML force, or medial-lateral shear, occurs as body weight is transferred from one limb to the other during gait. The ML force rarely exceeds 10% BW and is the lowest of the resolved forces from the GRF.⁸ The AP reaction force, or fore-aft shear, occurs as a result of the anterior braking force and posterior propulsive force in late stance. The maximal AP force is typically less than 25% of body weight.⁸

GRFs are typically measured using a force plate (or force platform) mounted in the floor of an instrumented gait laboratory. The force plate (and associated computer software) can measure a variety of kinetic variables, including VGRF, AP force, ML force, resultant force, and center of pressure. When these values are analyzed with a kinematic motion analysis system, joint forces, moments, and work can be derived. These

kinetic measures are not easily derived from observational gait analysis.

Motion Analysis

Motion, or kinematic, analysis is the evaluation of the pattern of motion of the body during gait. This pattern is inherently complex, as it involves the motion of a myriad of body parts moving with respect to each other in three-dimensional space at various speeds. Because of this complexity, kinematic walking models often simplify the body into basic body segments. The lower limb segments are called the foot, leg, and thigh. The upper body is often considered a single segment called the trunk or head-arms-trunk (HAT). In more complex analyses, the pelvis, arms (consisting of the hand, forearm, and arm), and head may be considered separate from the HAT, but this significantly increases the degrees of freedom and therefore the complexity. Even the simplest models should recognize that the upper body affects the kinematics of gait. To simplify evaluation, motion is usually analyzed with respect to just one plane (sagittal, coronal, or transverse) at a time.

Analysis of motion in the sagittal plane typically details the respective motion of the foot, leg, thigh, and trunk segments. Such motion parameters include ankle plantarflexion/dorsiflexion, knee flexion/extension, and hip flexion/extension. In-depth sagittal analysis may also include pelvic tilt. Coronal and transverse plane analysis involves motions of these same body segments, but the motion parameters are foot and leg internal/external rotation, foot inversion/eversion, thigh abduction/adduction, pelvic drop (pelvic obliquity), trunk lean, and trunk rotation. The typical positive and negative reference for each motion is listed in Table 11.

Table 11 – References for kinematic movement

Kinematic References	
Negative (-)	Positive (+)
Subtalar Motion	
Eversion	Inversion
Ankle Motion	
Plantar flexion	Dorsiflexion
Knee Motion	
Extension	Flexion
Hip Motion	
Extension	Flexion
Adduction	Abduction
External rotation	Internal rotation
Pelvis Motion	
Posterior tilt	Anterior tilt
Drop	Hike
Backward rotation	Forward rotation
Trunk Motion	
Extension	Flexion
Left lean	Right lean
Backward rotation	Forward rotation

Motion analysis, like stride analysis, varies greatly in potential complexity. Observational gait analysis uses simple qualitative descriptors for kinematic parameters such as “excessive,” “reduced,” or “limited.” This method relies heavily upon the skill and experience of the observer. Instrumented gait analysis attempts to quantify these parameters by using measurement equipment (such as electrogoniometers and/or camera-based measurement systems such as flash photography and motion-tracking cameras). Instrumented methods rely heavily upon the skill of the system operator and proper evaluation of the resultant data. Instrumented gait analysis uses sophisticated cameras and computer systems to track the motion of the patient. Small reflective markers are placed on the subject at specified locations to define the body segments. These “marker sets” define the anatomic model that the computer then uses to predict joint centers and replicate the patient’s motion. Such modeling and analysis reveal details that may be missed in an observational analysis. It also provides a record by which the effectiveness of interventions may be assessed.

Joint and Muscle Moments

Joint and muscle moments are derived from a combined analysis of kinetic (GRF) data and kinematic (motion analysis) data. A moment should be referenced as either a demand (joint) moment or a response (muscle) moment. 8 When referencing a moment according to the ‘demand’ or ‘joint’ convention, visualize the joint action that results from the GRF vector position with respect to the joint center. Consider the example of initial contact, where the GRF vector passes posterior to the ankle joint, anterior to the knee joint, and anterior to the hip joint (Figure 5). The vector is therefore attempting to plantarflex the foot, extend the knee joint, and flex the hip joint. Using the demand convention, this would be reported as positive ankle moment, a negative knee moment, and a positive hip moment. Using this convention, the hip moment may also be referenced as flexion moment, the knee as an extension moment, and the ankle as a plantarflexion moment.

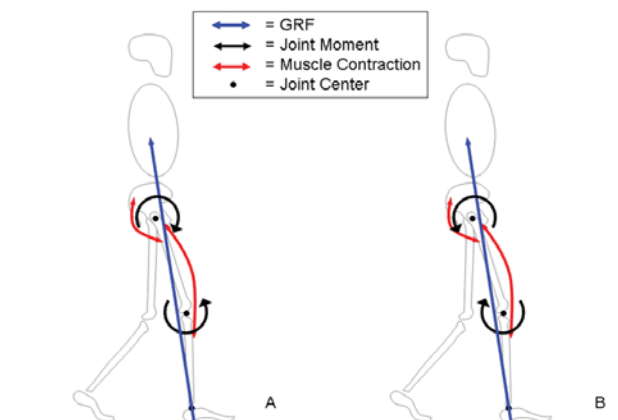


Figure 5 – Joint moments and muscle actions during loading response

When referencing a moment according to the ‘response’ or ‘muscle’ convention, visualize the muscular response to GRF. At initial contact, the ankle dorsiflexors flex to control plantarflexion, the knee flexors contract to prevent hyperextension, and the hip extensors contract to keep the

trunk upright. Therefore, in terms of reaction moments, this would be reported as a negative ankle moment, a positive knee moment, and a negative hip moment. Using this convention, the hip moment may also be referenced as an extension moment, the knee as a flexion moment, and the ankle as a dorsiflexion moment. One drawback to using the response moment convention is that muscle moments represent the net muscle reaction at any joint and may not reflect the true muscle activity. Behaviors such as stabilizing co-contractions at the knee in initial contact are difficult to detect in a muscle moment analysis, but may be easily detected in a muscle activity analysis.

To avoid confusion, it is best to be consistent and to specify the chosen convention (demand or reaction) when referencing moments. Throughout this text, the demand moment convention will be used to describe joint moments. Muscle power and work may also be derived from combined kinetic-kinematic analyses. These advanced analyses are beyond the scope of this text but are reviewed in detail elsewhere.⁹

Muscle Activity

The action and timing of muscles or muscle groups during the gait cycle can be measured to quantify muscle activity. These measures are usually referenced to the muscle activity present during normal walking gait. Collecting or analyzing muscle activity data requires familiarity with the active muscles, the types of contraction (concentric, eccentric, or isometric), and the actions (prime movers, synergists, and/or antagonists) present during each phase of the gait cycle.

The measures used to define muscle activity include the state of activity (active or passive), the magnitude of the contraction, and the duration of the contraction. Muscle activity is most commonly measured in instrumented gait with electromyographic (EMG) equipment designed to detect the minute electrical charge present when a muscle (or muscle group) activates. Both wire and surface EMG sensors are

used to quantify muscle action in gait.⁸ In observational gait analysis, muscle activity is more often derived from assessing the limb segment motion and joint range of motion.

Energy expenditure

As stated earlier, the fundamental goal of locomotion is the efficient progression of the body through space. Energy expenditure analysis is a measure of the metabolic cost of this effort to move the body during locomotion. Energy expenditure may be measured by a number of methods, both direct and indirect. The simplest text of energy expenditure is to measure walking distance over a specified time (eg, a 6-minute walk test). More advanced methods measure the oxygen consumed during an activity, which allows direct comparisons between patients, time-points, or interventions. To measure oxygen consumption, exhaled oxygen (O₂) and carbon dioxide (CO₂) are collected with an oxygen cart or a Douglas bag and analyzed to determine the amount of O₂ consumed. These values are normalized to body weight and reported as a function of time or distance. Rate of oxygen consumption (ie, uptake), net oxygen cost, and relative energy cost are measures used to characterize the energy expended in gait. The typical energy expenditure values for able-bodied and pathologic gait have been reported in great detail by Waters and others in the literature.^{8,10-12} A summary of these results for able-bodied subjects, transtibial amputees, and transfemoral amputees is shown in Table 12.

Analysis of (relative) energy consumption is not usually accomplished with observational gait analysis, but simple measures such as the timed distance may be easily added to the patient record. Detailed analysis of energy consumption requires access to specialized equipment and may not be suitable for all environments. Additionally, some patients may find the use of such equipment cumbersome or uncomfortable. When a detailed energy expenditure analysis is performed, however, the resultant data provide an effective tool for assessing physical condition and interventions.

Table 12 – Energy expenditure at self-selected walking able-bodied subjects and lower limb amputees^{10,11}

Amputation Level	Velocity (m/min)	Stride Length (m)	Rate of O ₂ Uptake (ml/kg-min)	Net O ₂ Cost (ml/kg-m)	Relative Energy Cost (% VO ₂ Max)	Heart Rate (1/min)
Able-bodied Adults						
Able-bodied	80 ± 10	1.42 ± 0.14	12.0 ± 2.2	0.15 ± 0.02	N/A	99 ± 13
Vascular Amputees						
Transfemoral	36 ± 15	1.00 ± 0.20	12.6 ± 2.9	0.35 ± 0.06	63	126 ± 17
Transtibial	45 ± 9	1.02 ± 0.13	11.7 ± 1.6	0.26 ± 0.05	42	105 ± 17
Traumatic Amputees						
Transfemoral	52 ± 14	1.20 ± 0.18	12.9 ± 3.4	0.25 ± 0.05	37	111 ± 12
Transtibial	71 ± 10	1.44 ± 0.16	15.5 ± 2.9	0.20 ± 0.05	35	106 ± 11

4. The Multidisciplinary Approach

A multidisciplinary approach is crucial to providing the best care for amputees. Members of the team may include the surgeon, primary care provider, physiatrist, prosthetist, physical therapist, occupational therapist, nurse, wound care specialist, podiatrist, internist (for diabetic care), psychologist, social worker, case manager, and peer visitor. The amputee and, if they wish, the amputee's family are also members of the team. By the time a transfemoral amputee enters the outpatient physical therapy office for the first time, some of these individuals may still be involved in the amputee's care, whereas others are on an as-needed basis. Typically, once amputees have reached the point where the incision site is healed and they are cleared for prosthetics, the multidisciplinary team consists of the doctor, the prosthetist, the physical therapist, and of course the patient.

In the modern era of health care, for this multidisciplinary approach to work, good communication is especially important. This is most easily achieved in a clinic setting where all providers are able to get together with the patient to talk about current status, goals, progress, roadblocks to achieving the goals, and any additional issues and concerns. In this way, communication occurs directly, and everyone leaves the meeting with a shared understanding. Unfortunately, this type of meeting rarely occurs, so the responsibility for communication with every member of the team falls on each provider. It is important to understand the best ways to communicate effectively in these situations.

With a multidisciplinary approach, all team members must do their part to achieve the goal of maximizing the amputee's function and outcomes. They must work together to ensure that "medical care, prosthetic fabrication and fitting, training and therapy, navigation of the funding process, and social reintegration occur."¹³ No one member of the team has all the answers, and each team member brings specific skills that will benefit the patient. Team members can learn from each other, and they should educate both the patient and the rest of the team. Table 13 lists communication do's and don'ts.

An effective communication path must be set up among all team members. Typically, most of the day-to-day communication occurs between the prosthetist and the physical therapist,

Table 13 – The do's and don'ts of team communication¹³

Do's	Don'ts
Be flexible	Assume you have all the answers
Try to sit down as a team to discuss plan	Communicate to the team through the patient
Educate and empower	Put down other team members
Allow patient to take control and responsibility	Point fingers
Act like a team	
Use specific skills of each team member to enhance the team	
Be positive and motivating	
Keep an open mind	

usually by phone. The physical therapist should be aware that the prosthetist is a great resource not only for questions regarding the prosthesis but also for patient behaviors, issues they have encountered that need to be addressed, and any other questions regarding patient potential, possible goals, and overall assessment. Good therapist–prosthetist rapport therefore is an important component of comprehensive care. Communication should not occur through the patient but rather directly from provider to provider. Miscommunication may occur if the patient is asked to relay information from one provider to another.

The patient's first visit to a multidisciplinary clinic is a good opportunity to develop or review the rehabilitation plan that covers the entire rehabilitation phase, from deciding on prosthetic components and goals to functional discharge goals from physical therapy. Setting up this type of plan from the beginning with each team member present is very beneficial to the patient and the team, but it is not a common occurrence. Typically, the patient meets with the prosthetist first, and the prosthetic plan is already in place by the time the physical therapist is involved. The physical therapist does not usually take part in planning the prosthetic prescription. If, however, the physical therapist can meet with the patient to complete a functional evaluation prior to the prosthetic prescription, the PT could provide the prosthetist with good information on the potential functional level of the patient.

5. Functional Levels

Medicare K Levels

In March 1995, the US federal government announced a system¹⁴ of classifying an amputee's potential functional level for the purpose of determining which prosthetic components would be reimbursed by Medicare (Table 14). This classification system is used by prosthetists and physicians but is not typically used by physical therapists. Many insurance companies also follow these Medicare guidelines. According to the guidelines, the physician and/or the prosthetist will assess an amputee's potential functional level using the five-tier classification system. This will determine which prosthetic components will be approved for reimbursement. Coverage for components not approved for the patient's Medicare level will be considered based on clinical documentation of the functional need.¹⁵

Table 14 – Functional levels and lower extremity prostheses¹⁴

Level 4	The patient has the ability or potential for prosthetic ambulation that exceeds basic ambulation skills, exhibiting high impact, stress, or energy levels typical of the prosthetic demands of the child, active adult, or athlete.
Level 3	The patient has the ability or potential for ambulation with variable cadence typical of the community ambulator who has the ability to traverse most environmental barriers and may have vocational, therapeutic, or exercise activity that demands prosthetic utilization beyond simple locomotion.
Level 2	The patient has the ability or potential for ambulation with the ability to traverse low-level environmental barriers such as curbs, stairs, or uneven surfaces typical of the limited community ambulator.
Level 1	The patient has the ability or potential to use a prosthesis for transfers or ambulation on level surfaces at fixed cadence typical of the limited or unlimited household ambulator.
Level 0	The patient does not have the ability or potential to ambulate or transfer safely with or without assistance, and a prosthesis does not enhance their quality of life or mobility.

Under this system, each level of potential function is associated with a list of components that would be approved for Medicare coverage, with more components covered at higher functional levels. For example, a transfemoral amputee classified as a Level 3 would be eligible to receive not only the components listed under Level 3, but also those listed for Levels 1 and Level 2 if the prosthetist believed those components would complement the amputee's function and mobility. If a prosthetist orders prosthetic components that are not listed for the amputee's designated level (or lower), the insurance claim is likely to be denied or delayed pending further clinical documentation of functional need.

Table 15 lists general categories of prosthetic knees and feet that are covered at each Medicare level. Because so many types of prosthetic components are on the market and new ones are always being added, specific brand name component parts are not listed.

One difficulty with determining Medicare K levels in a multidisciplinary team is that prosthetists rate patients based on their potential, but physical therapists typically rate their

Table 15 – Medicare allowable components for each functional level

	Prosthetic Knees	Prosthetic Feet
Level 4	All components	All components covered
Level 3	Fluid	A flex foot system* or equal; usually includes a combined carbon fiber foot and pylon unit
	Pneumatic	Energy-storing foot
	Electronic	Dynamic response
Level 2	Single-axis	A flex walk system* or equal; usually refers to a low-profile carbon fiber foot system
	Constant-friction	Flexible keel foot
Level 1	Single-axis	Multiaxial ankle/foot
	Constant-friction	External keel SACH foot
		Single-axis foot

*The term flex foot and flex walk are actually used in the Medicare Supplier Manual. It now includes feet by many manufacturers that have similar design features.

patients based on actual performance. For example, a prosthetist may rate a patient as a Medicare K level 3 based on his or her assessment that the amputee has the potential to walk up and down hills and walk at a variable cadence at some point during rehabilitation. Typically, this rating is based on the patient's history, age, current condition, previously existing comorbidities, and desire to ambulate. On the other hand, physical therapists evaluate based on actual functional performance as assessed at the initial evaluation. Physical therapists do not evaluate using Medicare K levels, but understanding this classification system will help explain why a patient has certain prosthetic components and why Medicare will not cover other components.

Functional Independence Measure

The Functional Independence Measure (FIM), developed in 1987, is the most widely used and accepted functional assessment tool in rehabilitation.¹⁶ The FIM is a clinical tool based on the Uniform Data System for Medical Rehabilitation¹⁷ and can be used with patients of all ages and disabilities. The FIM must be administered only by trained personnel who are certified in the FIM system. The FIM is usually given to all patients within 72 hours of admission to a rehabilitation unit, and it is given within 72 hours of discharge from inpatient rehabilitation. Although it is used mostly in inpatient settings, it also can be used in outpatient settings.

The FIM is an 18-item, 7-level functional scale assessing both cognitive and physical disability in the areas of self-care, sphincter control, mobility, locomotion, communication, and social cognition. The scale measures both what the individual is able to do independently and how much physical or verbal assistance is needed from another person or assistive device to complete the task. Assistance is quantified according to the amount of care and time/energy required from the caregiver to complete the task. The FIM level scale goes from a maximum score of 7, defined as complete independence, to a minimum score of 1, defined as complete dependence. Complete

independence is defined as “all of the tasks described as making up the activity are typically performed safely, without modification, assistive devices, or aids, and within a reasonable amount of time.”¹⁶ The level scale is then subdivided based on the degree of assistance needed by the patient to perform the functional tasks. Table 16 provides complete definitions and scoring for each level.

Amputee Mobility Predictor

This Amputee Mobility Predictor (AMP)¹⁸ is another functional assessment tool used to assess an amputee’s current functional status for the purpose of predicting future ability to ambulate with a prosthesis. The AMP may be used as part of the initial evaluation to determine if a patient will be able to use a prosthesis. This test addresses general mobility, strength, and balance. It takes approximately 10 minutes to complete and requires few tools. It can also be used to establish pre-prosthetic goals for patients as well as to set performance goals for patients. The test is made up of 21 tasks, including:

- sitting and standing balance
- sitting and standing reach test
- transferring from chair to chair
- arising from a chair
- standing balance
- single-limb standing balance on sound limb and prosthesis
- nudge test
- picking objects up off the floor
- walking
- gait analysis
- turning while walking
- stepping over obstacles
- ascending and descending stairs

The AMP is to be conducted according to instrument instructions by Gailey and associates.¹⁸ Each participant is scored on these 21 tasks with a maximum possible score of 47.

Table 16 – Functional Independence Measure (FIM)

Functional Independence Measure (FIM)TM	
Score	Mobility Descriptor
7	Complete Independence – All of the tasks described as making up the activity are typically performed safely, without modifications, assistive devices, or aids, and within a reasonable amount of time.
6	Modified Independence – One or more of the following may be true: the activity requires an assistive device; the activity takes more than reasonable time; or there are safety (risk) considerations.
5	Supervision or Setup – Subject requires no more help than standby, cueing, or coaxing without physical contact, or helper sets up needed items or applies orthoses or assistive/adaptive devices.
4	Minimal Contact Assistance – Subject requires no more help than touching, and expends 75% or more of the effort.
3	Moderate Assistance – Subject requires more help than touching, or expends half (50%) or more (but less than 75%) of the effort.
2	Maximal Assistance – Subject expends less than 50% of the effort, but at least 25%.
1	Total Assistance – Subject expends less than 25% of the effort.

6. Overview of Prostheses

This section reviews transfemoral and knee disarticulation prostheses. Sockets, styles and suspensions, basic knee component characteristics and functions, foot styles and functions, and alignment concepts that involve both the physical therapist and the certified prosthetist are covered.

Understanding these concepts will help the physical therapist better assist patients in their progress toward a higher quality of life as a prosthesis user. This knowledge will also help the prosthetist and physical therapist communicate better for the sake of the patient.

The prosthetist's job is to fabricate and configure a prosthesis that meets the specific needs of a particular amputee. In pursuing this goal, the prosthetist faces several challenges. First, the fit of the prosthesis usually changes as the residual limb recovers after amputation. In the immediate postoperative period, the residual limb may be swollen. As the limb matures and recovers from the surgery, it often changes shape due to fluid reduction, swelling reduction, and muscle development or atrophy. The fit may also change with weight gain or loss, daily activity, or the effect of dialysis or other medical treatments. Also, the components of the prosthesis may be appropriate for the first several years but then need changing as the amputee becomes an established prosthesis user. The alignment of the prosthesis may need adjustment so that it continues to support the amputee's walking habits over time. Also, parts and components wear out and need repair or replacement.

The Prosthetist

The prosthetist is a clinician trained to fit prostheses (artificial limbs) to people who have had amputations. Prosthetists have to be creative and able to use many different approaches because no two amputees are alike.

The recovery timeline varies greatly among amputees. For some, the process from surgery to final prosthesis is short, but for others it is lengthy, with many stages of rehabilitation. According to a recent consensus conference on postoperative management for lower extremity amputation,¹³ the postoperative recovery period (including activity recovery, reintegration, prosthetic management, and training) is typically 12 to 18 months, regardless of the etiology of the amputation. The prosthetist may be brought onto a case preoperatively, though it is more common for them to first see the amputee after surgery. Prosthetists often work closely with the treating physician and surgeons to establish a comprehensive approach to rehabilitation.

The relationship between a prosthetist and an amputee changes over time. The relationship between the recent amputee and the prosthetist is a close one, with many visits taking place within the first months. Unlike the relationship between an amputee and a physical therapist, which typically is intense but short, the relationship between the amputee and the prosthetist can last a lifetime. Once the residual limb has matured, the visits become less frequent, perhaps less than

once a year or only when a problem needs to be addressed or a change in components is required.

Finding the right prosthetist is extremely important. The skills of the prosthetist should match the needs of the amputee. For example, a prosthetist that spends most of his or her time working with below-knee amputees may not be a good choice for a patient with a complicated above-knee amputation. The personality of the prosthetist is also extremely important. The amputee should feel comfortable communicating with the prosthetist. If the amputee needs a lot of personal attention, the prosthetist should be willing and able to provide that kind of care.

The prosthetist and the amputee will form one of the longest lasting relationships in clinical care and as a result, the amputee and the prosthetist should be in tune with one another to ensure proper appropriate prosthetic care. Amputees have the choice within their insurance coverage program of which prosthetist to see. An amputee should interview several prosthetists, discussing their plans and goals, to find the right fit both in skill and personality. An amputee may change prosthetists several times during the course of their life of care in order to find one which best suits their interests, needs, and quality of care. The relationship between an amputee and a prosthetist can often be life long, whereas an amputee and a physical therapist may only be together for a brief, but intense period of time during the rehabilitation process.

The physical therapist and the prosthetist should work together throughout the rehabilitative process. The physical therapist should feel comfortable contacting the prosthetist with questions, concerns, or observations to make sure that the patient's rehabilitative needs are being addressed in a timely manner. A prosthetist should feel equally comfortable consulting the physical therapist for updates on the patient's progress and use of the prosthesis. The goal is for the care providers to work together as a team.

Creating a Prosthetic Plan

Successful rehabilitation means different things for different amputees. Some amputees will use a prosthesis daily; others will use it intermittently for transfers, minimal ambulation, or cosmetic purposes; and for some the use of a prosthesis is neither possible nor desirable. The prosthetic plan involves addressing emotional, social, and physical goals for the amputee. The first element in any prosthetic plan is the identification of the user's goals and needs. Once these are identified, the prosthetist can assess the physical needs of the amputee. The prosthetist must assess several factors before designing a prosthetic device: the condition of the residual limb, the patient's general health, the patient's goals, and the patient's potential ability to use a prosthesis and potential level of ambulation.

Assessing the condition of the skin, tissue, and bone as well as the muscle mass of the residual limb is important for determining the type of prosthesis the patient can use.

Amputation etiology, comorbidities such as diabetes or cancer, and contralateral limb conditions also must be taken into consideration.

Prosthesis Fabrication

Once the physical evaluation is concluded, the prosthetist begins the process of creating a prosthesis. This includes the following steps: (1) taking physical measurements, (2) fabricating a temporary socket, (3) applying the knee, shin, and foot components, and (4) fabricating a final socket with appropriate alignment.

The length and circumference of the residual limb are first measured to record the overall size of the residual limb. This serves to establish a baseline to which future measurements can be compared. The prosthetist will also note any unique geometry, scars, or other features that may need to be addressed in the fabrication of the prosthetic socket. Typically, an exact mold of the residual limb does not make a good socket.

Fabrication of the prosthetic socket requires a number of steps, including capturing the residual limb shape, creating a positive model of the limb, modifying the positive model to indent areas or regions that will bear increased load and relieve regions where bone, prominence, scars, or hypersensitivity require decreased load, and finally fabricating the prosthetic socket. These steps can be accomplished through conventional, hand fabrication techniques, through automated, computer-aided techniques, or through a combination of these methods (Figure 6).

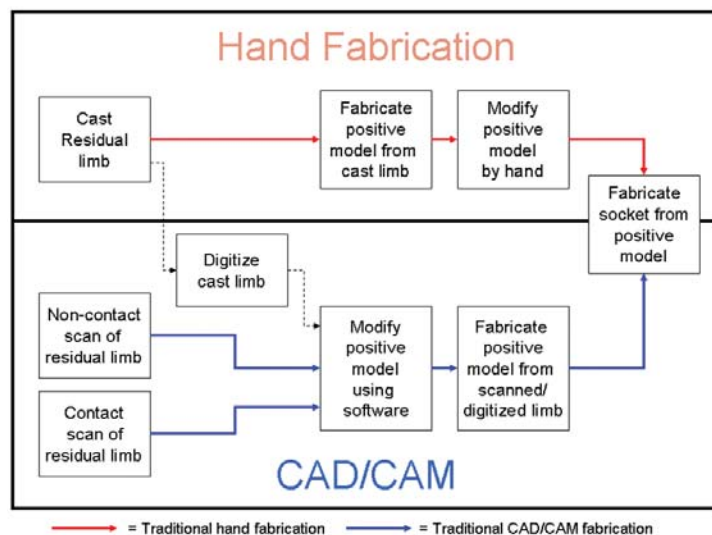


Figure 6 – CAD/CAM process for manufacturing a prosthetic socket

First, the bone and muscle landmarks as well as the overall shape of the residual limb are captured either by hand or with scanning equipment as part of a computer-aided design (CAD) process. Casting the residual limb by hand involves wrapping the limb with a plaster casting material, starting at the most proximal level of the limb (just above the greater trochanter) and wrapping circumferentially until the most distal end is wrapped completely. This process involves touching areas

near the perineum and genitalia and may be awkward or embarrassing for some amputees. The wrapped material is allowed to harden for several minutes, and then the amputee slips out of the cast, similar to slipping out of a pair of pants. The prosthetist then uses the removed cast as a mold to create a positive model or duplicate of the residual limb that serves as the template for the prosthetic socket.

Capturing the shape of the residual limb using CAD methods usually involves a scanning process. This process varies according to the manufacturer of the equipment used, and can be either a contact or non-contact method. In either case, the amputee is asked to hold the residual limb very still and a reference marker may be temporarily applied to the surface of the limb during the scanning process. Contact methods involve the use of a stylus or 'wand' which the prosthetist uses to touch the skin of the residual limb. Non-contact methods use an optical camera and/or laser to view the residual limb. The information recorded by the either method is transmitted to a computer and a three-dimensional model of the residual limb is available for the prosthetist to alter and to use as a template for the prosthetic socket.

Next, a positive model must be created from the captured shape. Using hand fabrication techniques, the residual limb cast is filled with plaster. The plaster is allowed to harden, and the cast is removed. With CAD techniques, the positive model is automatically generated by the software during the capture process. Alternatively, computer-aided-manufacturing (CAM) systems can be used to fabricate a positive model from plaster, foam, or other malleable materials.

The positive model must then be modified to account for specific loading, relief areas, brim shapes, and other changes in shape required for proper prosthetic fitting. As mentioned earlier, an exact mold of the outer shape of the residual limb does not make a well-fitting socket. The original mold must be modified to relieve areas of tissue that cannot tolerate pressure and to specifically load areas that can. With the traditional hand fabrication, the positive model is altered by removing or adding plaster in specific areas. Using CAD/CAM techniques, this is accomplished using the CAD software program. The prosthetist can choose to apply standard modifications or specific modifications can be made to the computer-generated model of the residual limb.

Once the positive model has been modified, the prosthetic socket can be fabricated based upon that shape. Using hand fabrication techniques, the modified model can be directly used for this purpose. For the CAD/CAM technique, a final positive must be created using a CAM system. This positive model is most often carved from plaster or foam. Using the positive model as a reference shape, the prosthetist will fabricate a temporary socket, or "check socket," by covering the model with molten plastic or another similar material. Once cooled, the positive model is removed and the edges of the socket will be trimmed and smoothed for a comfortable fit.

Check sockets are used early in the fitting process because they are durable enough for short-term use and yet can easily be

modified to accommodate the minor shape changes that occur in the residual limb as an amputee adjusts to wearing a socket. This socket is often transparent to facilitate assessing the fit. The amputee is initially asked to step into the check socket and then stand safely in it so that the prosthetist can assess pressure points, appropriate tissue distribution, and skeletal alignment within the socket. This process may require several visits and the prosthetist may use several check sockets before an optimal fit is achieved.

Once an appropriate, comfortable check socket fit is established, the prosthetic components are attached and anterior-posterior (AP) and medial-lateral (ML) alignment, and height of the prosthesis are adjusted. In some cases, this socket may be reinforced with fiberglass or other materials and the amputee will be asked to walk in it for several days or weeks to assess its comfort. Reinforced ambulatory check sockets can also be used to manage times of rapid volume change after initial or revision surgery, or to allow a “test drive” of a radically different socket style. Though durable, a check socket is not designed for long-term use and is replaced with a final or definitive socket once the fit has been optimized.

The definitive socket is made with very durable materials, often carbon or glass fibers impregnated in a resin. The socket may have a flexible inner liner or no inner liner at all. Modification of a definitive socket is difficult and typically only minor adjustments can be made. Careful fitting during the check socket phase is very important to achieving a comfortable definitive socket.

Factors That Affect Prosthesis Design

Knowing the patient’s goals helps to determine prosthesis design. For example, if the patient has a desire (and the ability) to learn how to run with a prosthesis, this should be incorporated into the prosthetic design process.

Cost is another factor to be considered when creating a prosthesis. Prosthetic devices are complicated and varied, and different insurance providers and health care plans classify the components, configuration, and patient needs differently. As discussed in Chapter 5, Medicare reimbursement is based on the assignment of an amputee to a K level, which requires an assessment of the individual’s potential function. As a result of these restrictions, the funds available for a prosthesis can be limited. The prosthetist is challenged with creating the best possible prosthesis within the funding available.

Once these determinations are made, a prosthesis can be designed that is appropriate for the patient’s goals. A transfemoral or knee disarticulation prosthesis includes the following components: a socket, knee, shin/pylon, foot/ankle, and suspension mechanism (Figure 7). These components will be discussed in detail later.

Levels of Amputation

The levels of amputation discussed in this section are the knee disarticulation and transfemoral levels. Socket shape,

modifications needed to load and relieve specific tissue areas, and socket brim shape can be different for the different amputation levels.

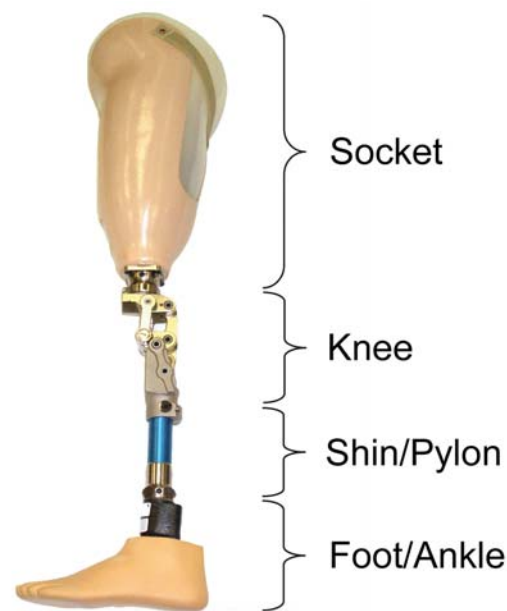


Figure 7 – Diagram of transfemoral components

Knee Disarticulation Level

Knee disarticulations are far less common than transfemoral amputations. Advantages of knee disarticulations are that the residual limb has distal end–weight-bearing capability, complete muscle use, and a longer lever arm; in addition, a less aggressive (smaller) socket is required. Disadvantages include lack of tissue or skin coverage at the distal end, resulting in possible skin breakdown and discomfort. In addition, the long residual limb, in combination with the added length of the knee components, results in one knee center being lower than the other, called knee center asymmetry. Often, a knee disarticulation socket can have increased end bearing, and will therefore require much less loading at the socket brim in the groin, ischial, and peroneal areas.

Transfemoral Level

The residual limb that results from a transfemoral-level amputation may be categorized as long, medium length, or short. The long transfemoral limb has most of the femur intact and may even retain a portion of the femoral condyles. Because the adductor tubercle is retained, most of the thigh musculature is available to help control the prosthesis. The medium-length limb, often referred to as a midhigh-level amputation, is a more common amputation level. At this level, usually the femur has been transected somewhere between just above the condyles and the midhigh region. In the short residual limb, the remaining femur is generally no more than 10 cm long.

Overall, the shorter the residual limb, the more challenging the prosthetic fit. Also, very short transfemoral amputations are complicated by the loss of the balancing musculature and the shorter lever arm. This makes efficient ambulation more

difficult. In particular, this lever arm and reduced muscle strength make hip stabilization during the stance phase of gait more difficult. This often results in an increased Trendelenburg in single-limb stance.

Prosthetic Socket Fit

The socket is the interface between the residual limb and the prosthetic device and is the most important part of any prosthesis. If the socket does not fit, the rest of the prosthesis will not function properly. The fit and function of the socket can greatly affect gait, pain level, or the ability to accomplish physical tasks.

Sockets are designed to enclose the skin, tissue, muscle, and bone of the residual limb and serve as an efficient interface between the residual limb and the prosthetic components (Figure 8). Ideally, the socket must be sturdy enough to bear the full weight of the amputee as well as provide a safe and comfortable environment for the residual limb. The socket should meet the following criteria: (1) the fit should be comfortable, (2) the suspension should be effective, and (3) it should allow the amputee to move and/or ambulate.

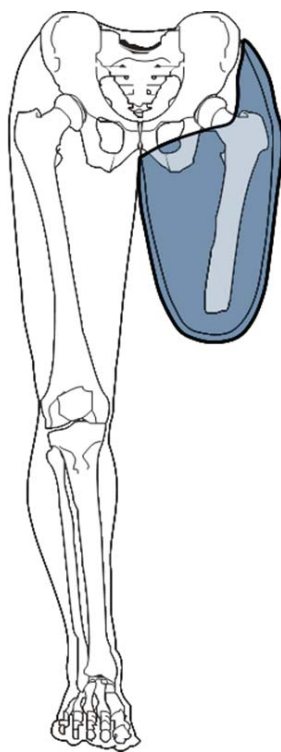


Figure 8 – Diagram of transfemoral amputation

Socket fit determines the utility of the socket and often the success of the entire prosthesis. The socket must be comfortable for the amputee throughout daily use and activities (Table 17). Several factors can cause poor fit, including weight gain; weight loss; medical conditions that cause changes in the volume of the limb, such as from dialysis or medication; other medical complications; and pregnancy. The prosthetist should be alerted to problems relating to fit and should address them as soon as possible to prevent lasting damage to the residual limb and other parts of the body of the amputee.

Table 17 – Characteristics of well and poor fitting sockets

Well-Fitting Socket	Poorly Fitting Socket
Comfortable in all aspects of use	Only comfortable at certain moments, if at all
Little to no skin breakdown on the residual limb	Apparent skin breakdown or redness on the residual limb especially around bony protuberances, proximal brim areas, or distal end
No complaints of nerve soreness, pressure points or pain	Complaints of bruising or pain in the groin area or distal end
No distal end or proximal edema	Complaints of pain, breakdown, blistering in the proximal brim areas, swelling and/or redness around the distal end
Healthy distal end tissue and appearance	Complaints of distal end soreness, discomfort or pain
Little to no muscle fatigue from constriction	Complaints of muscle fatigue, constriction, sense of limb being pinched, numb or tingling sensation
No blistering, chaffing, raw skin at proximal levels	Proximal skin edema
Skin with healthy coloration in appearance without significant blanching or redness	Discoloration of skin, blanching or excessive redness after doffing the prosthesis
Soft healthy skin and tissue at distal end	Distal area hardness or fluid filled sacks
No open sores, cuts, or abrasions	Existence of open sores, cuts, or abrasions

Socket Styles

Many different socket shapes and styles have emerged over the years. These have evolved largely as a result of individual clinical prosthetists seeking creative ways to meet their clients' needs. No two sockets are exactly the same, each having been specifically designed for the individual user. Choice of socket style depends greatly on the physical, mental, and emotional attributes of the amputee as well as the preference of the amputee and prosthetist.

Transfemoral Sockets

Socket style is most commonly defined by the brim, or proximal section. The brim is the proximal part of the socket, which in transfemoral prostheses contains the pelvis. The two basic foundational socket designs that are regularly used in the clinical setting are the quadrilateral socket and the ischial containment socket.

Quadrilateral Socket

Developed in the 1950s, the quadrilateral socket, also known as the quad socket, has four walls, each with its own specific function (Figure 9). The posterior wall (or seat) is the major weight-bearing area, supporting the ischial tuberosity and the gluteal muscles. The posterior wall is thick in the medial area, to better support these anatomic structures, and thinner in the lateral area, where less support is needed. The posterior wall is also contoured to incorporate the hamstring muscles, which enhances mobility. The anterior wall is molded over the femoral triangle, providing stabilizing pressure to help

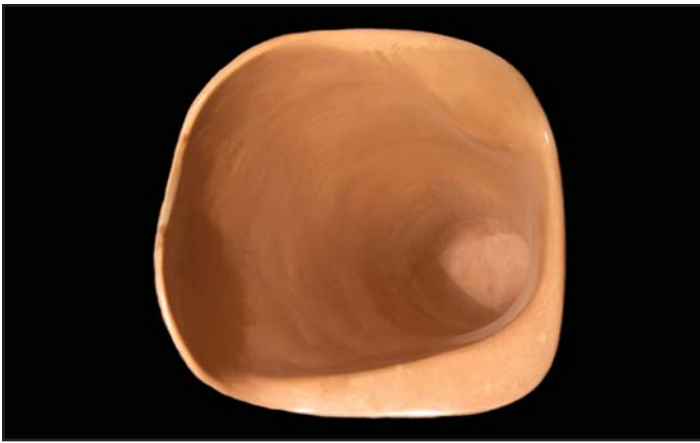


Figure 9 – Quad socket brim



Figure 10 – Narrow medial-lateral socket brim

keep the ischial tuberosity securely seated. The lateral-anterior wall is contoured to allow space for the rectus femoris muscle. Traditional quadrilateral sockets provide a lateral wall that is the same height as the anterior wall. However, a prosthetist may choose to extend this wall beyond the greater trochanter in order to increase lateral trunk stability. The medial wall is vertical and parallel to the sagittal plane. This wall prevents lateral shift of the socket on the limb during stance phase. Typically, the medial and posterior wall are the same height. However, the medial wall may be made lower if necessary to relieve pubic ramus pressure or discomfort. Sockets are typically configured to incorporate 7-9° of adduction and 5° of flexion at the hip (in addition to any contracture present) to assist in pelvic control and normal gait mechanics.

Quadrilateral sockets are usually designed to be in total contact with the residual limb. This design prevents distal end edema, or inappropriate fluid retention in the residual limb. Prolonged lack of total contact may result in significant skin injury, discoloration, and thickening. Occasionally, amputees who have severely painful limbs or who reside in very warm, humid environments (South East Asia, for example) choose a quadrilateral socket with no distal contact; however, their skin must be closely monitored for reactive tissue.

Narrow Medial-Lateral Socket

The narrow medial-lateral (ML) or ischial containment socket (Figure 10), was developed in the early 1980s to provide total contact with the residual limb and total surface weight bearing. This type of socket provides greater comfort during loading and weight bearing, more normal swing phase, and greater pelvic control during stance. The narrow ML socket envelopes the entire residual limb, as well as the ischium and the pubic ramus, which rest within the socket rather than on a “seat,” as in the quadrilateral socket. The narrow ML socket is reported to provide greater rotational stability in the frontal plane than the quadrilateral socket. The lateral wall of the narrow ML socket extends above the greater trochanter to give stability to the pelvis during stance phase.

Variations in Transfemoral Socket Design

Transfemoral socket styles also include variants that incorporate flexible inner liners or malleable thermoplastics supported by

a smaller and/or more region-specific rigid frame (Figure 11). Sockets of this kind are typically used by more ambulatory amputees and may address the needs of a specific user more appropriately than the standard styles.



Figure 11 – Narrow medial-lateral socket with flexible inner liner

Another variant is the Marlo Anatomical Socket (MAS), named for prosthetist and inventor Marlo Ortiz Vazquez del Mercado, which provides more room for natural gluteal muscle placement (Figure 12).

Anecdotal reports indicate that these newer socket styles may provide some advantages, including enhanced suspension, increased comfort, and less heat retention. It is important to remember, however, that a newer design may not be the best design for a particular amputee. Prosthetists vary their techniques and approaches to meet the comfort level and needs of an individual amputee. No single socket style is best for all amputees or all situations. Any of these socket styles may be appropriate for any number of amputees. Some amputees may use several different styles throughout



Figure 12 – MAS socket style

their lifetime as their needs and desires change. The fit and appropriateness of a socket is ultimately more dependent on the individual making the prosthesis and the satisfaction of the amputee than on a particular style.

Knee Disarticulation Sockets

Sockets for most knee disarticulation amputees are designed to provide some weight bearing through the distal end of the limb (the femoral condyles). The socket design for a knee disarticulation–level amputee with strong musculature can be less cumbersome than for a transfemoral amputee because the proximal brim can terminate below the perineum. For amputees who require more stabilization, the socket style will be more similar to that for a transfemoral amputee.

Socket Suspension

A common question is “How does the prosthesis stay on?” The method of securing the socket and attached components to the residual limb is called suspension. Typical suspension methods include suction, liner with pin lock, liner with lanyard, and Silesian belt or hip joint and pelvic band. Each method may have disadvantages and advantages for a particular user.

Suspension is important because pistoning, or movement of the limb up and down inside the socket during the gait cycle, may occur if suspension is inadequate. The resulting friction may cause skin irritation and breakdown.

Suction

Suction suspension is created by a socket that is slightly smaller than the residual limb, leaving no room for air between the socket and the skin. The residual limb is then in direct contact with the socket material (ie, there is no sock or interface). The goal of the suction socket is to create negative pressure within the socket, much like the suction created when you hold your finger over the end of a straw: As long as no air gets in, the liquid remains in the straw. When there is air in a suction socket, the prosthesis will not suspend properly and friction blisters, sores, and other skin conditions will develop. The user of a suction socket pulls the residual limb into the socket, replacing the air space with soft tissue. These sockets usually have a valve at the distal end of the prosthetic socket (Figure 13). This valve is removed before donning the prosthesis,



Figure 13 – Suction socket, “flexible socket and brim”

and then replaced once the user has completely pulled the residual limb into the socket. The suction system must provide sufficient negative pressure to hold the prosthesis securely on the residual limb through swing phase. Table 18 gives an overview of suction suspension.

Table 18 – Key characteristics of suction suspension systems

Suction Suspension	
Advantages	Disadvantages
Eliminates pistoning	Requires consistent limb volume
Improved proprioception	May be “hot” or sweaty
Feels “lighter” and less cumbersome	May be difficult to don
Indications for Use	
Long residual limbs	
Good skin condition	
Good patient balance	
Good upper extremity strength	
Contraindications for Use	
Very short residual limbs	
Severe scarring, delicate tissue or skin	
Upper extremity weakness	
Frequent volume fluctuations	
Dermatitis issues	
Heart conditions or balance concerns	
Poor vision	

Liner with Pin Lock

Another method of suspending a socket is to incorporate a roll-on liner, which acts as an intermediary between the residual limb and the socket (Figure 14). These liners are most



Figure 14 – Elastomeric liner

commonly made from silicone or other elastomers. Often, a pin mounted at the distal end of the liner (Figure 15) engages a lock at the bottom of the socket. These pins range in length from ½ inch to 3 inches, depending on the lock type and the needs of the patient. To don this type of system, the amputee



Figure 15 – Liner with pin

first rolls on the liner so that the pin is lined up with the end of the residual limb, then steps into the prosthesis and “ratchets” down into the pin lock located at the base of the socket frame (Figure 16). Table 19 gives an overview of liner with pin lock suspension systems.

The locking pin system has several advantages. First, it can accommodate residual limb volume fluctuations. The volume of some residual limbs fluctuates considerably throughout the day, resulting in a poor socket fit. Second, for amputees who have compromised skin due to burns and grafting, the liner provides a safe and comfortable interface during static standing and dynamic gait, assuming the skin can tolerate the materials.

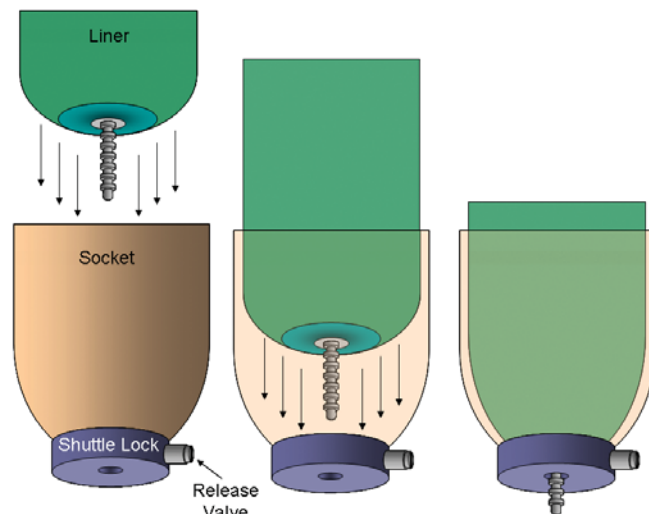


Figure 16 – Pin and lock

One disadvantage of this system is the discomfort produced at the distal end of the residual limb due to “milking.” This behavior is caused by proximal-distal socket motion, often called pistoning.¹⁹ During swing phase, the weight of the prosthesis causes it to separate slightly from the end of the residual limb, causing a vacuum or a pulling sensation between the distal part of the limb and the liner. This can cause edema, fluid pooling, swelling, pain, or blistering. Other disadvantages may also include skin irritation at the proximal end of the liner, issues related to hygiene and occasional difficulty with disengaging the lock, complicating prosthesis removal.

Table 19 – Key characteristics of liner and pin suspension systems

Liner & Locking Pin	
Advantages	Disadvantages
Seated donning procedure	Possible distal end pulling or “milking” sensation
Greater room for volume fluctuation	Decreased sense of proprioception
Softer distal support	Increased sweating
Smoother donning and doffing procedure	Possible bacterial infections (more stringent hygiene requirement)
Indications for Use	
Short to long limbs	
Semi-compromised skin conditions	
Compromised balance	
Frequent minor volume changes	
Contraindications for Use	
Distal end prominences	
Irregular residual limb shape	
Upper extremity weakness	
Dermatitis issues	
Large invaginated scars, hygiene concerns, intolerance of compressive forces, adhesions, large volume changes	

Liner with Lanyard Suspension

In situations where a locking pin is inappropriate or intolerable, the prosthetist can modify the pin lock system to incorporate a

lanyard, a strap or rope attached to the distal end of the liner. The strap, typically made from a durable Velcro material, feeds through a distal slot in the socket frame and attaches to the compatible Velcro piece on the external face of the socket (Figure 17). This type of suspension is easily donned and doffed, and some amputees report that it minimizes the “milking” sensation during ambulation.

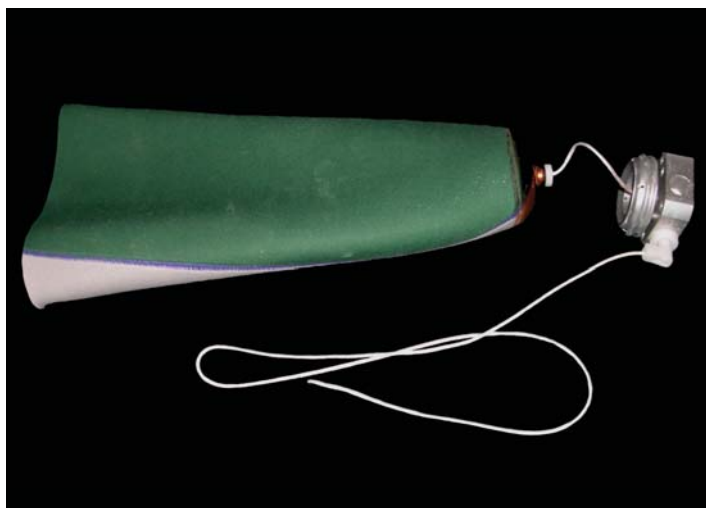


Figure 17 – Liner with lanyard

Silesian Belt Suspension System

The Silesian belt is either a custom or prefabricated belt that wraps around the waist from the lateral wall of the socket and attaches to a second strap on the anterior wall. It usually attaches to itself by Velcro or a buckle (Figure 18). The Silesian

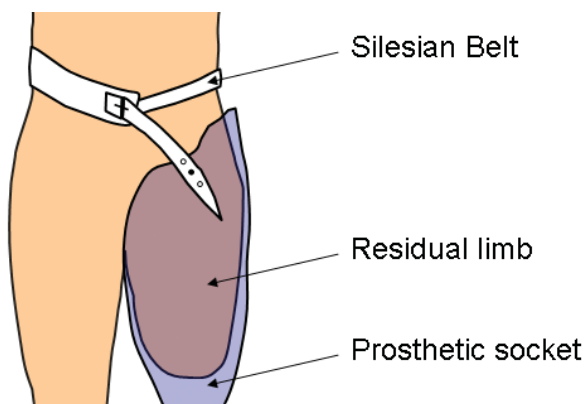


Figure 18 – Silesian belt suspension system

belt can be used to maintain socket suspension when suction or liner systems are not an option. They also may be used as an auxiliary suspension system with liners or suction systems or for improved transverse rotational control. Table 20 gives an overview of Silesian belt suspension.

Vacuum-Assisted Suspension

This type of suspension is based on the idea that if vacuum is added to a liner-based suspension system, it will provide greater stability, improved proprioception, and less volume fluctuation.

Table 20 – Key characteristics of Silesian belt suspension systems

Strap or Silesian Belt	
Advantages	Disadvantages
Easy to don	Added bulk around the waist
Adjustable	Less anatomic, uncomfortable
Indications for Use	
When other suspension styles are not optimal	
Offers auxiliary suspension	
Supports greater rotational control	
Contraindications for Use	
A pendulous abdomen	

Anecdotal reports indicate that added benefits include increased wound healing properties and better vertical shock absorption. Vacuum-assisted systems create a pump-actuated vacuum at the liner-socket interface. As the amputee walks, the weight or motion of the body compresses a pump to create a vacuum between the liner and the socket. This type of system is still new, and little independent research has been published reporting on its function and utility. Therefore, indications and contraindications have not clearly been identified and supported.

Sealed Liner Suspension System

Another type of liner that is becoming popular incorporates a hypobaric sealing membrane (HSM) that conforms to the shape of the internal socket wall, providing an airtight seal. When the liner is donned and the socket is stepped into, air is expelled through a distal valve, creating suction below the seal. A release button on the valve allows equalization of air pressure for easy removal of the prosthesis. The benefit of this type of suspension is that it does not require a pin or lanyard when using a liner. This system is also new to the market, and few studies have been conducted on the suitability of the design for transfemoral and knee disarticulation amputees.

Socket Donning Methods

For most transfemoral amputees, donning the prosthesis can be a challenge. Because sockets vary in style, suspension, and use, different donning and doffing methods also exist. The purpose of each is to provide the user with the best and safest method for donning and doffing. The correct donning procedure results in the residual limb being fully inside the socket with correct skeletal and muscular alignment. Poor or incomplete donning technique results in one or more of the following:

- Proximal soft tissue that folds over the brim of the socket, typically on the medial side
- A gap of 1 cm or more between the distal end of the limb and the base of the socket
- Residual air expulsion with movement such as walking, sitting, standing
- The prosthesis feeling too tall or unstable
- Pain
- Unusual rotation of the knee and foot
- Improper location of the ischium.

While donning can be a challenge for all socket styles, it is particularly difficult for suction socket and Silesian belt systems. The various donning techniques discussed here take into consideration both the physical and emotional needs of the amputee. Physical challenges to consider include poor balance, diminished eyesight, and limited upper limb strength and dexterity. Each technique can be adapted to address an individual amputee's needs.

Slip Sock

A slip sock helps to pull the soft tissue of the residual limb into the socket. The slip sock is usually made from a double-layered piece of slick fabric such as nylon. Some socks have a strap, pull, or loop at the distal end. The sock is placed loosely over the residual limb, the sock and residual limb are placed in the socket, and the sock is pulled through the distal end opening. As the sock is pulled through the socket, the tissue of the residual limb is pulled into the socket with no discomfort. The amputee must move the limb up and down to slip the tissue in and the sock out. This technique requires some practice, patience, and good balance (Figure 19).



Figure 19 – Slip socket method

Elastic Bandage

The elastic bandage method is similar to the slip sock. The amputee wraps the residual limb circumferentially, from as high on the residual limb as possible to just proximal to the distal end. Enough of the bandage should be left at the end to extend through the distal valve opening; this will be used to pull the bandage out. Once the limb is wrapped, the user steps into the socket, pulls the bandage from the distal end, and in so doing, pulls the tissue into the socket. This technique has

several disadvantages. It requires some force; the amputee needs good balance to be able to stand in the socket and pull down into the socket at the same time; and the technique has been reported to be associated with a “rope burn”-type skin irritation (Figure 20).



Figure 20 – Elastic wrap method

Wet Fitting

A “wet fit” technique also can be used with suction sockets. First, a wet-to-dry lotion (a lotion that dries quickly to a powder) is applied liberally to the residual limb. The lotion lubricates the limb so that the user can step easily into the socket and achieve an appropriate fit. The lotion then dries in the socket over time, leaving the residual limb with a secure fit in the socket. Caution should be used with wet fit donning, as compression of the proximal tissues at the socket brim may lead to an adductor roll (Chapter 1).

Prosthetic Components

The transfemoral or knee disarticulation prosthesis can be either endoskeletal or exoskeletal. In an endoskeletal prosthesis, the components may be left uncovered (Figure 21) or are hidden inside a cosmetic cover. With an endoskeletal system, components such as knees and feet can be interchanged easily. Another advantage to an endoskeletal prosthesis is that the prosthetist can adjust the alignment and service the components without destroying the exterior of the prosthesis.

An exoskeletal system has a rigid exterior that replaces the tubular weight-bearing components in the thigh and leg of the prosthesis (Figure 22). Exoskeletal prostheses are more durable than endoskeletal prostheses, but they do not allow for easy alignment or component changes.



Figure 21 – Endoskeletal prosthesis



Figure 22 – Exoskeletal prosthesis

The choice of endo or exoskeletal prosthesis depends largely on the preferences of the amputee, in addition to the prosthetic needs. Cosmetic covers can easily be damaged, torn, or stained and may be difficult to clean. Therefore, exoskeletal systems are more common in the pediatric population because of their durability and ease of cleaning, but endoskeletal systems are also used widely.

Prosthetic Knees

Transfemoral Prosthesis Configurations

The prosthetic knee is designed to mimic the function of a normal human knee, including providing the user with shock absorption and stance support during gait. Various types of knees are available from a number of manufacturers. The knees differ in the type of hinge and the method(s) of control used by the knee in the swing and/or stance phases of gait. The physical characteristics of knees are described in detail here, please see Chapter 12 for proper gait training techniques.

Prosthetic knees use one of two main types of hinge joints, a single-axis joint or a polycentric joint. The single axis joint flexes about a fixed point of rotation whereas a polycentric joint flexes about a moving instant center of rotation (ICR). Because of the design of the mechanical linkage in the polycentric knee, the distal portion of the knee unit first slides posterior, then flexes about the proximal attachment of the knee unit (Figure 23). This is often advantageous for amputees because it effectively shortens the prosthetic limb during swing phase

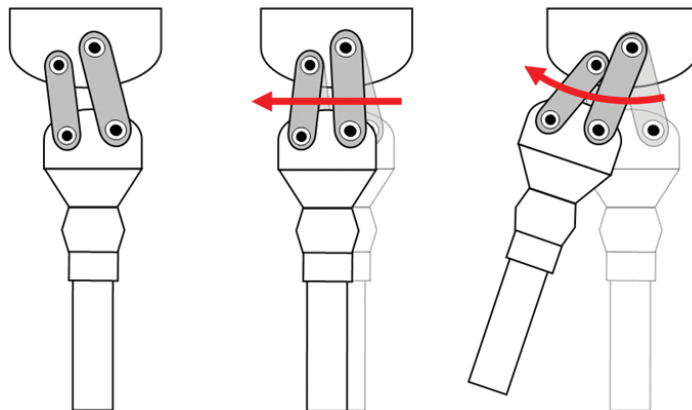


Figure 23 – Polycentric knee mechanism

and allows the prosthetic toe to easily clear the ground. It also creates a more natural appearance while the amputee is sitting as compared to other knee units (Figure 24).

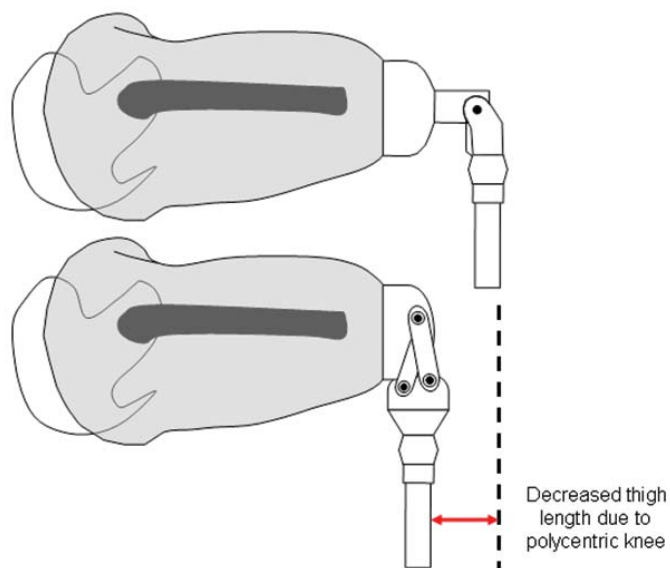


Figure 24 – Flexed polycentric and single-axis knees

The stability of a knee in stance is determined by where the weight line or ground reaction force (GRF) falls with respect to the knee center. If the weight line is anterior to the knee center (single-axis knee) or ICR (polycentric knee), the knee will remain extended and stable. If the weight line falls posterior to the knee center or ICR, the knee will flex. This behavior is illustrated for both types of knees in Figure 25.

Prosthetic knees can use various methods to control the knee behavior during the swing and stance phases of gait. Knees may include manual locking, constant friction, weight-activated, and/or fluid mechanisms. Knee units often incorporate more than one control mechanism for the different phases of gait and the timing of these mechanisms may be controlled mechanically or by a microprocessor. A brief summary of common knee units is included below and a list of selected commercially available units is included in Table 21.

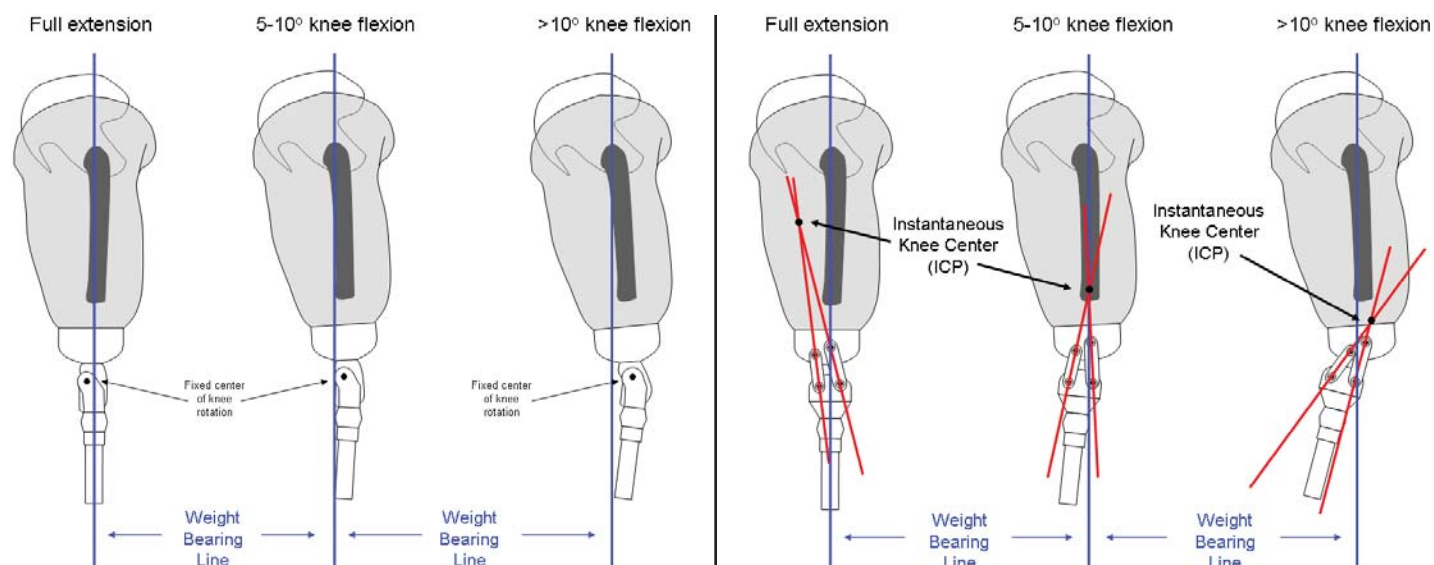


Figure 25 – Stability in single-axis and polycentric knees

Table 21 – Examples of commercially available prosthetic knee units by hinge type and control system

Knee Unit	Hinge	Stance Control System	Swing Control System
Hosmer SAFK	Single-axis	None	Friction
Otto Bock 3R22			
Hosmer WALK			
Otto Bock 3R15	Single-Axis	Weight Activated Friction Brake	Friction
Seattle Safety Knee			
Hosmer SALK			
Otto Bock 3R40	Single-axis	Manual Lock	Friction
Seattle SALK			
Otto Bock 3R95			
Otto Bock 3R36	Polycentric	None	Friction
Ohio Willow Wood GeoLite			
Seattle Natural Knee			
Seattle Select	Polycentric	None	Fluid (Pneumatic)
Otto Bock 3R106			
Hosmer SpectrumEX			
Otto Bock 3R55	Polycentric	None	Fluid (Hydraulic)
Ossur Total Knee 2100			
Otto Bock 3R60			
Otto Bock 3R80	Single-axis	Fluid (Hydraulic)	Fluid (Hydraulic)
Ossur Mauch SNS	Single-axis	Fluid (Hydraulic)	Fluid (Hydraulic) or Manual Lock (user selected)
Endolite Hydraulic SNS			
Hosmer Entegra 180			
Seattle Systems SPK700	Single-axis	Weight Activated Friction Brake	Microprocessor (Pneumatic)
Seattle Systems SPK750	Polycentric	None	Microprocessor (Pneumatic)
Seattle Systems SPK760	Single-axis	Fluid (Hydraulic)	Microprocessor (Pneumatic)
Endolite IP+	Single-axis	Weight Activated Friction Brake	Microprocessor (Pneumatic)
Endolite Adaptive	Single-axis	Microprocessor (Hydraulic)	Microprocessor (Pneumatic)
Otto Bock Compact	Single-axis	Microprocessor (Hydraulic)	Fluid (Hydraulic)
Freedom Innovations Plié			
Ossur Rheo	Single-axis	Microprocessor (Hydraulic)	Microprocessor (Hydraulic)
Otto Bock C-Leg			

Constant Friction Knee

Constant Friction knees are single-axis or polycentric knee units (Figure 26) that apply friction to the joint to control knee flexion and extension. The amount of friction (and the relative



Figure 26 – Constant friction knee

ease of bending the knee) may be adjusted to accommodate a patient's strength or speed of gait. The constant friction knee is only stable when the GRF is anterior to the center (single-axis) or ICR (polycentric) of the knee unit. These knees are most commonly used by young adults or children because of their simplicity and durability or by an amputee who wants a mechanically reliable knee unit that is easy to use and maintain.

Manual Locking Knee

Manual locking knees are single-axis knees that provide stability through a physical lock on the knee unit (Figure 27).



Figure 27 – Manual locking knee

The knee remains extended and stable for as long as the lock is engaged. When the lock is disengaged, the knee swings freely and stability is achieved only when the weight line is anterior to the knee center. These knees are most commonly used for the elderly amputee who needs assurance that the knee will not flex and collapse during stance phase. To flex the knee in order to sit, the amputee pulls a string or cord secured at the proximal socket to disengage the locking mechanism.

A prosthesis with a manual locking control is often designed to be slightly shorter than the opposite limb to provide room for the toe to clear during swing phase because the amputee cannot bend the knee to clear the foot when the lock is engaged. This often results in a somewhat abnormal gait (See Chapter 12).

Weight Activated Knee

The weight activated friction brake knee is a single-axis knee that incorporates a friction brake that is activated by the patient's body-weight (Figure 28). As the amputee loads



Figure 28 – Weight-activated friction brake knee

the prosthesis, the internal components of the knee compress, either significantly increasing the resistance to bending or fully locking the knee in extension. The friction brake in the knee then unlocks as weight is relieved in late stance, allowing the knee to swing freely during swing phase. Stability is achieved through adequate loading of the friction brake. This knee is appropriate for elderly, low-level ambulators who may use assistive devices such as walkers and canes or recent amputees who need an extra degree of security while they get used to wearing a prosthesis.

The weight-activated friction brake knee has some drawbacks. The weight on the knee has to be completely unloaded before it can flex, allowing normal swing phase or sitting. Further, if the amputee does not load the knee properly (i.e., when the knee is flexed more than 20 degrees), the knee is likely to collapse and the user may fall. For these reasons, weight-activated knees are not recommended for both limbs of a bilateral amputee. It is however, often used on one limb for this patient population. Amputees must learn how to properly load and unload this type of knee properly in order to guarantee smooth gait, safe stance phase ambulation, and controlled sitting (See Chapter 12).

Fluid Control Knee

The fluid controlled knee is a single-axis or polycentric knee that incorporates hydraulic or pneumatic systems to resist joint motion (Figure 29). Hydraulic mechanisms



Figure 29 – Fluid control knee

incorporate oil, whereas pneumatic mechanisms incorporate air, but both control motion by forcing the fluid through a valve. The size of the opening in the valve, and hence the resistance to motion, can be adjusted by the prosthetist to accommodate different patients. These types of knees are “cadence responsive,” which means that as an amputee walks faster, knee flexion is limited. As they slow their speed, knee flexion becomes easier. This allows an amputee to ambulate at various walking speeds. These knees are commonly indicated for amputees who wish to walk at different cadences. Some of the disadvantages of these knees are a need for increased maintenance and a greater weight due to the increased complexity of the components compared to the previously mentioned knee units.

Fluid control knees have evolved in complexity from a single resistance control to multiple controls that allow a prosthetist to adjust the behavior of the knee in the different phases of gait (i.e. terminal swing). For example, the Total knee (Össur, Rejivick, Iceland) allows the prosthetist to set different resistances to extension, flexion from 0 to 60 degrees, and flexion from 60 degrees and greater. Other fluid controlled knees offer advanced control of the knee unit by changing behavior in the swing and stance portions of gait. These knees, often referred to as stance-and-swing (SNS) knees, provide a different resistance to flexion and extension in stance than they do in the swing phase of gait. Additionally, some provide a yielding stance control that supports the amputee, even when the knee is slightly flexed. SNS knees are commonly used by medium- to high-level ambulators for traversing community barriers or uneven terrain or for participating in recreational sports.

Microprocessor Control Knee

The microprocessor control knee is a single or polycentric axis knee that uses a computer microprocessor to adjust the behavior of the knee during gait. Which phases of gait are controlled and how they are affected by the microprocessor vary, depending upon the prosthetic knee model (see Table 21). Discussion of microprocessor knee features in this text will focus on the Otto Bock C-Leg® (Figure 30), but may be applicable to other types of microprocessor knees.



Figure 30 – Microprocessor knee

The C-Leg® uses a microprocessor to control a hydraulic valve and provide variable resistance to knee motion. The microprocessor constantly monitors gait parameters such as knee angle and weight on the prosthesis to determine whether the amputee is in swing or stance phase, and controls the knee joint accordingly. Like some fluid control knees, the C-Leg® also allows the knee to flex slightly under weight without collapsing, thereby more closely mimicking normal locomotion.

Commonly reported benefits of microprocessor control knees include a more natural gait; increased proprioception; better balance; better stumble recovery; increased ability to traverse stairs, ramps, and rough terrain; less need to concentrate on the mechanics of walking; and a more energy-efficient gait, resulting in less physical fatigue. Limitations of the microprocessor control knee include a need for recharging, limited resistance to the elements (water, moisture), an increased cost of repair, and the additional training required for optimal use of these devices.

Knee Disarticulation Prosthesis Configurations

Because the femoral condyles are preserved in knee disarticulation amputees, there is limited space for a prosthetic knee and fewer knee options available to the prosthetist. If

a conventional transfemoral knee unit is used with a knee disarticulation prosthesis, the knee center will be located more distal than the opposing limb. Because of this, the gait pattern will also be affected by the different locations of the knee centers. Specific polycentric knees designed for knee disarticulation amputees are often indicated regularly for knee disarticulation amputees because they allow easier clearance of the prosthetic foot in early swing phase, as described earlier.

Prosthetic Feet

Like prosthetic knees, prosthetic feet should ideally mimic the normal function of the missing body part, in this case the foot. These functions include shock absorption, normal rollover during gait, stabilization over uneven terrain, and adaptation to slight inclines and declines. Many types of feet are available today, including the solid ankle-cushion heel (SACH) foot, the single-axis (SA) foot, the multiaxial (MA) foot, and the energy storage and return (ESAR) foot.

SACH Feet

The simplest and most economical foot is the SACH foot, which is the predecessor of many of the foot designs currently available. The SACH foot is made of a solid keel (often made from wood) with a foam heel cushion, and the entire foot is encased in polyurethane. With no moving parts, the SACH foot is very inexpensive, durable, and requires little maintenance. The heel of the SACH foot compresses at heel strike, stimulating plantar flexion. The stiffness of the heel can vary and is determined by the prosthetist based on the ambulatory needs of the amputee. A heel that is too stiff for the user will cause early knee flexion and knee instability. An overly soft heel will be difficult to roll over and may create the impression of sinking into a hole. A disadvantage of a SACH foot is the lack of toe stiffness at late stance phase, causing the patient to have little or no support on the prosthetic side at terminal stance and a short step length on the contralateral side to compensate for this lack of support. The SACH foot can be used for just about any level of amputation, depending on the preference and goals of the amputee and the prosthetist.

Single-Axis Feet

The single-axis feet pivot about the ankle like a simple hinge. Dorsiflexion and plantar flexion are limited by bumpers made of hard rubber. At heel contact, the heel bumper compresses, reducing the plantar flexion moment. This allows the foot to come to foot flat early in stance phase. This early foot flat moves the GRF in front of the knee very early in stance, instigating a knee extension moment and therefore enhancing the stability of the prosthetic limb. The single-axis foot also has a dorsiflexion bumper, which limits the amount of dorsiflexion throughout midstance and terminal stance. The prosthetist selects the firmness of these bumpers according to the weight and function categories of the amputee. The single-axis foot is often used for elderly users or for amputees who have difficulty with stance-phase knee stability. Table 22 lists characteristics of the single-axis foot.

Table 22 – Single-axis foot characteristics

Action	Advantages	Indications
Ankle dorsiflexion and plantar flexion	Promotes knee stability with early foot flat	Patient requires knee stability
Components	Disadvantages	Contraindications
Ankle bolt	Increased weight	Active patients
Plantar flexion bumper	More need for maintenance	Patients requiring torque absorption and inversion/eversion
Dorsiflexion bumper		

Multiaxial Feet

Multiaxial feet allow limited motion in dorsiflexion and plantar flexion as well as inversion, eversion, and transverse rotation. These movements are moderated by a set of bumpers. This multiaxial motion is reported to help amputees cross uneven terrain, maneuver slight inclines and declines, and participate in activities requiring rotation of the foot, such as golf. Because multiaxial feet have multiple moving parts, they are typically heavier and require more servicing than single-axis or SACH feet. In addition, they may feel less stable because of these multiple degrees of freedom. Table 23 lists characteristics of multiaxial feet.

Table 23 – Multi-axial foot characteristics

Action	Advantages	Indications
Dorsiflexion and plantar flexion	Absorbs torque	Active patient
Inversion and eversion	Absorbs shock	Patient requiring torque absorption inversion and eversion
Transverse rotation	Allows foot to conform to uneven surfaces	
	Decreases shear forces	
	Decreases moments at the socket and knee	
Components	Disadvantages	Contraindications
Universal joint	More need for maintenance	Patient with poor balance
Plantar flexion bumper	Increased weight	
Dorsiflexion bumper		

Energy Storage and Return Feet

Energy storage and return feet, also called dynamic-response feet, were developed to provide greater function during dynamic activities such as running. These feet have flexible keels, which provide shock absorption during loading. As the foot is unloaded, the energy is expelled, pushing the foot forward and providing the amputee with greater function. The faster the gait, the more energy is stored and released. The

stiffness or 'give' of the keel is determined by the manufacturer and is largely based on the amputee's weight and level of activity. These feet are commonly used by athletes and high-activity ambulators, but they can be used by other amputees as well. Table 24 lists characteristics of ESAR feet.

Table 24 – Energy storage and return foot characteristics

Action	Advantages	Indications
Heel compression	Stores and releases energy	Active patients
Compression of internal mechanism from midstance to heel-off	Provides smoother gait	Community ambulators
Dynamic push-off of keel from stored energy	Decreases energy expenditure	
Some feet provide inversion, eversion, and rotation	Light weight	
Components	Disadvantages	Contraindications
High tech material for heel and keel mechanisms	Expensive	Household ambulators/ K1 or K2

Adjustable Ankle-Foot Systems

One development in prosthetic feet is the incorporation of reliable and effective ways to accommodate varying shoe styles and heights. These feet were designed in response to user requests, largely from female amputees who wanted feet that would easily accommodate a variety of shoe styles. An adjustable ankle-foot system in these feet provides a range of heel height settings that are selected by the amputee using either a locking pin or screw located on the foot. Disadvantages of these feet include reduced durability and a change in the foot's (i.e. keel's) function at higher heel heights.

Cosmetic Covers

Cosmetic covers or cosmeses can be an optional, but very important part of a prosthesis. The purpose of the cosmesis is to protect the prosthesis, provide an anatomical shape to the limb, and give the prosthesis an appearance similar to the opposing limb. The various types of cosmesis offer the user advantages and disadvantages. Soft covers are less durable, but easy to replace. They are also less expensive and provide access to the internal mechanical components of the prosthesis. Hard cosmeses are more durable but are difficult to repair or replace and often make access to the internal components difficult.

Alignment

Once the prosthetic components are selected, the prosthetist puts them together to make a prosthetic limb in a process called alignment. The goal is to provide the user with the most natural, stable, and energy-efficient gait possible. Alignment of the transfemoral prosthesis involves the socket, knee, shin, and foot components and is done in three stages: bench, static, and dynamic alignment.

The Alignment Process

Bench alignment is the process of configuring the prosthetic components without the patient. Typically, manufacturers of prosthetic components such as knees and feet provide recommendations for how they should be attached together and to the prosthetic socket. The prosthetist will use this information in conjunction with his or her experience and knowledge of the patient to make an initial estimate of a well-aligned prosthesis.

Static alignment is done with the patient standing in the prosthesis with the body weight distributed equally on both extremities. An alignment reference line is visualized from the proximal socket to the base of the foot (Figure 31). Common

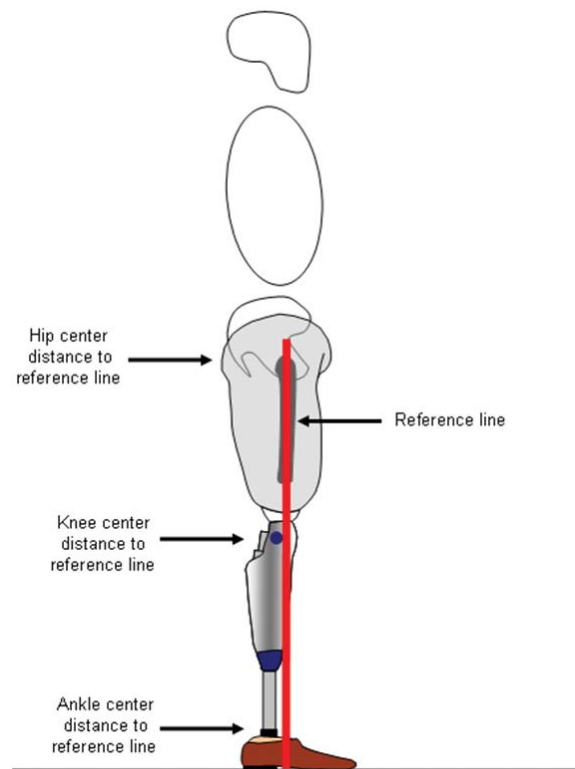


Figure 31 – Alignment reference line

types of alignment reference line include the Trochanter, Knee, and Ankle (TKA) line and the weight bearing (WB) line. Generally, the more posterior the knee center is to the reference line, the more stable the prosthesis will be. However, the more posterior the knee is with respect to the reference line, the more difficult the knee will be to flex in terminal stance. A suitable balance between safety, stability, and control is desired.

Dynamic alignment is the process of aligning the prosthesis based on observing the amputee walk while wearing the prosthesis. One main goal of dynamic alignment is to identify how the prosthetic limb is used and controlled by the amputee. Gait deviations that may be a result of malalignment are identified and addressed. The position and orientation of the knee, foot, and pylon are adjusted to achieve a more normal gait pattern.

Although the basic socket alignment has been established during fabrication of the prosthesis, minor adjustments should be made during the dynamic alignment process. The most common of these is the AP and ML placement (placement of the socket relative to the knee, shin, and foot components). This adjustment is often made when the amputee is able to ambulate for longer periods of time and has established a “normal” pattern of prosthetic gait. This process of dynamic alignment may require several sessions and should incorporate navigating community barriers such as uneven terrain, stairs, and inclines.

The physical therapist can conduct an evaluation of alignment during rehabilitation activities and provide feedback to the prosthetist to assist in dynamic alignment. This is the best time for the physical therapist and the prosthetist to interact to help the amputee achieve optimal gait and function. Often it is difficult to determine the cause of the gait deviation, which may be poor prosthetic fit, malalignment, muscle weakness, limb length or patient habit.

Alignment Challenges

The first few alignment sessions are fairly controlled, with few variables. As the amputee becomes more used to ambulating with the prosthesis, however, the alignment may need to be

re-addressed to maximize function and help the amputee avoid pathologic gait patterns.

As simple a change as a different shoe style may require adjusting the alignment of the prosthesis. Prosthetic feet, unless they incorporate a self-adjustable heel, are configured for a specific shoe heel height. If a higher heel is worn, the alignment of the prosthesis is changed. Therefore, amputees should see their prosthetists when changing to shoes with a different heel height so that the alignment of the prosthesis can be changed safely.

Alignment with Microprocessor-Controlled Knees

Microprocessor-controlled knees such as the C-Leg (Otto Bock, Duderstadt, Germany) provide unique benefits for the transfemoral amputee, given appropriate alignment of the knee center. The stability of traditional knee components relies on alignment of the knee center adequately posterior to the ground reaction force. Unlike the traditional prosthetic knee, however, newer microprocessor-controlled knees require a more anterior knee center alignment (i.e. less stable than traditional knees) for optimal performance. This presents a challenge to prosthetists, who must adapt their fitting and training methods to accommodate this new technology.

7. Skin Care

Amputees need to care for their residual limb skin on a daily basis. Good skin health can mean the difference between a comfortable prosthetic fit with no complications and problems such as an uncomfortable socket fit, time out of the prosthesis for healing, infections, and surgical revisions. Most amputees have problems with the skin of the residual limb at one time or another. Some have problems with incision healing, and for some amputees, wound care is an ongoing problem. In addition, for the transfemoral amputee, skin breakdown can occur at the distal end, in the medial groin, at the ischium, along the brim of the socket, or areas of excess tissue. Causes include poor socket fit; poor hygiene of the skin, liner, or socket; incorrect socket alignment; allergic reactions; or ingrown hairs. Skin breakdown or irritations can present as rashes, blisters, infections, ingrown hairs, open wounds, verrucous hyperplasia, and ulcers. The physical therapist should immediately inform the prosthetist of any problems with the skin of the residual limb, and the physician should be informed of any serious or ongoing skin conditions.

The Incision

The general principles of plastic and reconstructive surgery apply to amputation incision location and scar placement, although the location of the scar may assume even more importance because of the prosthetic interface and socket design. When uncomplicated primary healing occurs and the resulting scars are nontender, pliable, mobile, and durable, scar location does not really matter. However, when healing is less than ideal, and the scars become adherent, tender, thin, nondurable, thick, or prominent, location matters a great deal. The wise surgeon plans scar placement to minimize potential future complications in the event of less-than-perfect healing. With lower limb amputations, the amputation site functions as the patient's foot and, therefore, requires reconstructive design to provide a durable interface with the socket for walking and the transfer of body weight.

Fasciocutaneous flaps should be as broad based as possible to maximize perfusion and avoid compromising blood supply. The skin closure must be without tension but also without redundancy. Particularly in the dysvascular limb, care must be taken to avoid separating the skin from the underlying subcutaneous tissue and fascia. It is also important to avoid placing scars over a bony prominence or the subcutaneous bone. The more skin surface that is available for contact with the prosthetic socket, the less pressure will be applied to each unit area of skin surface. A cylindrically shaped residual limb with muscular padding will provide a better prosthetic fit and is susceptible to fewer skin problems than a bony, atrophic, tapered residual limb.

Occasionally the corners of the incision have redundant tissue and develop a fold in the skin or a squared-off shape instead of the more ideal rounded shape. This is sometimes referred to as a dog-ear appearance. Although skin typically reshapes itself well and minor irregularities often improve on their own, large corners or redundant areas may not remodel. The first

approach is to encourage proper shape with shrinker socks. Most irregular skin areas will remodel during the first 3 to 4 months after surgery. If these areas fail to remodel and instead develop into an area of folded-over skin, skin irritation and breakdown may occur with prosthetic wear. Surgical revision is needed if modification of the liner or socket does not resolve the problem.

Skin Grafts

Along with fasciocutaneous flaps and free-flap techniques, skin grafts can be a viable option to create a well-healed and durable residual limb. Split-thickness skin grafts applied over a cushioned, mobile muscle bed are ideal and can withstand forces applied by a prosthesis. Grafts will be most successful when they do not adhere to bone. Without the fine layer of subcutaneous fat to absorb shear, grafts are not as durable as normal skin. Socket liners made of elastomeric materials have improved prosthetic outcomes for individuals with scar and skin grafts. This is especially helpful for burn survivors, who often require skin grafts on amputated limbs. The grafted skin and burn tissue will tolerate more pressure over time if the shear and skin stretch are minimized by careful prosthetic fitting. A gradual introduction to wearing the prosthesis will also help establish tolerance. The amount of time wearing the prosthesis, the amount of force applied, and the activity levels must be carefully controlled and slowly increased. Even a badly burned residual limb with free graft coverage may become accustomed to a prosthetic device if introduced to it over a period of many months. This approach is likely to result in optimum function and thereby avoid reamputation at a higher anatomic level.

Potential Skin Conditions

Skin problems are a major concern for amputees throughout their lives. The surgeon, physical therapist, and prosthetist all need to be familiar with the many types of potential short and long-term skin and wound-healing problems. Postoperative infections, wound dehiscence, and partial skin flap failure occur with unfortunate frequency in the early postoperative phase. Reactive hyperemia, epidermoid cysts, verrucous hyperplasia, contact dermatitis, superficial skin infections, folliculitis, hidradenitis suppurativa, candidiasis and other dermatophytoses are potential long-term skin ailments. Complicated skin problems often require multidisciplinary care involving prosthetists, wound care specialists, dermatologists, and the original surgical team.

The first step to preventing skin breakdown is good general hygiene. This includes keeping the residual limb and prosthetic socket clean by washing them with gentle soap, rinsing the limb and socket well to remove all soap residue, and thoroughly drying them both. This process should be repeated at least once per day, more often if perspiration is heavy. Foreign materials such as bandages should not be applied to the limb while it is in the socket because such materials can actually increase pressure in that area, causing skin breakdown. Amputees also should avoid shaving a residual limb because shaving increases the risk of ingrown hairs and folliculitis.

Reactive Hyperemia

Reactive hyperemia is the early onset of redness and tenderness after amputation (Figure 32). It is usually related to pressure



Figure 32 – Reactive hyperemia

and resolves spontaneously. Unlike similar conditions, such as cellulitis, the redness of reactive hyperemia blanches easily when compressed by the examiner's finger or it resolves soon after elevation of the limb and removal of the prosthesis. Cellulitis does not easily blanch, is much warmer to the touch, and does not show rapid improvement with elevation and removal of the device.

Epidermoid Cysts

Epidermoid cysts commonly occur at the prosthetic socket brim, especially posteriorly. These cysts are difficult to treat and often recur, even after excision. They typically start as ingrown hair follicles or inflamed sweat glands. The earliest appearance is very similar to that of an acne lesion or pimple (Figure 33). The best initial approach is the application of



Figure 33 – Epidermoid cyst

moist heat, such as by applying a warm tea bag. If early lesions do not resolve within a few days, topical antibiotics, topical hydrocortisone, or even oral antibiotics may be required. Additionally, the prosthetist should consider a slight modification of the socket to relieve pressure over the cyst. Larger lesions may drain either a clear serous fluid or a blood-tinged fluid. The patient typically feels relief of pressure and pain when the lesion drains. If these lesions become chronic and last over several months or recur frequently in the same location, surgical excision and scar revision can be considered.

Verrucous Hyperplasia

Verrucous hyperplasia is a wartlike overgrowth of skin that sometimes occurs on the distal end of the residual limb (Figure 34). It is caused by a lack of distal contact in the



Figure 34 – Verrucous Hyperplasia (Reprinted with permission from Smith DG, Michael JW, and JH Bowker, 2004, *Atlas of Amputation and Limb Deficiencies, Surgical, Prosthetic and Rehabilitation Principles*, 3rd Ed.)

socket and failure to remove normal keratin. The disorder is characterized by a thick mass of keratin, sometimes accompanied by fissuring, oozing, and infection. Any infection should be addressed first, and then the limb should be soaked and treated with salicylic acid paste to soften the keratin. Topical hydrocortisone is occasionally helpful in resistant cases. Prosthetic modifications to improve distal contact are necessary to prevent recurrences. Because the distal limb is often tender and prosthetic modifications may be uncomfortable at first, an aggressive preventive approach is greatly preferred.

Contact Dermatitis

Contact dermatitis sometimes occurs in amputees and may be confused with bacterial or fungal infection (Figure 35). The



Figure 35 – Contact Dermatitis (Reprinted with permission from Smith DG, Michael JW, and JH Bowker, 2004, *Atlas of Amputation and Limb Deficiencies, Surgical, Prosthetic and Rehabilitation Principles*, 3rd Ed.)

primary cause of this type of dermatitis is contact with acids, bases, or caustics, like that may result from failure to rinse detergents from prosthetic socks. Patients should be instructed to use mild soap and to rinse socks, liners, sockets, and the residual limb extremely well. Allergic contact dermatitis is commonly caused by the nickel and chrome in metal, antioxidants in rubber, carbon in neoprene, chromium salts used to treat leather, and unpolymerized epoxy and polyester

resins in plastic laminated sockets. Once infection is ruled out and contact dermatitis is confirmed, treatment should include removal of the irritant and use of soaks, corticosteroid creams, and compression with elastic wraps or shrinkers.

Folliculitis

Folliculitis occurs in hairy areas, typically soon after the patient starts to wear a prosthesis (Figure 36). Pustules develop



Figure 36 – Folliculitis

in the eccrine sweat glands surrounding the hair follicles. This problem is often worse if the patient shaves the area, and it is aggravated by sweating and by rubbing from the prosthetic socket. The frequency tends to increase in the warmer months as warmth and perspiration create a favorable environment for bacteria. Treatment includes improving skin and socket hygiene, moist compresses, incision and drainage of boils, administration of antibiotics, and topical application of a bacteriostatic agent.

Hidradenitis Suppurativa

Hidradenitis suppurativa, which occurs in apocrine glands in the groin and axilla, tends to be a chronic condition and responds poorly to treatment (Figure 37). The apocrine glands become



Figure 37 – Hidradenitis

irritated due to the exposure to sweat, bacteria, and the friction that occurs within a prosthetic socket. Socket modification to relieve any pressure in these areas can be helpful.

Candidiasis and Other Dermatophytoses

Candidiasis and other dermatophytoses present with scaly, itchy skin, often with vesicles at the border and clearing

centrally (Figure 38). Dermatophytoses are diagnosed with a potassium hydroxide preparation and are treated with topical



Figure 38 – Candidiasis

antifungal agents. The socket must be cleaned thoroughly and repeatedly to minimize the chance of recurrence. Elastomeric liners can be difficult to clean, making complete eradication of the fungal organisms nearly impossible. Therefore, liners will often need to be replaced. If the fungal infections continue to recur, the patient should consider changing to a suspension system that does not use elastomeric liners.

Skin Care

The initial evaluation by the physical therapist is a great opportunity to start educating the amputee on skin care and the prevention of skin breakdown. Encouraging the patient to be proactive will help eliminate or decrease significantly the risk of skin breakdown and time out of the prosthesis. For the diabetic patient, vigilance is critical. Frequent skin checks are important, especially when beginning to wear a new socket. Excessive redness or any blister formation indicates that the patient needs to limit time in the prosthesis and see the prosthetist immediately for evaluation of the socket. Skin care for the diabetic cannot be overstressed, and good skin hygiene for all amputees should be encouraged. This includes daily cleaning of the liner, socket, and residual limb skin with mild soap and water and drying completely. This should be done at night after doffing the prosthesis. If the amputee perspires a lot while wearing the prosthesis or if skin issues are present, the skin should be cleaned more than once per day. Patients who wear a liner should have two so that one can be worn while the other one is being cleaned and dried. Prosthetic socks also need to be cleaned daily. Liners and socks should be rinsed well after washing because soap residue can cause skin problems such as contact dermatitis.

Skin Desensitization

If skin sensitivity is an issue for a recent amputee, it is important to perform skin desensitization on the residual limb. Skin desensitization consists of gradual introduction of stimuli, starting with soft materials such as cotton balls and gradually progressing to coarser materials such as linens and towels. Skin desensitization can also be accomplished by a variety of techniques that allow the amputee to accommodate to sensations on their residual limb, including towel pulls on the distal end, vibration, or gentle massage. This should be taught

to the amputee as part of a home program or as an activity they can do while in the hospital, as only the amputee knows his or her own tolerance level. Some new amputees are afraid to touch the residual limb and will need to be encouraged to do this. These desensitization activities have the added advantage of putting the amputee in direct contact with the residual limb.

Skin desensitization can begin immediately after surgery if care is taken to avoid the incision site until it is healed. It is important to not rub directly over the healing incision, but desensitization can begin on the area surrounding the incision. Once the incision has healed, scar mobilization can begin.

Contralateral Limb Care

Because the contralateral limb becomes the dominant weight-bearing limb, it is at high risk of skin problems, and prevention becomes extremely important. A shoe that is well-fitting, supportive, and comfortable is necessary to help prevent future problems with the sound side foot. Custom footwear may be necessary, as well as frequent checks of skin integrity. The amputee should be instructed on how to perform skin checks and what to look for during the first physical therapy visit. A mirror is useful for viewing the bottom of the foot and between the toes. Diabetics with impaired vision will need to have a trained caregiver perform the skin checks.

Skin Issues and Physical Therapy

Skin Checks

New amputees and established amputees using a new socket must be diligent in performing skin checks before, during, and at the end of each physical therapy session. This will entail removing all the socks and the liner, if they have one, and inspecting the skin completely. Assessment should begin at the groin and ischial tuberosity region and continue along the length of the limb to the distal end. Typically, the skin on the residual limb will be red all over when the liner and socks are removed, and this redness should dissipate within a few minutes. Signs of potential problems include areas of redness that do not dissipate within 10 minutes, bruising or purplish skin anywhere on the limb that does not dissipate, any blister formation containing either fluid or blood, or any opening of the incision area. These warning signs should be conveyed to the prosthetist, and the patient should be encouraged to visit their prosthetist immediately. For dysvascular patients or patients with reduced sensation, these skin checks may need to occur more frequently throughout the session.

Distal Edema

Another skin condition that may arise during therapy is distal edema (Figure 39). This occurs if the distal end of the residual limb does not contact the socket, leaving a space that creates negative pressure. This negative pressure causes fluid to accumulate at the distal end of the residual limb, and after wearing the prosthesis for just a few hours, this fluid will continue to stay at the distal end. This can cause



Figure 39 – Distal edema (Reprinted with permission from Smith DG, Michael JW, and JH Bowker, 2004, *Atlas of Amputation and Limb Deficiencies, Surgical, Prosthetic and Rehabilitation Principles*, 3rd Ed.)

discoloration: initially, redness, and over time, changing to a purplish, bruised appearance. When this fluid is not reintegrated into the circulatory system, the distal end can become hardened. If this continues over days and weeks, the tissue will continue to discolor and harden, resulting in skin breakdown and death of the tissues, culminating in verrucous hyperplasia. Distal edema most often occurs because of poor donning practice or a poor socket fit, as may result from the residual limb changing shape because of weight gain, limb volume changes, or a medical condition.

Heat Rash

Heat rash is a frustrating skin rash that can develop from excessive heat and moisture. This is especially common in individuals who live in hot and humid climates. It can be seen in individuals who use elastomeric liners, foam liners, a sock interface or even in suction suspension systems. Typically, excessive heat combined with a moist environment will cause the skin to become red and irritated. While frustrating for the amputee, the most effective treatment is simply to remove the prosthesis, dry the residual limb, and allow time for the skin to cool down before re-donning the prosthesis with a clean, dry sock or liner. This process may need to be repeated several times throughout the day for some amputees.

Irritation from Elastomeric Liners

The use of roll-on elastomeric liners by amputees is steadily gaining in popularity. These liners can sometimes cause skin irritation and redness and it is often the physical therapist who may first see these problems. Two types of skin irritation can be associated with the use of elastomeric liners. The first occurs only at the top edge of the liner and is due to friction and traction between the skin inside the liner and the skin above the liner. Treatment options may include adjusting the thickness of the top edge of the liner, altering the trim line of the liner, or adding skin lubricant to the skin under the top edge of the liner. Another form of irritation is redness and irritation over a larger portion of the residual limb. This is often either a type of contact dermatitis or heat rash, similar to those discussed previously. For individuals without vascular disease the application of topical over-the-counter hydrocortisone cream at night can provide relief. Also, removing the limb and allowing the skin to cool and dry at select times of the day may be beneficial. If these minor skin reactions fail to resolve with simple treatment

or if blisters or skin breakdown develops, the patient should cease use of their prosthesis until meeting with their prosthetist. Rarely, the skin irritation may become so severe that it can necessitate a switch to an alternative suspension system.

Blisters

Blisters also are common in amputees (Figure 40). Causes include increased friction in the socket as a result of poor



Figure 40 – Blister (Reprinted with permission from Smith DG, Michael JW, and JH Bowker, 2004, Atlas of Amputation and Limb Deficiencies, Surgical, Prosthetic and Rehabilitation Principles, 3rd Ed.)

socket fit, shrinkage throughout the course of the day, or a wrinkled sock. Amputees should be taught how and when to add sock ply throughout the day because when shrinkage occurs, adding more sock ply can prevent the formation of blisters. If blisters have formed and the amputee needs to wear the prosthesis to get home, applying a transparent film to decrease friction may be helpful. A good rule of thumb is if the amputee comes in with blisters or if blisters form during the session, gait training is over for the day, as the blisters will only get worse. Never encourage a patient to pop a blister, as this creates an open wound through which bacteria can enter. Dysvascular patients should discontinue prosthesis use until the blisters have healed. They also should see the prosthetist prior to redonning the prosthesis for an evaluation of the socket in case it requires adjustment.

A blister that is not addressed and/or does not heal may ulcerate if it becomes infected (Figure 41), and the amputee will not be able to wear the prosthesis until the ulcer has healed. This condition requires medical management, and the amputee should be referred to their physician immediately.



Figure 41 – Ulcer

The Adductor Roll

Because a transfemoral socket needs to contain and transfer load to the ischium, it extends fairly high on the medial thigh. Over time, the tissue on the proximal medial thigh may become a bit redundant and begin to fold over the proximal brim of the socket. This is called an adductor roll. If the surgeon did not perform an adductor myodesis, the amputee is more likely to have a problem with an adductor roll, but the problem can develop in other circumstances as well, such as if an individual gains weight and the residual limb no longer fits all the way down into the socket. The medial side of the socket then pushes up the skin and tissue of the thigh, creating an adductor roll. This tissue is especially prone to blisters, breakdown from rubbing on the socket brim, and folliculitis. Fabrication of a new socket that contains the tissue on the medial thigh and a new donning technique to pull the tissue down into the socket are frequently required to improve this situation.

8. Acute Care

The acute care phase occurs from immediately prior to surgery until hospital discharge. Patients who are undergoing an amputation because of long-term conditions may be debilitated and therefore may need general strengthening and conditioning as well as general mobility training. Some of these patients have been hospitalized prior to the surgery and therapy may begin before the amputation. The physical therapist can work on strengthening and basic mobility skills with them in preparation for the amputation. Patients who are undergoing an amputation as a result of trauma, however, are not likely to have this pre-surgery phase. After surgery, physical therapy may include basic range of motion, initial tissue desensitization, and general strengthening and conditioning.

Dressings

The immediate postoperative dressings on the residual limb will vary depending on the surgeon. Typically, a drain will be in place and dry dressings, gauze, and elastic wrapping resembling a spica cast will cover the entire limb. This type of dressing helps to control edema and start the shaping process. It is commonly used until the drain is removed a few days postoperatively. The surgical dressings are then commonly replaced with gauze and a compression garment, such as an elastic sock or “shrinker” to help shape the residual limb (Figure 42). A waist band may be incorporated into the



Figure 42 – Shrinker

shrinker to ensure that it remains properly in place on the residual limb. The shrinker should be removed and reapplied every few hours to promote circulation, but should be worn continuously throughout the day, except during bathing and skin inspection. A donning ring may be used to reduce the discomfort and increase the ease of donning the shrinker (Figure 43). A variety of different shrinker materials and designs are available, but they all serve the same purpose of providing compression to residual limb. Prosthetist preference usually determines which type the patient will wear.

Compression wrapping with an elastic bandage may be used as an alternative to a shrinker to control edema and promote shaping of the residual limb. This form of dressing is often used with atypical limb shapes that do not conform well to standard shrinkers shapes. Compression wrapping can be applied as early as when the drain is removed. Wrapping the residual limb with elastic bandage is difficult to do properly each and every time. When applied correctly, the compression



Figure 43 – Donning ring

wrapping controls edema better than a shrinker, but it is very difficult to achieve uniform pressure with this method. If applied incorrectly, the elastic wrapping can easily create a tourniquet effect, which can cause increased edema and skin problems.

Immediate post-operative prostheses (IPOP) are temporary prostheses that are used to allow a recent amputee to begin partial weight-bearing immediately following the amputation surgery (Figure 44). They include a rigid cast or adjustable plastic socket and the prosthetic components needed to stand, bear weight, and begin ambulation with the use of an assistive device. These devices are common in transtibial or below-knee amputations, but rarely used for transfemoral amputees. The cast required to properly distribute weight-bearing in a

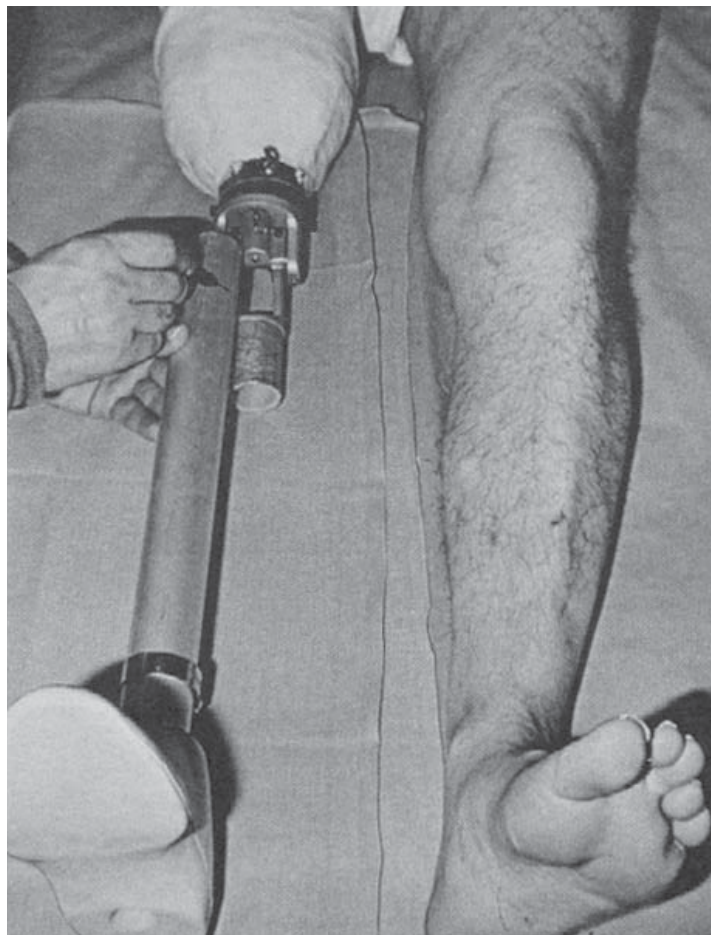


Figure 44 – Immediate post-operative prosthesis (IPOP)

transfemoral IPOP must encompass a portion of the pelvis. These casts, called spica casts, are quite uncomfortable for an amputee when lying in bed or sitting in a chair. For this reason, they are not commonly used for transfemoral amputation.

Range of Motion

After surgery, it is important to consider range of motion (ROM) treatments in order to prevent joint contractures. Gentle ROM of the hip can begin as early as 48 hours after surgery, but should never be performed without a prescription from the surgeon. The type of surgical procedure and the status of the involved tissues will determine the types of motions and the intensity of ROM treatments that can be performed. The most common contracture for the transfemoral amputee is hip flexion, external rotation and abduction. ROM limitations may be present because of preoperative orthopaedic or neurologic conditions that can cause tightness in muscles, joint capsules, ligaments, and skin.

For the transfemoral amputee, it is essential to achieve and maintain functional hip ROM in both lower limbs. Contractures can begin to develop as soon as 72 hours after amputation and immobilization of the limb. Therefore, proper body positioning should begin immediately after surgery. This is particularly important for elder amputees, for whom contractures may develop more rapidly than in younger patients. If tolerable, patients should be encouraged to lay prone (i.e., on their stomach) (Figure 45) or supine (i.e., on their back) with the pelvis level and the hip in neutral position for



Figure 45 – Prone Lying

5 to 10 minutes three times a day. Prone lying is preferable, but if the patient is not comfortable or can not assume the position for medical reasons, the hip should be stretched twice a day for 5 minutes to prevent hip flexion contractures. When supine, the amputee should keep the residual limb flat on the bed and avoid propping it up on a pillow.

Skin and Tissue Desensitization

After surgery, many amputees experience skin hypersensitivity due to disruptions in the neuromuscular system and edema in the traumatized tissues. Desensitization is an important therapeutic intervention that should be introduced following the surgery in order to prepare the residual limb for the prosthetic prescription and reduce the likelihood of residual limb pain associated with sensitive tissues. The following therapies may prove to be beneficial for desensitization.

Towel Pulls

The amputee places a towel over the distal residual limb, and while holding both ends of the towel, gently pulls proximally toward the body (Figure 46). The patient should initially begin



Figure 46 – Towel Pulls

by applying light pressure and then slowly increasing pressure as their tolerance allows. It is important to perform towel pulls gently, even though the incision site will be protected by a dressing. The patient can be instructed to perform this treatment on their own several times a day.

Touching and Rubbing the Residual Limb

Encouraging the patient to touch and rub the residual limb with their hands is also helpful to the desensitization process. Touching or rubbing with different fabric textures can be used to vary the sensory input to the sensitive residual limb. Clinicians should be aware that some recent amputees will subconsciously neglect or find it difficult to even look at the residual limb. These patients will require additional encouragement to touch the limb and begin this process of desensitization. It is therefore important to encourage the patient to begin this activity immediately after surgery so as to promote healing, both physically and psychologically.

General Mobility

General mobility training should also begin during the acute phase. This includes bed mobility, transfer training, wheelchair mobility training, and gait training with an appropriate assistive device. The amputee will not have received a prosthesis, so ambulation will require the use of a walker or crutches. If they are deemed safe, crutches are typically preferred over a walker during early ambulation because of the potential for increased mobility and fewer postural adaptations such as increase trunk flexion. Promoting appropriate posture and independent mobility during the acute care phase of rehabilitation will allow for a smoother transition to ambulation with a prosthesis. Mobility training should be personalized to the discharge plan, with consideration given to discharge location and environment, caregiver availability, and functional level of the patient.

9. Initial Outpatient Evaluation

The initial outpatient physical therapy evaluation of a transfemoral amputee is similar to that for any other patient, but with a few additional assessment items.

Subjective Assessment

The subjective evaluation focuses on the patient's medical history, with an emphasis on the previous level of activity and function; comorbid health conditions; vocation, tentative return-to-work plans; and patient goals. This evaluation should also include the home situation, including the current home environment and potential caregivers. Information such as the number of steps into the home, the number of floors and stairs in the home, the outdoor terrain, and the availability of a caregiver needs to be assessed. This is especially relevant for the amputee with comorbidities that limit independence in the home. Pain issues, including phantom pain, phantom sensations, and residual limb pain, will also need to be discussed. This information will help guide the physical therapist as well as the prosthetist in determining appropriate prosthetic components, treatment plan, and discharge goals.

Objective Assessment

The objective portion of the evaluation covers assessment of the following:

- Range of motion (ROM)
- Strength
- Functional mobility
- Gait analysis
- Balance and posture
- Sensation
- Neurological status
- Residual limb tissues
- Contralateral limb status
- Cardiovascular health and endurance
- Equipment requirements
- Ability to don and doff prosthesis and shrinker

The Amputee Mobility Predictor (AMP)¹⁸ may also be administered to obtain an objective, baseline measurement that can be used to evaluate progress through the rehabilitation program.

Range of Motion

Differential diagnosis is performed to assess the residual limb ROM including the extent of any limitations and the tissue(s) responsible. The contralateral limb, pelvis and spine should be included in the evaluation. The tissues responsible for ROM limitations may include superficial or deep scar tissue, muscles, joint capsules, ligaments or bones. The cause and recommended treatment for ROM limitations should be documented. The amputated side hip should clearly be a priority for evaluation with transfemoral amputees as contractures at the hip can affect prosthetic fit, prosthetic alignment, and overall function.

Strength

The muscles associated with all movements of the residual limb hip should be assessed for strength. This evaluation should

include both controlled manual muscle testing and functional testing as the patient performs activities such as standing, walking and negotiating ramps or stairs.

Until such time as a prosthesis is fabricated for the patient, the amputee will require the use of an assistive device for ambulation. Therefore it is important to assess and include both upper limb strength and lower limb strength in the prescribed strengthening program. Moreover, strength of the core musculature or trunk stabilizers, specifically the abdominal, back extensors, and hip flexor muscles should be included in the comprehensive rehabilitation program.

Functional Mobility

The initial evaluation should assess general mobility, including transfers and bed mobility. The initial rehabilitation program should include basic transfer and bed mobility training. As mobility improves, assessment and training should progress to include a variety of transfers including bed, toilet, and car. Functional mobility assessment and training should also include ambulation with and without the prosthesis. For amputees who come to rehabilitation in a wheelchair, basic wheelchair skills also need to be assessed and included in the training program.

Gait Analysis

Depending on the level of function demonstrated by the patient during the initial evaluation, the amputee's gait may need to be assessed with or without the use of a prosthesis, or with or without the use of an assistive device. Gait assessment should include level surfaces, curbs, inclines and possibly stairs. For safety, gait assessment of a patient with a relatively new prosthesis and without an assistive device should be performed in the parallel bars. Assessment of amputees with advanced prosthetic gait abilities may also include ambulation on uneven terrain, hills, and stairs. Attention should be focused on the patient's skill with an assistive device, step pattern, and step symmetry.

Balance and Posture

Static and dynamic sitting and standing balance should likewise be assessed. Standing posture should be assessed while the amputee is wearing the prosthesis. Asymmetries between anatomical landmarks and any compensatory postures should be noted.

Sensation

Sensation of the residual limb should be assessed to determine if the amputee is able to sense changes to the skin within the prosthetic socket. Good residual limb sensation is important for detecting changes in socket fit and for preventing potential injury to the residual limb tissues. Light touch, sharp/dull and hot/cold are the three most common tests used to determine if the sensations of touch and temperature are intact. Those patients with decreased sensation must learn to monitor the skin carefully with regular visual and tactile inspections repeated throughout the day. In patients with dysvascular disease and/or diabetes, sensory assessment of the contralateral foot and leg is also necessary. It is important to also note and assess any areas of scar tissue or skin grafting because these areas may have sensory impairment.

Neurological Status

A neurological screen should be performed to assess for increased muscular tone, altered deep tendon reflexes, or impaired coordination. Those amputees suspected of neurological involvement should be referred to a specialist for a complete examination to rule out complications related to traumatic brain injury, cerebral vascular disease, dementia, or any other central nervous system involvement. If neurological involvement is confirmed, modifications to the treatment and prosthetic approach may be required.

Residual Limb Tissues

A complete inspection of the residual limb skin should be included in the evaluation. This includes scar tissue, graft tissue, graft donor sites, open wounds, incision line, blisters, reddened areas, abnormal skin flaps such as dog ears and adductor rolls, and overall health of the skin. The incision line should be assessed for any adherence or reduction in mobility. If the incision line has not healed, use of the prosthesis will need to be postponed until the surgeon orders prosthetic gait training. See Chapter 7 for a complete discussion of issues affecting the skin of the residual limb.

Compression Dressings

Recent amputees generally should wear some form of a compression dressing such as a shrinker or elastic compression wrap to help control edema and start shaping the residual limb. Initially, the shrinker or compression wrap should be worn 23 hours per day, removing it for bathing and to allow the skin to breathe periodically. The shrinker or wrap should be removed and reapplied every 1 to 3 hours throughout the day, depending on activity. Once the amputee has his or her prosthesis, the shrinker should be worn whenever the prosthesis is off, until the residual limb volume has stabilized.

Patients who have significant volume fluctuations may always need to wear the shrinker when they do not have the prosthesis on, especially when they are out of the prosthesis for extended periods of time.

Measurements

The physical therapist should measure the length and circumference of the residual limb during the initial evaluation. These baseline measurements will enable the physical therapist to monitor volume fluctuations and report any significant changes to the physician or prosthetist. Consistency of measurement technique, location, and patient position are important. Frequently, length measurements are taken from the greater trochanter or ischial tuberosity to the distal end of the femur. A residual limb that is approximately half the length of the contralateral femur is considered a mid-length transfemoral amputation. Residual limbs that are shorter or longer than mid-length are referred to as short or long transfemoral amputations, respectively. Circumferential measurements are taken at 2 or 3 points along the limb, with the measurement distance from the greater trochanter measured and documented consistently each time. The amputee's posture at the time of measurement should always be noted.

Contralateral Limb Status

The contralateral limb should be assessed in all lower limb amputees, but it is especially important in the diabetic or dysvascular patient. The assessment should include skin status, sensation, pulses and skeletal deformity. A diabetic limb screen includes visual assessment of the lower limb and foot skin; measurement of the popliteal, dorsalis pedis, and posterior tibialis arterial pulses; and evaluation of foot sensation using a monofilament sensory test. Patients with one or more clinical signs related to decreased sensation, vascular compromise, or foot deformity on the contralateral side should be monitored closely by members of the rehabilitation team. Education regarding skin care and hygiene may need to be included in the treatment plan. The patient also should be encouraged to see a podiatrist for foot care, which can include nail care, wound care, and removal of excessive callus formations.

Cardiovascular Health and Endurance

General cardiovascular health and endurance should be assessed. Heart rate and blood pressure should be monitored at rest and during exercise. Exercise heart rate should be monitored during ambulation or wheelchair mobility training. Specific information, such as distance travelled and heart rate should be recorded. Likewise, record any shortness of breath, fatigue, dizziness, or lightheadedness. These are indicators of decreased endurance and cardiovascular stress that will need to be considered when formulating the treatment plan.

Equipment Requirements

Mobility and assistive equipment the patient owns or rents should be evaluated to determine equipment needs. Bilateral and, on occasion, single limb transfemoral amputees who use a wheelchair may require the installation of an axle adaptor to accommodate the reduction in body weight due to limb loss. This adaptor enables adjustment of the rear axle position so as to increase the wheelbase and prevent the wheelchair from tipping over as the user negotiates curbs and ramps. This can also affect wheelchair propulsion, as greater shoulder extension is needed to reach the wheels. Another option is to move the axle less posterior and to add anti-tip bars to the chair.

For recent transfemoral amputees who sit in a wheelchair for extended periods of time, residual limb support needs to be provided to prevent excess skin pressure on the back of the thigh. Full thigh support also helps to reduce pressure on the ischium. If the wheelchair seat is not deep enough to support the limb, a seat extender should be used. A slideboard padded to be level with the seat and slid under the seat cushion works well (Figure 47). It is important to level out the cushion on the opposite side so that a pelvic obliquity does not result. A piece of plywood fabricated to fit completely under the cushion with an extension for the residual limb support also may be used.

The wheelchair cushion should be assessed, especially for patients who spend a large part of the day in the wheelchair. The shortened femur in transfemoral amputees causes the pelvis to drop on the amputated side. The resulting spine malalignment may lead to back and pelvic pain. Many different cushions can be modified to keep the pelvis level.



Figure 47 – Seat Extender

If the patient has a prosthesis during the first session, document the components present in the prosthesis and the name of the amputee's prosthetist. Meeting with the rehabilitation team to discuss the prosthetist's, physical therapist's, and patient's goals can improve the continuity and success of the rehabilitation outcomes. The prosthetist will usually have insights to the amputee's prosthetic history and will be able to provide information concerning prosthetic fit, current abilities, and functional limitations. Rationale for specific component selection and function of the prosthesis can also be discussed at this time and can provide the physical therapist with additional information pertinent to planning the rehabilitation program.

Ability to Don and Doff the Prosthesis and Shrinker

Amputees fitted with a prosthesis should demonstrate their ability to don and doff their prosthesis and compression garment. The physical therapist should also evaluate the amputee's ability to adjust sock ply so as to accommodate residual limb volume changes. When the limb volume decreases, additional sock ply should be added. Conversely, when the residual limb volume increases, the patient should decrease the ply.

Amputee Mobility Predictor

The AMP¹⁸ is designed to assess an amputee's current functional status with regard to ambulating with a prosthesis. This measurement tool can be used as part of the initial evaluation to determine if a patient will be able to use a prosthesis. The AMP addresses general mobility, strength, and balance, requires very few tools, and takes only approximately 10-15 minutes to complete. The AMP can also be used to establish both preprosthetic goals and performance goals for patients.

Comprehensive Assessment

Once the initial evaluation is complete, a comprehensive assessment should be made based on the amputee's current mobility and personal goals as well as the physical therapist's goals for functional mobility, including return-to-work plans as well as recreational activity goals. The assessment should include any ROM or strength deficits, current mobility limitations including level walking indoors, level and uneven terrain walking outdoors, stairs, hills, general mobility such as bed mobility and transfers, and balance. Balance recovery and transfers on and off the floor are also addressed. The need for support group information or peer visitation should be considered. Finally, this assessment should include any barriers to achieving the overall goals and an assessment of the amputee's potential for rehabilitation.

The Treatment Plan

The treatment plan should address the amputee's rehabilitation goals as well as the limitations listed in the comprehensive assessment. The plan may include:

- Therapeutic exercise, including appropriate ROM and strengthening
- Manual therapy
- Modalities as needed
- Prosthetic gait training
- Functional training
- Balance and coordination
- Gait training including stairs, hills, and ramps

10. Preprosthetic Treatment

The transfemoral amputee typically receives their first physical therapy treatment within a few days of the amputation surgery. The initial, post-surgical treatment orders may be for bed mobility, transfer training, wheelchair mobility, and ambulation with assistive devices. Range of motion (ROM) and strengthening should also be continued throughout the preprosthetic phase of treatment.

The initial preprosthetic treatment may take place either in the hospital after the amputation or in an outpatient setting. Some amputees require extended therapy to achieve independence in basic mobility, whereas others require only brief periods of therapy to achieve independence in basic mobility while in the hospital. The length of the preprosthetic therapy depends on several factors, including comorbidities, strength, ROM, overall health, and insurance benefits. When patients leave the hospital, some are transferred to a rehabilitation center or a skilled nursing facility, whereas others go directly home.

In some cases, patients will have already received their prostheses by the time they are seen in the outpatient setting. For recent amputees seen for the first time with their initial prosthesis, preprosthetic treatments would include ROM, strengthening, balance and skin care education, and prosthetic gait training. Optimally, patients would receive preprosthetic training before receiving the prosthesis. Numerous benefits may be realized from engaging the amputee in their preprosthetic training. These include educating the patient about their prosthetic expectations and experience, initiating their home exercise program, and avoiding the adverse effects of physical deconditioning. Recognizing the total number visits available to the patient during the initial evaluation will help determine a strategy for the treatment plan. Empowering amputees with limited resources to be responsible for their home exercise program in order to save treatment sessions for later prosthetic gait training is important to the overall goal of successful prosthetic use.

Range of Motion

If ROM limitations are present, soft tissue mobility treatments are essential. Some techniques require specialized application by the physical therapist and others may be performed independently by the amputee at home. Techniques available to the physical therapist may include, but are not limited to:

- scar tissue softening and release
- manual therapy techniques
- soft-tissue mobilization
- myofascial release techniques
- stretching
- joint mobilization
- deep friction massage

Contracture Prevention

The best treatment approach to contractures is prevention. As noted in Chapter 8, the transfemoral amputee most commonly acquires a hip flexion, abduction, and external rotation joint

contracture. It is important to remind the patient to lay prone for 5 to 10 minutes each day and to maintain their stretching program, with assistance by a caregiver if needed. Patients who primarily sit or use a wheelchair should make it a practice to stretch at least three times a day and to walk with their assistive device whenever possible.

It may be helpful to inform the amputee that hip flexion contractures require prosthetic socket, component, and alignment accommodations. Depending on the severity of the contracture, this may result in a definitive socket that is cosmetically inferior to one that does not require accommodation of the contracture. Hip contractures can also cause significant gait deviations because the amputee is unable to achieve sufficient hip extension. Although it is possible to fit an amputee with a contracture greater than 30° with a prosthesis, the amputee's ability to ambulate will be compromised and gait deviations will be more apparent. Contractures and associated gait deviations may increase the likelihood that the amputee will also experience low back pain. Therefore, preventing contractures is a critical component of long term prosthetic success.

Scar Mobilization

Patients need to be taught scar mobilization techniques to assist with soft tissue healing and to keep the scar tissue pliable. Immobile scar tissue will stress the adjacent tissue and may result in healing delays, especially when forces by the prosthetic socket are present. Such stresses can cause further injury to the soft tissues and delay the prosthetic training program.

Strengthening

Establishing a comprehensive strength and muscular endurance program for amputees is essential. Patients who require supervision will need to attend physical therapy, whereas patients with sufficient motivation, capability, and resources can work on strengthening at home or at a fitness center.

Restoration of the residual limb hip and trunk strength is essential for pelvic stability and successful prosthetic ambulation. The dynamic stump exercises first described by Eisert and O'Tester and later modified by Gailey and Gailey can be introduced once the surgical myoplasty or myodesis has healed.²⁰⁻²² Since only a towel roll or step stool is required, these exercises can easily be included as part of the home program. Figures 48-53 illustrate exercises where the amputee presses the limb into the towel roll, lifting their hips off of the resting surface and holds the peak position for ten seconds and repeats each movement for ten repetitions. The amputee should be encouraged to do these exercises daily. They can be done before the amputee has received the prosthesis, but they also can be performed throughout the course of the prosthetic training program.

To further strengthen the proximal muscle groups and for improved trunk stability, additional abdominal, trunk, and hip exercises should be performed. A complete strengthening program should include lumbar stabilization, proprioceptive neuromuscular facilitation (PNF), elastic band



Figure 48 – Hip extension



Figure 49 – Hip extension



Figure 50 – Hip abduction



Figure 51 – Hip adduction



Figure 52 – Bridging



Figure 53 – Bridging

or pulley exercises, medicine ball activities, and general core strengthening activities. The greater the pelvic core strength, the more efficient will be the postural control needed for safe and effective prosthetic ambulation. Any general strengthening program should be able to be performed independently at home or at a community fitness center.

Posture

Reestablishing proper standing posture can be performed with cues and instruction while the patient stands in front of a mirror. The most common posture issues include excessive trunk flexion, decreased weight bearing over the prosthesis, and adduction of the sound limb under the body while abducting the prosthesis. Head and shoulder posture is also important as the amputee learns to walk without looking down at the ground. Once the patient has a prosthesis, the physical therapist should stress standing balance with equal weight bearing and upright trunk posture.

Functional Mobility

Functional mobility encompasses many different skills. Which functional mobility skills need to be addressed will depend upon where the patient is along the rehabilitation continuum. A recent transfemoral amputee should review or be instructed in all aspects of functional mobility, including transfers, bed mobility, mobility with the wheelchair, and ambulation without the prosthesis. Regardless of the expected prosthetic capabilities, developing as many safe and independent mobility skills as possible is a primary goal.

Transfers

All types of transfers need to be addressed, including transfers out of a wheelchair, toilet transfers, car transfers, and floor transfers. At some point during treatment, floor transfers should be assessed both with and without the prosthesis on. This is most likely to occur during outpatient treatment.

Slideboard Transfers

Transfers tend to be more difficult for the transfemoral amputee than the transtibial amputee because a shorter residual limb makes it more difficult to balance, use the limb as a support, and use it as an assist for the transfer. In addition, for recent transfemoral amputees, pushing down with the residual limb may be uncomfortable and therefore the amputee tends to hold it up in the air, making the transfer even more difficult. For many recent amputees, use of a slideboard will facilitate learning to transfer if they are unable to come to a stand and transfer using a stand-pivot technique. Initially, the amputee is taught to transfer by moving toward the sound side, but transfers should be taught in both directions because some home settings, especially bathrooms, may have limited space, allowing only one transfer direction.

Stand-Pivot Transfers and Sit-to-Stand

Stand-pivot transfers can be done with or without an assistive device. The instruction for the amputee is the same as for any other patient except that balance—with and without the use of assistive devices such as the prosthesis, walker, or crutches—needs to be stressed. An amputee's standing balance is typically more compromised without the use of a prosthesis or assistive device. Therefore, the ability to transfer from sit to stand with and without the prosthesis is an important skill. As with all aspects of functional mobility, the type of transfer will depend on many factors, including strength, ROM, balance, comorbidities, sensory loss, age, motivation, and fear.

Gait Training

Gait training for the recent transfemoral amputee in an acute setting usually focuses on ambulation without the prosthesis. This training is the same as for any patient learning to walk with assistive devices. The type of assistive device used depends on the amputee's strength and balance as well as patient and physical therapist preference. Learning to ambulate without the prosthesis is important for all amputees because

there will be times when the amputee is unable to wear the prosthesis, such as when the prosthesis is being repaired or adjusted, at night when the amputee gets up to go to the bathroom, or when medical issues such as skin breakdown arise. For this reason, patients should have another mobility aid that they can use without the prosthesis. General walker or crutch skills such as side stepping, backward stepping, stepping up and down curbs, going up and down ramps, stairs, and ambulating on uneven terrain will need to be taught.

Depending on how much training the patient received while in the hospital, some outpatient gait training for general skills without the prosthesis may be necessary. This may require one or more sessions, depending on the functional level of the amputee and whether the patient is confident about ambulating without a prosthesis.

Aerobic Conditioning

Aerobic conditioning can begin before the amputee receives the prosthesis but also should continue during gait training and should be encouraged as a lifelong part of the amputee's conditioning program. Many different types of aerobic conditioning may need to be tried to find the best fit.

Aerobic conditioning for the transfemoral amputee can include swimming without the prosthesis, riding a stationary bike with and without the prosthesis, and using an elliptical machine, treadmill, and upper body ergometer. For swimmers, instruction might include how to safely transfer into and out of the pool, different flotation devices that are available, and what swimming techniques will work best for each individual. A swim prosthesis may also be a viable option. Some transfemoral amputees prefer not to swim in public pools because they are not comfortable being seen without a prosthesis by people they do not know. This is a very personal choice and should be addressed with the amputee.

11. Initial Prosthetic Gait Training

Amputations at the thigh and knee levels place much greater demands on the amputee than do amputations in the calf or foot. If an individual with a transtibial amputation retains adequate function of the knee, even if the amputee never regains the ability to walk, the knee joint allows the amputee to actively extend the prosthetic knee to rise up to a standing position. The prosthesis can provide a point of contact with the ground for balance and support, and the person retains the knee power needed for transfer activities. Amputees with calf or foot amputations often start working with a prosthesis very soon after surgery, depending on wound healing.

The situation can be different for transfemoral amputees. The prosthesis is of limited assistance with transfers or in rising from a sitting to a standing position. Transfers are actually more difficult with a transfemoral prosthesis than without it because the prosthetic knee is not able to help the amputee come to a stand, the prosthesis adds weight, and the socket may limit trunk and hip flexion.

The length of time required to achieve pre and postprosthetic goals varies tremendously, depending on the amputee's motivation, general health, and physical fitness. A young, healthy person who loses a limb to trauma or tumor often masters necessary skills within 1 or 2 days. Most healthy elderly people also master these skills in a very short time. Patients who have severe trauma, major medical problems, or are limited by other medical conditions might need much more time to heal and rehabilitate. This is especially true for patients who have secondary comorbidities. The level of motivation can also play a huge role in whether and how quickly rehabilitation goals are met. Unfortunately, some amputees just are not capable of accomplishing these goals and would not benefit from using a transfemoral prosthesis. Others have no desire to walk with a prosthesis and therefore are not candidates for a prosthesis. For those patients who possess the ability and desire to use a prosthesis, prosthetic gait training will be required.

Mastering Basic Skills

Because the prosthesis does not provide lifting power, the transfemoral amputee must have sufficient strength in the contralateral limb, the torso, the pelvis, and the arms to get the body up and over the prosthetic device, and added strength in the thigh and pelvis to use a transfemoral prosthesis properly and safely. Some physicians require their patients to meet certain criteria before they will prescribe a transfemoral prosthesis. If the ultimate goal is ambulation with a transfemoral prosthesis, the amputee should first master three skills: transfers, sit-to-stand, and ambulation without the prosthesis before being fit for a prosthesis or beginning prosthetic gait training (see Chapter 10).

Transfers

The transfemoral amputee should be able to transfer independently, either using a slideboard or a stand-pivot technique.

Sit-to-Stand

The amputee should be able to independently come to a stand either out of the wheelchair or off a mat table. This may involve coming to a stand without the use of an assistive device, coming to a stand into a walker or parallel bars, or coming to a stand using crutches.

Ambulation without the Prosthesis

The transfemoral amputee who wishes to ambulate with a prosthesis also should be able to ambulate without a prosthesis. At a minimum, the amputee should be able to ambulate the length of a set of parallel bars and back without needing a rest and with minimal assistance.

Physician Orders for Prosthetic Gait Training

Physicians write prescriptions for prosthetic gait training for recent transfemoral amputees in many different ways. The prescription might read "evaluate and treat" or "gait training," or the physician might prescribe gait training with weight bearing limitations such as partial weight bearing (PWB), toe-touch weight bearing (TTWB), or touch-down weight bearing (TDWB). The most helpful prescription is "advance weight bearing as tolerated with frequent skin checks" (Figure 54). This allows the physical therapist to work with the transfemoral amputee on prosthetic gait training immediately in the parallel bars and then progress as patient tolerance allows. Even if the amputee is not able to tolerate full weight bearing initially, beginning weight-shifting techniques can be worked on with the amputee bearing as much weight as needed through the upper extremities. As the amputee tolerates more weight on the residual limb, the amount of weight borne by the upper limbs can be decreased.


	Seattle Medical Center Seattle, WA 98100
Physical Therapy Prescription	
Patient Name:	John Doe
Date:	12 December, 2005
Dx:	Left above-knee amputation
Rx:	ROM, Prevent hip contracture, Strengthening, Gait training, With prosthesis, advance weight bearing as tolerated with frequent skin checks
Signed:	Robert Smith, M.D.

Figure 54 – Proper prescription for prosthetic gait training

The least helpful type of prescription is for prosthetic gait training with limitations on weight bearing without any reason to limit the weight bearing; for example, “TTWB, 40lbs of weight through the prosthesis.” In this situation, prosthetic gait training cannot be started. Many physicians write orders this way because they think this is the best way for the patient to get used to the pressures the residual limb will experience in the socket, but prescriptions like this slow down the rehabilitation process and the progression of ambulation. This type of prescription should be written only in the presence of lower limb fractures or other medical conditions warranting limited weight bearing, in which case the patient is not ready for true prosthetic gait training. These patients need instruction in how to use a walker or crutches while maintaining the weight-bearing precaution. It is best to wait until the prescription changes to “advance weight bearing as tolerated” to begin true prosthetic gait training.

Weight Shifting

All initial gait training should be done in the parallel bars to make the amputee feel more secure. It is often beneficial to put a mirror at one end of the parallel bars for visual feedback. Training should start with anterior/posterior (Figure 55) and lateral weight shifting (Figure 56).^{21,23} First, have the amputee perform these activities using both upper limbs. Then, advance the patient to single upper limb support, and finally to no upper limb support.²¹ During the weight-shifting activity, encourage the amputee to note how the pressure on the residual limb changes with movement from one side to the other.^{21,23}



Figure 56 – Lateral weight shift



Figure 55 – Anterior-posterior weight shift

Shifting Onto the Prosthetic Side

Shifting onto the prosthetic side is a combination of the anterior and lateral weight shift. Initially, the amputee stands in the parallel bars with the prosthetic foot approximately one step length in front of the opposite foot and shifts his or her weight first onto the prosthetic side foot and then back onto the sound side foot (Figure 57).²¹ Use manual cues to help the amputee achieve proper weight shift onto the prosthesis. A side mirror helps the physical therapist check to be sure that the shift is not too far anterior, and a mirror at the end of the bars helps the amputee see if sufficient lateral weight shift is achieved and ensure a lateral trunk lean does not occur. This activity can easily be started with bilateral upper limb support, transitioning to single upper limb support. As a challenge, ask the amputee to try to have the support on the prosthetic side. This will help determine if sufficient weight shift is achieved because the amputee will not be able to depend on the increased pelvic stability received from upper limb support on the sound side. Manual cues at the shoulders may be helpful to prevent a lateral trunk lean from occurring.

While working on this activity, it is important to stress base of support because if the amputee can maintain a stable base



Figure 57– Anterior weight shift

of support during the shifting drill, it will be easier to do so when he or she begins to ambulate. The feet should be kept about shoulder width apart, or about four inches from heel to heel, to maintain a stable base of support.^{21,23} Once they start ambulating, many amputees will abduct the prosthetic side in an attempt to keep the sound limb directly under the center of mass because they do not trust the prosthesis. To train the amputee to maintain a stable base of support, put a tape line on the floor and cue the amputee to keep his or her feet an equal distance on either side of the tape line. Doing this with and without visual feedback will help the amputee “feel” the difference between when they are abducting the prosthesis and when they are keeping it even with the sound side.

A lateral trunk lean is usually observed when the amputee avoids shifting their full weight onto the prosthetic limb. Weight shifting can be practiced while stepping forward and back with the sound side foot. This will give the amputee practice in keeping the pelvis stable while moving over the prosthetic side. Cues that can be given to train hip extension throughout stance may include (1) tighten the buttocks muscles while in stance phase, (2) push the bottom part of the residual limb back into extension, (3) keep both anterior and superior iliac spines (ASISs) moving forward throughout stance phase and (4) roll over the foot from heel to toe.

Stepping With the Prosthetic Side

It is also important to work on stepping with the prosthetic limb. Have the amputee shift onto the sound side, and emphasize the need for pelvic rotation during the preswing phase of gait (Figure 58).²¹ This will increase the amount of knee flexion and allow the foot to clear the floor in swing. During initial swing, the amputee should achieve approximately 20° of hip flexion and at terminal swing the prosthetic foot should be positioned so that the heel strikes the ground at initial contact.



Figure 58– Stepping with the prosthesis

Some amputees may have difficulty in getting the knee to flex, others may worry about the prosthetic foot clearing during swing phase. To compensate, the amputee may elevate the prosthetic side hip (i.e. “hip hike”) or rise up on the sound side toe (i.e. “vault”) to assist with advancement of the prosthetic limb.²¹ These habits are difficult to break, so prosthetic side stepping drills should be encouraged to prevent them from starting. Stepping with the prosthetic side will allow the amputee to become confident with prosthetic limb advancement and a smooth weight shift over the prosthetic limb will promote knee flexion during late stance and into swing phase.

It may be helpful to explain that for most knees, a knee extensor moment is required to keep the knee stable in stance. When the knee becomes fully extended in midstance, the

knee joint center will be posterior to the ground reaction force (GRF) vector and the knee will remain stable without active hip extension (Figure 59). As the amputee enters terminal stance and preswing on the prosthetic side, the amputee will flex at the hip to initiate knee flexion. As the GRF then passes posterior to the knee joint, the knee will release into swing phase. For some patients, this information will be helpful in understanding how the knee works; for others, it will be confusing and overwhelming. Clinical judgment should be used to decide what is appropriate for each individual patient.

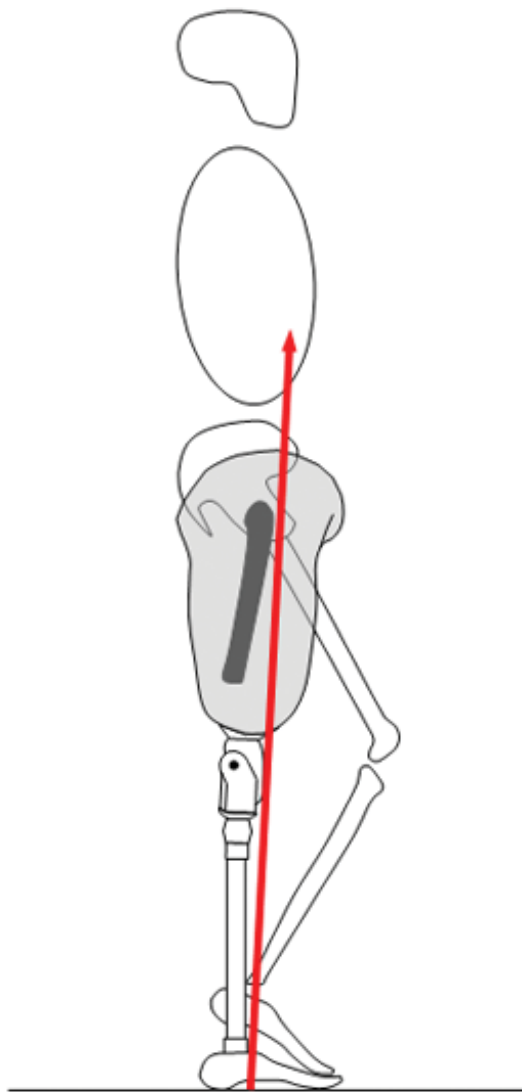


Figure 59– Knee stability in midstance

In addition to the weight shifting activities, it is important to learn pre-gait skills in the parallel bars in order to educate the patient as to how those skills transfer into independent ambulation. Progress may be faster if the amputee reviews weight shifting and other pre-gait skills for a few minutes each session, then practices ambulation under the physical therapist's supervision. This will help maintain the fundamental skills and give the amputee a chance to experience a sense of accomplishment as new skills are mastered.

Pelvic Rotation

For the transfemoral amputee to acquire an acceptable gait pattern, pelvic (and trunk) rotation should be restored. Recall, that in able-bodied gait, the pelvis begins in 5 degrees of forward rotation at initial contact. Through stance, the pelvis rotates backwards 10 degrees to reach 5 degrees of backward rotation at preswing. Forward rotation is again started at pre-swing, reaching 5 degrees of forward rotation by the end of the gait cycle.

The transfemoral amputee often tends to posteriorly rotate the pelvis in a “kicking” motion in an attempt to initiate knee flexion for swing phase. The altered pelvic rotation results in a loss of balance and a reduction in prosthetic knee flexion. Restoration of proper forward pelvic rotation during pre-swing in the parallel bars while working on the weight-shifting activities over the sound side will help to promote correct pelvic motions. Resistive gait training inside the parallel-bars followed by resistive gait training on level ground in an open area can help normalize pelvic movement and increase the patient's confidence.²¹

If the transfemoral amputee does not have full range of motion at the hip, achieving pelvic rotation will be difficult. It is important to work on pelvic rotation, however, because without it, trunk rotation and arm swing either will not occur or will be asymmetric.

Balance and Proprioception Training

Balance and proprioception training should be initiated early in prosthetic gait training because these skills will enable the amputee to gain a sense of stability while standing on or ambulating in the prosthesis. Most amputees will still be getting accustomed to the pressures inside the socket and will not be expected to tolerate full weight bearing initially. Upper limb support with the parallel bars or walker will help with the transition to full weight-bearing over the prosthesis.

While working on these activities, the amputee should pay attention to differences in socket pressure when shifting weight over the prosthetic and sound limb sides. Although a difficult concept to accept at first, developing the ability to sense changes in pressure within the socket will allow the amputee to rapidly adapt to balance perturbations and reduce the risk of falls.^{21,23}

The activities described below are just a few of the exercises appropriate for the transfemoral amputee. The amputee ultimately needs to be able to tolerate full weight bearing through the prosthesis for these exercises to be effective. The exercises described here may be performed with visual feedback using a mirror, though the goal is to have the patient perform them without using visual cues.

Toe taps on a step

This exercise may be performed early in the prosthetic training program. Start the amputee with upper limb support in the parallel bars to both hands free of support. The sound limb foot toe taps side-to-side and then heel-to-toe while using the using the prosthetic side hip musculature to maintain

an upright posture (Figure 60). The goal of this exercise is to achieve and maintain full weight bearing on the prosthetic limb throughout the exercise.



Figure 60– Toe tap

Slow toe taps

The stronger amputee who is newly introduced to this drill will perform the toe tap very quickly. To more effectively challenge the amputee's balance, have them perform the toe tap slowly. This requires significantly more balance and control.

Toe taps to steps of multiple heights and positions

Another variation of the toe tap exercise is toe taps with steps of multiple heights and positions. (Figure 61). This encourages the amputee to move in the transverse plane within the prosthesis using the hip musculature. Additionally, performing this drill at different speeds will develop the balance and stability required for ambulation on various terrains.

Standing on a compliant surface

A helpful balance exercise is to have the amputee stand with both feet on a compliant surface such as a mat or thick foam pad (Figure 62).²³ Be sure that the amputee's weight is evenly distributed over both lower limbs, as the amputee will typically try to shift all the weight onto the nonprosthetic side. Training the transfemoral amputee to use the prosthetic side hip musculature to help control movements or to maintain balance reduces the reliance on the sound side for balance recovery. As the amputee performs these activities, he or she should pay attention to pressures within the socket as they will help the patient to anticipate balance perturbations.

Ball rolling

Another drill for improving single limb balance and prosthetic weight-bearing is ball rolling with the sound side foot.²⁴ Begin this exercise in the parallel bars to encourage confidence because this can be a difficult and scary exercise for all amputees, regardless of their experience with a prosthesis. Start with a tennis ball and progress to a basketball which will vary muscle recruitment for the exercise. Have the patient put the sound side foot on the ball and either work on static



Figure 61 – Toe taps to steps of multiple heights and positions



Figure 62 – Standing on a compliant surface



Figure 63 – Ball rolling

balance in this position or roll the ball forwards-to-backwards, side-to-side, and in circular motions (Figure 63). Each type of movement requires the use of different muscle groups and corresponding reactions to maintain balance.

Once ball rolling with a hard ball is mastered, start ball rolling using a soft rubber ball. If the amputee puts any amount of weight on the ball with the sound side, the ball will become unstable and difficult to control. This drill encourages weight bearing and balance corrections on the prosthetic side.

Tandem walk

Start by placing a straight, taped line on the floor. Instruct the amputee to walk with a heel-to-toe pattern with emphasis on maintaining stability and balance while they are ambulating on the prosthetic side (Figure 64).²¹ Initially, the amputee will find it difficult to recruit the appropriate hip musculature and maintain balance over each limb. Transfemoral amputees with shorter residual limbs will also have more difficulty with this activity because of decreased ability to generate muscle power. With this narrow base of support, the tendency for gait deviations increases. Working in and out of this narrow base of support trains the amputee to stabilize the hip in multiple positions. This drill works on placement of the prosthetic and



Figure 64 – Tandem walk on a line

sound foot as well as the proprioception and balance required to walk. Note that some amputees will not be able to get into a tandem position because of the medial brim style of the prosthetic socket.

Side stepping and cross-over stepping

It is important for the amputee to learn different walking patterns such as walking backward, side stepping, and turning around.²¹ Besides being great balance exercises, side stepping and cross-over stepping help the amputee learn step recovery. Cross-over stepping trains the amputee to step the prosthetic foot around the sound side foot, a skill needed when a step reaction is required to recover from or prevent a stumble or fall (Figure 65).



Figure 65 – Cross-over stepping

Another important skill is stepping the prosthetic foot in front of the sound side foot. The amputee needs to learn that when the prosthetic foot crosses in front of the sound side foot, the weight must be shifted forward and the hip on the prosthetic foot must be extended to be sure the prosthetic knee will be under an extensor moment and thus will be locked for weight acceptance. It is difficult to achieve a stable pelvic position with a narrow or crossed base of support. However, improving this skill can improve balance and minimize the risk of falling.

Stool rolling

To perform this advanced balance activity, the amputee needs to be able to tolerate full weight bearing on the prosthetic side. While standing, the amputee puts the sound side foot up on a stool with wheels (Figure 66). This is best done on a hard, smooth surface rather than carpeting so that the stool rolls more easily.



Figure 66 – Stool rolling

This can start as a balance activity, with the amputee standing in place with the sound side on a rolling stool. Once the amputee is comfortable with this position, have them move the stool in forwards-to-backwards and side-to-side directions and in counterclockwise and clockwise rotations. Keeping the knee on the sound side bent, thus keeping the stool closer to the body will make the stool rolling easier to accomplish. With the sound side knee straight, the lever arm is longer, making it more difficult to control the balance. Side-to-side movements are best performed with knee extended. Quarter-circle turns will help the amputee to practice movement in the transverse plane.

Elastic band balance activity

To challenge the amputee's balance on the prosthetic side, tie one end of an elastic band around the sound side ankle and the other end to the base of a table or sturdy sofa. Instruct the amputee to flex, extend, abduct, and adduct the sound side hip while maintaining balance over the prosthetic limb (Figure 67). Begin with single upper limb support. Once the amputee is comfortable performing the exercise, challenge him or her to try to perform the exercise without upper limb support. Increasing the speed of the sound side leg will also increase the difficulty of the exercise.



Figure 67 – Elastic band therapy

Gait Progression

All balance and pre-gait activities should be done in conjunction with gait training activities. The purpose behind each drill will become more apparent to the amputee if gait training is incorporated into the program. For example, work on weight shifting for a few minutes and then have the amputee integrate weight shifting into walking. Alternating between these tasks will help to maintain the patient's enthusiasm and to reinforce the relevance of the prosthetic gait training process. It is also important to work on ambulation both with and without visual feedback, eventually using no visual feedback. The amputee also needs to learn how to self-correct and feel the difference

between correct and incorrect gait patterns. Once the amputee is in the community, visual feedback will not be available, and therefore self-correction becomes very important.

Use of Assistive Devices

The type of assistive device used depends on preamputation activity levels, functional level, and long term goals. The initial assistive device is often a walker or crutches. However, some amputees will use only a wheelchair as their primary mode of mobility. The typical gait pattern used for walker and crutch ambulation is a flexed hip and trunk posture, which is exactly opposite the posture needed for correct prosthesis ambulation. Both can cause habits that will need to be corrected and avoided.

Many amputees are eager to ambulate independently and will abandon their assistive device prematurely. This may result in undesirable gait deviations because single limb balance over the prosthesis has not yet been achieved. Many transfemoral amputees who do not use an assistive device during household ambulation may choose to use a straight cane during long-distance ambulation or while ambulating in the community because of inadequate endurance. Compromised hip strength and balance will often result in fatigue and the need for such additional support.

Falling Techniques

Unfortunately, falls are inevitable for most transfemoral amputees. They often occur when the amputee tries new activities such as outdoor walking. Falls are also common in the home, when the toe of the prosthetic foot catches on throw rugs, thresholds, and uneven surfaces. These situations need to be addressed in therapy, but even with the best therapy, falls will happen. Falls can happen at any time during the rehabilitation process or even years after rehabilitation. Therefore, it is important to try to alleviate the amputee's fear of falling by practicing floor to standing transfers. A variety of techniques should be tried to determine which works best for each individual.

"Timber falls," or falls to the side, may occur when the amputee is off balance. More often, the transfemoral amputee falls straight down because the knee buckles. Because a fall with a prosthetic knee usually occurs very quickly, it is difficult for the amputee to control the fall, even with training. The best way to fall is to roll as the ground is struck to minimize the risk of injury to upper or lower limbs and to the prosthesis.

12. Gait Training with Different Knees

Manual Lock Knee

Characteristics and Indications

The manual lock knee is locked for both swing and stance phase. This knee is the most inherently stable of all the knee units, but it does not allow normal gait mechanics. This knee is prescribed for patients who are exceptionally weak, have limited vision or for patients who prefer this type of knee. This knee may also be indicated for bilateral transfemoral amputees, though it is not a typical configuration.

Gait Training

Gait training with this knee focuses mainly on balance because the patient moves over an extended knee. Swing phase is usually accomplished by hip hiking or by circumduction of the prosthetic limb. The prosthetist will often fabricate the prosthesis to be shorter than the contralateral limb for ease of toe clearance. This results in a gait pattern with a significant lateral trunk lean over the prosthetic side. This gait deviation cannot be eliminated if the device has been shortened.

Single-Axis Knee

Characteristics and Indications

The single-axis knee works essentially like a free moving hinge as it swings from flexion to extension. Often, this knee is coupled with a friction control to allow the prosthetist to limit the rate of swing for the amputee. This knee has limited inherent stability, so voluntary control by the amputee is crucial. The single-axis knee is indicated for amputees who have long residual limbs and/or good hip musculature and whose potential for voluntary control is high. Knee stability is achieved while the knee center remains posterior to the ground reaction force (GRF). When the knee is aligned properly, the GRF will be anterior to the knee center, extending the knee until the end of terminal stance when the patient moves this limb forward to initiate swing. Once the knee is in swing phase, it can provide no stability if the amputee stumbles. This would result in a fall unless the amputee has quick reflexes on the sound side and can quickly recover from the stumble. The knee also gives little stability when going down hills and stairs and can buckle easily on uneven terrain. To increase the stability of the single-axis knee, fluid-control units can be added to provide stance phase control.

Gait Training

Because stability with the single-axis knee depends largely on voluntary control by the amputee, physical therapy is especially important. The physical therapist will need to instruct the amputee on how to achieve maximum voluntary control as well as balance and stability. Therapy should focus on the basics of weight shifting, hip extension, and pelvic control. Achieving a good heel strike, followed by a strong hip extensor contraction at initial contact through terminal stance in order to generate a strong extensor moment so the knee stays locked until preswing, is very important. If a good heel strike and knee extension is not achieved at initial

contact, the knee will have a flexion moment during loading response, likely resulting in a fall. Proper positioning and use of this knee is important with level walking, but even more so on uneven terrain, when an even stronger hip extensor contraction is needed to maintain an extensor moment in stance.

The single-axis knee allows for only one walking speed because the friction setting in the knee determines the rate of knee flexion and extension. The prosthetist will determine the friction setting based on the patient's strength, balance, and gait and the types of activities for which the prosthesis will be used. If the friction is set too high, the amputee will have difficulty getting the knee to bend during swing phase, and it will be slow to extend at the end of terminal swing. This may result in excessive uneven step length and gait deviations such as vaulting on the sound side or circumducting the prosthesis during swing phase. If the friction is set too low, too much heel rise on the prosthetic side and a fast, hard extension during terminal swing are likely to occur. The knee and shin components may impact forcefully and loudly at the end of swing phase. If the resistance is set extremely low, the knee may come out of extension at terminal swing and start moving back into flexion before initial contact occurs. This will result in decreased stance phase stability in loading response. If the patient increases his or her gait speed, these gait deviations will become more pronounced.

Weight-Activated Friction Knee

Characteristics and Indications

Also known as the stance-control knee or, historically, as the safety knee, the weight-activated friction knee uses mechanical friction to provide resistance during stance phase. The use of friction throughout stance phase results in greater safety and stability than the single-axis knee provides. The unit is designed with a spring-loaded brake which functions only during stance, allowing free swing when it is unloaded. This brake mechanism will keep the knee stable if it is slightly flexed on initial contact. The amount of flexion allowed for the knee to remain locked depends on the manufacturer, but may range between 15 and 40 degrees. Therefore, the brake mechanism will help prevent the knee from buckling if the amputee does not achieve full knee extension at initial contact. The weight-activated friction knee is indicated for an amputee with weak hip musculature, decreased balance, or a short residual limb. These are prescribed frequently for the elderly population because they provide stability even if a strong knee extensor moment is not generated. They are often very helpful for an elderly amputee who may not be able to consistently achieve a solid heel contact and feel secure with every step.

Gait Training

Gait training with a weight-activated friction knee is the same as with the single-axis knee, requiring a good weight shift and hip extension. The benefit of training with the weight-activated friction knee is the support it gives the patient who has difficulty getting the foot out in front and remembering to extend at the hip. This does not negate the importance

of teaching weight shifting and hip extension, however, as learning these concepts will help the amputee maneuver uneven terrain and hills as well as give the amputee a better understanding of how the knee works. The big drawback of this particular knee is that it allows only one gait speed, but for the patient who does not need to walk at different speeds, the stability offered outweighs the advantage of variable cadence. Instruct the amputee that when sitting down while wearing the weight-activated friction knee, weight must be shifted off the prosthetic side so that the knee can release into flexion.

Polycentric Friction Control Knee

Characteristics and Indications

The polycentric friction control knee is the most inherently stable of all the knees except for the manual lock knee. These knees typically have a complex linkage that maintains an instantaneous center of rotation (ICR), meaning that the center of rotation of the knee is constantly moving during stance phase. Because the linkage typically has either 4 or 6 segments, this knee is often referred to as a “four bar” or “six bar” knee. The moving ICR helps to maintain the knee center behind the ground reaction force which provides stability. In most polycentric knees, this center of rotation is located proximal and posterior, toward the muscle belly of the hamstrings, for maximum stability. Resistance to flexion and extension is controlled through the friction applied at the polycentric joint, which is set by the prosthetist for the activity level of the patient. Because of the inherent stability of these knee units, polycentric knees are often indicated for bilateral amputees and amputees who cannot ambulate safely on other types of knee units. These units are also often prescribed for transfemoral amputees with long residual limbs and knee disarticulation amputees because of the shortening effect of the polycentric knee in early swing phase.

Gait Training

To initiate swing phase, the center of rotation must move anterior the GRF, unlocking the knee and allowing knee flexion. The amputee accomplishes this by achieving a good weight shift and roll over the foot. The polycentric knee unit also shortens slightly during flexion, helping the toe clear more easily in swing phase. This behavior also causes the knee center to fold under when the amputee is sitting, avoiding a knee length discrepancy.

Stability at midstance and terminal stance is increased with the polycentric knee, but a good heel strike and strong hip extension are still important at initial contact because the knee may buckle if the amputee stumbles. Gait training should focus on a full weight shift and hip extension on the prosthetic side. This is necessary to achieve a good rollover of the foot from initial contact to terminal stance, which is needed for the knee to release for swing phase.

Hydraulic and Pneumatic Knee Mechanisms

Characteristics and Indications

Hydraulic and pneumatic knee mechanisms are used in conjunction with both single-axis and polycentric knee units.

The fluid in the hydraulic unit, typically silicone oil, provides proportional resistance to knee motion. Similarly, the air in a pneumatic unit provides resistance to knee motion. In both cases, the resistance to motion is provided by forcing the fluid (air or oil) through a port, or opening in the control unit. This resistance can be adjusted by the prosthetist to be compatible with the amputee's gait and preferences. Hydraulic units are cadence responsive, so the gait pattern is smoother and more natural at varying walking speeds. Pneumatic units also have the advantage of being cadence responsive, but they are generally considered less effective than hydraulic units. Gait training with either a hydraulic or pneumatic unit depends on the type of knee to which it is added. Hydraulic and pneumatic knee units are most often indicated for active amputees who are able to ambulate at multiple speeds.

Gait Training

With most fluid control units, the amputee must deactivate the stance control to release the knee for swing. This occurs automatically by achieving a good weight shift and a solid, heel-to-toe roll over the prosthetic foot. Most fluid control units require a hyperextension force at the knee during terminal stance for the hydraulic or pneumatic unit to disengage into free flexion. If the amputee does not roll over the ball of the foot, the knee will remain locked in extension and not release for swing phase. Physical therapy should focus on achieving a good weight shift and hip extension, although the amputee does not need to fire the hip extensors excessively hard at heel strike because fluid control knees commonly have built-in extension assist. These knees also remain stable even if the knee is slightly flexed at heel strike because the fluid control mechanism resists flexion rather than collapsing.

Microprocessor Knee Mechanisms

Characteristics and Indications

Microprocessor knees offer the function and performance of fluid-control knee, but with improved control by way of a microprocessor computer. The microprocessor constantly monitors the knee angle and loads through the prosthesis to determine the proper resistance to flexion and extension. With this control, the knee can more rapidly adapt to changes in gait, including changes in the amputee's cadence or the transition from level walking to stairs or hills. Because microprocessor knees contain the batteries needed to power the computer, these knees must be recharged on a regular basis to function optimally. When the knee loses power, each knee enters into a safety mode which is manufacturer-specific. Microprocessor control knee units are indicated for active amputees who wish to ambulate at various cadences. They may also be indicated for the geriatric population because of the improved stance phase control as compared to other knee units. These knees are not recommended for extremely active or heavy individuals as they are only rated for certain weights and environments.

Gait Training

Gait training with a microprocessor knee is often very specific to the particular unit selected. Each knee offers a variety of features that may or may not be similar to other,

available microprocessor knees. Key features of each knee, such as stumble recovery, default safety modes, and alternate operating modes should all be discussed and practiced with the patient. As with most fluid-control units, gait training for

microprocessor knees should focus on the necessary motions needed to disengage the stance features of the knee and enter into swing phase. Detailed instructions for gait training with the Otto Bock C-Leg are located in Chapter 14.

13. Advanced Gait Training

Although gait training is the basically the same regardless of the type of knee unit used, there are differences when training amputees to walk on stairs, ramps, and hills. These advanced training techniques are described below, followed by Table 25 and Table 26, which summarize different training techniques that might be appropriate for different types of prosthetic knees.

Stairs and Curbs

Stability when stepping up and down stairs and curbs is paramount for the transfemoral amputee. Strong hip extension on the prosthetic side is necessary to keep an extensor moment at the knee for both ascending and descending. Balance and control are also very important.

Ascending Stairs and Curbs

Ascending is most often accomplished with a step-to pattern, leading with the sound side (Figure 68).²¹ Stability and balance are necessary to achieve complete weight acceptance on the prosthesis, which will enable the amputee to ascend stairs and curbs safely, even without a handrail or assistive device. Training should emphasize achieving a good weight shift and stabilization by using the hip extensors and hip abductors on the prosthetic side before the sound side foot is put up on the step or curb. When stepping the prosthetic foot up on the step, it is usually best to abduct the limb to clear the step. If the amputee tries to drag the toe up the step, the toe may catch, causing a stumble. Also, remind the amputee that some steps have a lip, which increases the chance that the prosthetic toe may catch.

Table 25 – Techniques for maneuvering stairs and curbs with various prosthetic knee units

Type of Knee	Typical Ascent Technique	Typical Descent Technique	Special Considerations
Friction Control	Step-to, leading with nonprosthetic side	Step-to, leading with prosthetic side	None
Weight-activated friction	Step-to, leading with nonprosthetic side	Step-to, leading with prosthetic side	Greater stability in stance phase, allows between 15° and 40° of knee flexion at heel strike.
Fluid-control (hydraulic or pneumatic)	Step-to, leading with nonprosthetic side	Step-to, leading with prosthetic side	None
Hydraulic with high-resistance yielding stance	Step-to	Allows a step-over-step pattern	Amputee must avoid creating a hyperextension moment at knee on initial contact because this will disengage stance control. Stepping down with the prosthetic toe partially off the step will cause a controlled yielding of the knee. How quickly the knee yields depends on the setting of the stance phase resistance.

Table 26 – Techniques for ascending and descending ramps and hills with various prosthetic knee units

Type of Knee	Typical Ascent Technique	Typical Descent Technique	Special Considerations
Friction control (Single-axis)	Side-stepping or uneven step-to with nonprosthetic side significantly ahead	Side-stepping or uneven step-to with prosthetic side significantly ahead	None
Friction control (polycentric)	Side-stepping or uneven step-to with nonprosthetic side significantly ahead	Side-stepping or uneven step-to with prosthetic side significantly ahead	This knee folds under slightly, making it easier to get the prosthetic foot forward on hill ascent. A large step forward with the prosthetic foot still is not possible, however, because of the great demand on the hip extensors to translate the body weight forward over the prosthetic foot.
Weight-activated friction	Side-stepping or uneven step-to with nonprosthetic side significantly ahead	Side-stepping or uneven step-to with prosthetic side significantly ahead. On gentle descents, may allow a step-past or even step pattern.	Same techniques but can be a bit less stringent because this knee provides greater stability in stance phase, allowing up to 15° of knee flexion upon heel strike.
Fluid control	Side-stepping or uneven step-to with nonprosthetic side significantly ahead	Depends on type of knee hinge (single-axis or polycentric)	Depends on type of knee.
Swing and stance (SNS)*		Allows equal step pattern	On ramp descent, knee should be in slight flexion at initial contact. As long as a hyperextension moment is avoided, stance resistance allows a larger step to be taken with the sound side.

*The SNS knee allows the patient to manually lock and unlock the knee as well as change the knee flexion and extension resistance, otherwise known as dampening, as instructed by the prosthetist.



Figure 68 – Stair ascent

Toe taps on a step are one activity that can be initiated early in prosthetic gait training. Be sure to practice this activity both with and without upper limb support so the amputee is proficient in situations where a handrail is not available.

Descending Stairs and Curbs

The Step-to Method

Descending stairs is usually accomplished with a step-to pattern, leading with the prosthetic side (Figure 69).²¹ Stability and balance are important so that the amputee can achieve complete weight acceptance on the prosthetic side when stepping onto the step below. The prosthetic side hip extensors and hip abductors need to be active in order to provide the pelvic stabilization required for this activity. Many amputees are nervous about stair descent and tend to keep the hip flexed and their weight back on the heels when stepping down onto



Figure 69 – Step-to pattern for stair descent

the prosthetic side. They are fearful that extending the hip will shift their weight too far in front, causing them to fall forward. To address this fear, practice stepping down off one step onto the prosthetic foot while achieving hip extension and overall hip stability. The amputee should practice this drill both with and without upper limb support.

The Step-Over-Step Method

Some transfemoral amputees will be able to descend using a step-over-step pattern. The ability to descend stairs in this manner will be dependent upon the amputee's skill and the type of knee unit used. This skill is typically reserved for advanced users as it requires more balance and is less safe than a step-to pattern of gait.²¹

Other Methods

Some amputees who have difficulty with stair ascent and descent when facing forward may have more success with a side-stepping technique (Figure 70). Side-stepping is



Figure 70 – Side step pattern for stairs

accomplished by using a step-to pattern, leading with the sound side when going up and leading with the prosthetic side when going down.

Many younger amputees with good balance and strength go up stairs two steps at a time, typically using a handrail. These amputees usually descend using the typical step-to pattern, or they hold onto both handrails and swing down a few steps at a time. A summary of knee-specific ascent and descent techniques for stairs and curbs is provided in Table 25.

Ramps and Hills

The need for stability is even greater when walking on hills and ramps than it is for maneuvering stairs and curbs. Although similar, ramps have a gentler slope than a hill, and

many include a handrail. Many transfemoral amputees are able to negotiate ramps with little difficulty once they have learned proper techniques. Techniques for walking on hills are very similar to those used for ramps, but the margin of error may be significantly smaller, depending on the steepness of the hill. Most transfemoral amputees avoid walking on hills if at all possible.

Ascending Ramps and Hills

The ramp and hill ascent technique that is best for a particular amputee depends on the knee and foot components. Several different techniques should be taught so that the amputee can choose the best technique depending on the steepness of the hill or ramp. Many amputees, however, will always use the same technique regardless of the steepness of the incline.

One issue with prosthetic gait is that unlike the anatomic knee, the prosthetic knee does not bend on heel contact, so an even step-over-step pattern is difficult to achieve when going uphill. It is also difficult to take a large uphill step with the prosthetic side because the larger the step, the greater the hip extension that is needed to advance the body over the foot. Therefore, most amputees will use a type of step-to pattern, leading with the sound side (Figure 71). They will then step



Figure 71 – Hill ascent

with the prosthetic side just to or slightly past the sound side foot, depending on the steepness of the hill, the strength of the amputee's hip extension, and, to some degree, the flexibility of the foot. Because most prosthetic feet will reach a dorsiflexion limit during ascent, a very powerful hip extension contraction is required to propel the body over the foot on steep inclines. The amputee should be taught to externally rotate the prosthetic foot, and roll over the instep; in this way the foot will not hit the dorsiflexion limit as soon. An even step pattern is not likely when going uphill, but this technique will allow the amputee to take a more symmetrical step.

When going uphill while facing forward, many amputees will shuffle the prosthetic side foot to meet the sound side foot. Because they do not roll over the foot, the knee does not

typically release into flexion for swing phase, so the knee remains extended. When going up an incline, the knee has an extensor moment acting on it, which keeps the knee stable. Many transfemoral amputees also keep weight on the prosthetic toe when ascending, which also encourages an extensor moment at the knee. Whether or not this technique is effective depends on the type of prosthetic knee the amputee has. It is important to understand the mechanics of each type of prosthetic knee because some knees will release into flexion with the extension moment generated while ascending ramps and hills.

Maneuvering Steep Hills and Uneven Terrain

For extremely steep hills or hills on uneven terrain, ascent can be accomplished using a side-stepping pattern with the sound side leading on the uphill side.²¹ Another technique that is used less frequently but that may be effective is to use a "figure-S" technique similar to walking on a switch-back hiking trail. This effectively lessens the degree of the incline, but may require more energy because more steps are taken. However, many amputees feel safer and more in control with this technique.

Ramps

For ramp ascent, many transfemoral amputees will be able to use an even step pattern.²¹ Their ability to do so will depend upon the length of the residual limb, strength, balance, and training. When learning this technique, most amputees will initially require cues to extend the hip so they will be able to move easily over the prosthetic side as they move up the ramp.

Ramp and Hill Descent

The technique used for ramp and hill descent also depends on the type of prosthetic knee the amputee has. The knee component dictates how much stability is available while descending the hill, which will dictate the gait pattern the amputee can use safely. In most prosthetic knees, the knee center is placed posterior to the weight line for static alignment; once the body weight starts progressing forward and the knee center moves anterior to the GRF, the knee moves rapidly into flexion. When descending hills, this progression of the GRF happens more rapidly, causing the knee to flex even sooner. This rapid flexion can be scary and even dangerous if the amputee is not able to get the sound side leg out in front quickly enough. For this reason, amputees are usually taught to go downhill by leading with the prosthetic side and taking a shorter step with the sound side (Figure 72). On less severe downward grades, the amputee may be able to achieve an even step pattern, but as the grade increases, the amputee will need to take a larger step on the prosthetic side than on the sound side. This keeps the knee center posterior to the GRF and keeps the knee locked and stable. On steeper hills, a type of step-to gait pattern is used, keeping the sound side foot behind the prosthetic side to keep the knee stable. Some hydraulic control knees have a yielding stance feature which will allow an amputee to descend ramps with a step-over-step pattern.

Steep Descent

For extremely steep hills or hills on uneven terrain, a side-stepping pattern can be used.²¹ The amputee descends



Figure 72 – Step-to pattern for hill descent

sideways, leading with the prosthetic side. This allows the sound side lower limb to control the descent. As with hill ascent, a figure-S technique can also be used for steep descents. A summary of knee-specific ascent and descent techniques for ramps and hills is provided in Table 26.

Turning

The transfemoral amputee can learn to turn 180°, moving in either direction, in 2 or 3 steps.²¹ Turning in both directions should be practiced as it will increase pelvic stability and prepare the amputee for either motion. Turning over the prosthetic limb requires strong hip extension and abduction to keep the pelvis stable while rotating the body over the top of the prosthesis. The stool rolling activity is an effective tool for teaching this activity. As the amputee rolls the stool from side to side with the sound side foot, strong hip extension is needed to maintain the knee in a stable position.

Maneuvering Obstacles

Maneuvering around objects is an important skill that the amputee will use often, from stepping in the kitchen to stepping over objects to moving quickly to get out of the way of traffic. Physical therapy should anticipate and prepare the amputee for situations likely to be encountered in daily life.

The amputee should be able to maneuver around low objects by leading with either side. When leading with the prosthetic side, the amputee will need to circumduct the prosthetic side to clear the object. Once the prosthetic foot makes contact with the ground, a strong hip extension is required to keep the prosthesis stable while the body weight is shifted onto that side. When leading with the sound side, the prosthetic side must be stable prior to stepping over the object, and then the prosthetic side should be circumducted to clear the object. Many amputees, will choose to step over an object leading with the sound side for increased stability.

During therapy, all activities should be practiced at both the amputee's customary speed and at increased speeds. The

amputee should be comfortable making quick changes of directions and speeds.

Walking Backward

Many amputees are not comfortable walking backward, so the skill requires some practice. Most knees are most stable with an extensor moment at the knee, so the amputee should be instructed to keep the prosthetic foot behind the sound side foot, with the toe loaded, when walking backward (Figure 73).



Figure 73 – Backward walking

The same technique is used for single-axis, weight-activated friction, polycentric, hydraulic, and pneumatic knees. With the SNS system, even though a hyperextension moment at the knee will cause the knee to release into flexion for swing phase, this will not occur when walking backward because the weight line will still be anterior to the knee center, resulting in an extension moment. Therefore, the SNS knee will stay locked unless a knee hyperextension moment occurs.

Sidestepping

Sidestepping is an important skill for every transfemoral amputee to learn for maneuvering in tight spaces or for ease of movement.²¹ Training should focus on weight shifting and stabilizing at the trunk and pelvis with each lateral step. It is also important to teach sidestepping in both sideward

directions. The sidestepping technique will work with all prosthetic knees but it can be modified with a slight posterior placement of the prosthetic foot if the knee is stable in this position. If the amputee has a knee that requires toe loading to release the knee for flexion, it will be important to teach sidestepping onto a flat foot in order to avoid stepping backward onto the prosthetic toe. Doing so would cause instability and may cause the prosthetic knee to release into flexion, causing a stumble or a fall.

Carrying Objects

Carrying objects in front of the body while walking can be very challenging for the transfemoral amputee. One reason is that the object may obscure the floor or ground and the feet. This makes proprioception difficult, and therefore many amputees will not carry anything that keeps them from seeing their feet. Balance and proprioceptive activities should be

practiced both with the eyes open and with the eyes closed in order to prepare for this type of functional activity.

An additional concern with knee units such as the SNS unit that release into flexion for swing phase when a knee hyperextension moment is reached is that carrying a heavy object may cause this knee hyperextension moment to be reached sooner. The patient with this type of knee should work on carrying objects to learn to feel the difference in how the knee reacts with an increase in weight load.

Therapeutic Dynamic Activities

Other functional activities to address include bending over, lifting objects, overhead reaching, and plyometric activities. These are important training tools that will teach an amputee about how the prosthetic knee will respond during the various activities of daily living.

14. Microprocessor Knees: The C-Leg

Advances in prosthetic technology have resulted in the creation of components that mimic the appearance and feel of normal human gait. The field of prosthetics has reached a new level with the recent development of microprocessor-controlled knee units. These new prosthetic knees, which first came on the market in 1997, combine pneumatic and/or hydraulic components with microprocessors and integrated sensors. The microprocessor uses sensor information about changes in force and knee angle to continuously adjust the knee to provide the user with comfort, stability, and adaptability on stairs, hills, ramps, and uneven terrain. The benefits include lower energy consumption and a more normal gait, resulting in better overall function and quality of life for the user.

Several microprocessor knee units by various manufacturers are currently on the market. The best known of these, the C-Leg® by Otto Bock, will be discussed here. The C-Leg is a swing and stance phase hydraulic knee unit that is controlled by a microprocessor. Sensors in the knee joint and pylon measure the knee angle and ankle moments at each moment in time. These sensors provide feedback to the computer regarding direction, velocity, and rate of change of the knee angle, as well as plantar flexion and dorsiflexion moments at the ankle. Using these inputs, the C-Leg constantly adjusts hydraulic resistance to enable a smoother gait pattern and allow the amputee to go down stairs, hills, and ramps with a step-over-step pattern. The design of the C-Leg promotes increased stance phase stability over most knees on the market, with the overall goal to decrease or eliminate falls. To achieve this stability, the C-Leg remains extended in stance and only allows for flexion when sensor information indicates that it is safe. Other types of knee mechanisms do not maintain this type of control and safety monitoring and may inappropriately flex in some situations.

One feature present in the C-Leg is the ability to recover during a stumble. The C-Leg constantly monitors the knee angle and how the toe and heel are being loaded. When the microprocessor detects that the heel stops rising without reaching a predetermined setting, it senses a stumble and directs the knee to go into stance phase. This makes the knee stiff, allowing the amputee to move quickly over the leg and avoid a stumble.

The behavior of the C-Leg in both stance and swing phase can be customized to a patient's unique needs through a proprietary software program available to the prosthetist. Knowledge of this software and the available settings will enable the physical therapist to determine which gait deviations are caused by the patient and which are related to the alignment or settings of the prosthesis. Working closely with the prosthetist during a physical therapy visit will help to maximize therapy and determine which settings may need to be adjusted or which type of gait training is necessary. The prosthetist can then program and modify the C-Leg's settings as needed during the session.

Modes and Settings

The C-Leg has two modes of operation. The primary operating mode or 'first mode' has seven settings, which control the

C-Leg in stance and swing phase. The alternate mode or 'second mode' has two settings that allow the amputee to change the behavior of the C-Leg for various activities such as biking, skiing, or standing with a slightly flexed knee.

First Mode Settings

- Maximum toe load – Sets the value for the stance phase toe load that will cause the knee to release for swing phase.
- Stance flexion damping – Sets the resistance to knee flexion that the knee provides during hill and stair descent. This is initially set while the amputee moves from a standing to a seated position but often is adjusted to provide less resistance as the amputee gains confidence with descending hills and stairs. This does not affect walking speed or gait on level terrain.
- Stance extension damping – Sets the resistance to knee extension during stance and smoothes the transition from loading response to terminal stance.
- Initial swing flexion damping – Sets the resistance to knee flexion while the foot is on the ground so that the amputee can easily transition into swing phase. This setting interacts with the dynamic factor setting to determine the amount of heel rise during initial swing phase.
- Knee angle threshold - Sets the knee angle at which the C-Leg transitions from free swing to a controlled swing using the dynamic factor setting.
- Dynamic factor – Sets the resistance to knee flexion during swing phase. This setting controls how quickly the heel will rise at all walking speeds. This setting interacts with the knee angle threshold and the flexion damping settings to control heel rise during initial swing phase.
- Swing extension damping – Sets the resistance to knee extension that occurs at the end of terminal swing. This setting provides a smooth deceleration of the limb prior to initial contact.

Second Mode Settings

- Basic flexion damping – Sets the resistance to knee flexion.
- Increased damping with knee angle – Sets the increasing resistance to flexion as the knee angle increases.

Contacting the Prosthetist

During gait training, balance, and proprioception activities, the physical therapist may notice that the knee is buckling inappropriately or that it seems too easy for the amputee to get the knee to release for swing phase. In this case, the prosthetic alignment or C-Leg software settings may need to be adjusted. Inappropriate alignment or software settings can be dangerous, and the amputee should see the prosthetist as soon as possible. It is also important to remember that therapy can affect range of motion. For example, an increase in hip extension range can cause the maximum toe load to

occur sooner and thereby cause the knee to flex for swing phase sooner than expected. In this case, the amputee should see the prosthetist for an adjustment. If in doubt, contact the prosthetist to describe how the knee is behaving during various activities.

Gait Training with the C-Leg

The initial focus of therapy with the C-Leg may differ slightly depending on whether the patient is a recent amputee who needs to learn basic gait training or an established amputee who is transitioning from another device to the C-Leg and needs training on how to use the device properly. A review course in basic gait may be beneficial, even for the established amputee, to learn to use the C-Leg to its fullest potential. For these individuals, a review course in proper weight shifting, stabilization, balance, and proprioception will improve their mobility both with and without the C-Leg (See Initial Prosthetic Gait Training, Chapter 11).

Orientation

Begin with the amputee in the parallel bars using upper limb support. To feel the resistance of the knee, have the amputee lunge into the C-Leg (Figure 74). The position will be similar to that achieved if the patient lunges on the sound side and allows the front knee to bend. This will help the amputee feel



Figure 74 – Lunging into C-Leg

what the resistance will be like on hills and stairs. Next, review how to get the knee to release for swing phase. In order for this to occur, the amputee must meet two criteria: (1) the knee must be fully extended and (2) the toe of the prosthetic foot must be loaded to at least 2/3 of the maximum toe load setting. To accomplish this during gait, the amputee must achieve a good weight shift over the prosthetic foot and roll over the foot from heel to toe. The importance of basic gait training will be evident. A lateral trunk lean over the top of the prosthesis and/or a failure to achieve sufficient hip extension may prevent the amputee from consistently reaching the required toe load or achieving knee extension in stance, and the knee will not release for swing phase. The knee will remain stiff or locked in extension, resulting in a choppy gait pattern and frustration for the amputee. The settings on the C-Leg can be adjusted to help the amputee more consistently reach the required toe load, but fatigue or a sloppy gait pattern may prevent the amputee from achieving both criteria for knee flexion and a smooth release into swing phase. Proper training will help to ensure the C-Leg behaves as it should.

Static Standing

Amputees with standard (non-microprocessor) knee units tend to static stand with the prosthetic foot behind them, sometimes even putting more weight on the toe because the resulting extensor moment at the knee provides maximum stability. An amputee with a C-Leg, however, needs to stand with weight equally distributed over both feet because if the knee is extended and the toe is loaded, the C-Leg will release into flexion for swing phase. This could lead to a fall if the amputee is unaware that the C-Leg is no longer stable.

Backward Walking

Walking backward in the C-Leg requires a different technique than walking backward in a standard prosthesis. If the amputee has learned this skill in a different prosthesis, learning a new technique may be especially difficult. To walk backward with a standard knee unit, the amputee must keep the prosthesis behind the body and load the toe. This causes an extension moment at the knee, resulting in a very stable knee and maximum stability. With the C-Leg, this technique will cause the knee to release for swing phase, causing a fall.

The proper technique for walking backward with the C-Leg is to step back onto a flat foot or to shuffle the foot backward (Figure 75). This will ensure that the criterion of toe load is not being met and that the knee will stay stable and extended.

Many falls with the C-Leg occur in the bathroom when the amputee steps back and catches the heel on the tub. This loads the toe, releasing the knee. This also happens in the kitchen, when side stepping or stepping backward in a small space. Put your patients in as many situations as possible that they may run into in their daily lives to be sure they understand how the knee works and what will cause the knee to release.

Uneven Terrain

For walking on uneven terrain, the user's balance and confidence in the prosthetic knee are important. A decreased confidence in the knee may prevent the amputee from reaching one or



Figure 75 – Backward walk with C-Leg

both of the criteria required for knee flexion, resulting in a stiff knee in swing phase. Walking through weeds, tall grass, or on uneven terrain is difficult with any type of prosthetic knee, but the C-Leg knee may lock up in such conditions if the amputee is not confident in the knee and therefore does not achieve sufficient weight shift over the prosthesis for the knee to release for swing phase.

Descending Stairs

One of the advantages of the C-Leg is that it allows a step-over-step pattern when going down stairs. The standard technique for going down stairs with most non-microprocessor knees is a step-to pattern, leading with the prosthesis. The step-over-step technique is more energy efficient, allows for a more normal gait pattern, provides increased stability, decreases wear and tear on the sound side knee, and increases the amputee's overall confidence.

For stair descent, physical therapy should focus on (1) foot placement, (2) teaching the amputee how to “ride the knee” into flexion, and (3) balance. Begin with bilateral rails because learning this technique can initially be scary. First, help the amputee with foot placement because the knee will not release without proper placement. In order for the knee to release slowly into flexion, the prosthetic foot should most often be

placed with foot center on the edge of the stair. The exact placement will be different for each amputee, so some trial and error will be required to determine the best position. Cue the amputee to “sit into the knee” or “push into the knee” as he or she steps down to the next step with the sound limb. The particular stance flexion resistance setting will determine how slowly or quickly the knee will flex. First-time C-Leg users will often have the resistance set fairly high, so stair descent will be slow. Remind the amputee to keep the weight shifted over the top of the C-Leg, to keep the knee aligned with the foot, and to keep their back straight. If the amputee uses an assistive device such as a cane, the device and the prosthetic foot should be placed on the step at the same time. If the amputee leans forward and puts the cane down before the foot, the knee will not release consistently. The most challenging situation is descending stairs without using an assistive device or handrail. Achieving proper step placement in this situation requires good control and balance (Figure 76).



Figure 76 – Stair descent with C-Leg

Ascending Stairs

Like most prosthetic knees available today, the C-Leg cannot mechanically power the amputee up stairs. Stair ascent with the C-Leg is taught using a step-to pattern, leading with the sound side.

Hills

Another advantage of the C-Leg is that hill and ramp descent can be achieved with a controlled step-over-step pattern. This allows for a more natural gait pattern and decreases wear and tear on the sound side knee.

Ascending Hills

The technique for ascending hills with the C-Leg is similar to that for non-microprocessor knees, except the quality of gait may differ slightly. The C-Leg allows for a smoother pattern because it is easier for the user to release the knee into flexion and less vaulting is needed to clear the foot when stepping the prosthetic side up the hill. Thus, the amputee may be able to use a step-past pattern on a steep hill rather than the step-to pattern typical with non-microprocessor knees. An even, step-over-step pattern is typically not possible, as this requires very strong hip extension to advance over the prosthesis.

Descending Hills

The C-Leg allows controlled descent into knee flexion on the prosthetic side, with the speed of knee flexion determined by the amount of resistance programmed into the knee. This controlled resistance allows for a more natural gait pattern and decreases the wear and tear on the sound side knee. As with descending stairs, the physical therapist should instruct the amputee in “riding the knee” down or “sitting into the knee.” Amputees typically will not trust the prosthetic knee at first; it will take some time to overcome the fear that the knee will buckle. A good approach with some amputees is to start by teaching the step-over-step descent on stairs so that the amputee can use the handrails for stability and balance. Then transfer them to a hill or steep ramp and instruct the amputee to use the same technique as on stairs: sitting into the knee and staying upright over the prosthesis without leaning forward.

Next, progress the amputee to steeper hills. This will enable the amputee to experience the step-over-step pattern and feel the control the knee has to offer. Use guarding techniques as necessary to give confidence to the amputee. Typically, guarding in front with a hand on the chest will encourage the amputee to stay upright over the top of the prosthesis. Use cues such as “sit into the knee,” “push into the knee,” or “allow the knee to bend.” Many amputees initially take a very short step with the prosthetic side, which results in an awkward and off-balance gait. If this is the case, encourage the amputee to take a midsize step out in front with the prosthetic side. The initial tendency of most amputees is to start to allow the knee to flex slowly but then fire the hip extensors in order to lock the knee. With a C-Leg, this will cause the knee to go into stance mode and the knee will not flex. To overcome this tendency, encourage equal step lengths and good weight shift over the prosthesis. Some amputees find that matching step length with the physical therapist is helpful. It is important to tell the amputee that there is a learning curve with the C-Leg and that it may take some time to learn the necessary skills and feel confident using the prosthesis.

Ramps

Ascending and descending ramps with the C-Leg requires slightly different techniques than those used for hills.

Ascending ramps

Ascending a ramp can usually be accomplished using an even step pattern, the same as is taught with non-microprocessor knees. See Chapter 13 for details on training this skill.

Descending ramps

Learning to descend ramps is often more difficult than learning to descend hills for recent C-Leg users, especially for established amputees who have learned ramp descent with a non-microprocessor knee and are now relearning the technique with the C-Leg. Ramp descent technique with non-microprocessor knees is dependent on the grade of the slope as well as the surface. Transfemoral amputees with non-microprocessor knees can walk down a ramp using an even step-over-step pattern. However, they will often choose to use an uneven step pattern because they are unsure of the effect the grade of the ramp will have on the knee stability. They are even less likely to use an even step pattern on steeper ramps due to the rapid knee flexion moment that develops in early stance as the slope grade increases. With the C-Leg, ramps are descended using a gait pattern similar to level walking (i.e. an even step pattern with forward weight shift and hip extension) because the knee is able to provide controlled flexion and support as the knee moment transitions from an extension to a flexion moment. Many amputees will be tentative on ramps until they can determine the grade of the ramp and what kind of step pattern they are going to be able to take.

Many non-microprocessor knees will flex for swing rapidly on a descent because the weight line quickly moves behind the knee center. This often forces the amputee to take a quick step and lowers their confidence that the knee will bear weight. The C-Leg, however, must still reach the extension and toe load criteria in order to flex for swing phase. This allows the amputee to take a more natural step and to maintain confidence in the knee. However, the amputee will need sufficient forward weight shift and hip extension in order to reach the required flexion criteria. It will take some time for the amputee to gain confidence in the C-Leg, but when achieved, the knee will allow for a more normal forward progression. It is not unusual for the recent C-Leg user to have the knee lock up on them when descending a slope. This is either because they have not reached the required toe load and/or knee extension, or because the amputee rides into excessive knee flexion as if on a hill. If the amputee continues to have difficulties with learning this skill, it may help to ask the prosthetist to look at the knee center alignment. If the knee is aligned too stable, the amputee may have difficulty achieving the two criteria quickly enough, and the release into swing phase may not occur.

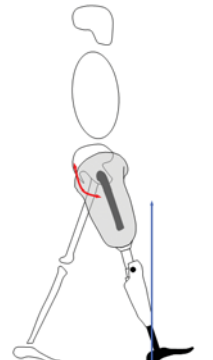
Summary

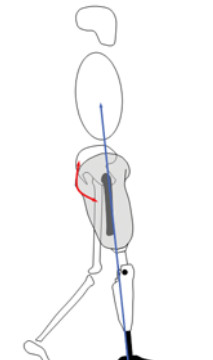
The C-Leg and all microprocessor knee units have taken the world of prosthetics to a whole new level. These microprocessor-controlled knees use advanced technology to more closely mimic the behavior of a sound knee. But with advanced technology comes the need for additional training. The amputee, the prosthetist, and the physical therapist must all be aware of the differences between a traditional

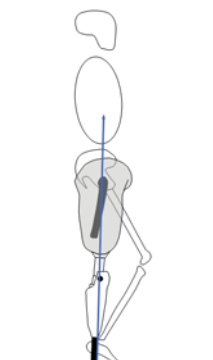
knee and a microprocessor knee in order to obtain the most benefit from the use of this device. Prosthetic alignment, software settings, and proper gait mechanics all play a key role in the success of microprocessor-controlled knees like the C-Leg. In order to provide an amputee with the most

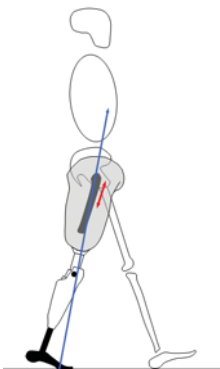
positive outcome and an efficient learning curve, a physical therapist must understand how these devices function and then discern whether gait deviations are a result of patient issues, alignment issues, or software settings. Only then can proper treatment be provided.

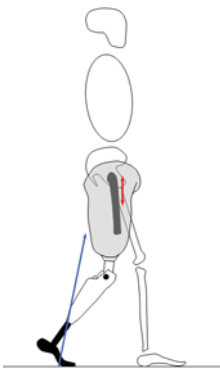
15. Gait Deviations in the Transfemoral Amputee

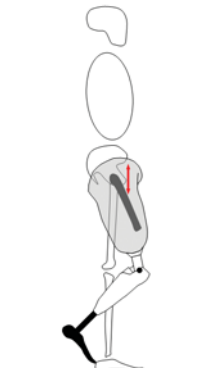
INITIAL CONTACT				
 <p>Primary Goals Knee fully extended Position limb for step</p>	Common Gait Deviations	Prosthetic Cause	Amputee Cause	C-Leg Alignment or Software Cause
	<ul style="list-style-type: none"> Knee not fully extended 	<ul style="list-style-type: none"> Excessive knee extension resistance 	<ul style="list-style-type: none"> Weak hip flexion in early swing initiation Weak hip extensors 	
	<ul style="list-style-type: none"> Unequal step length 	<ul style="list-style-type: none"> Excessive or insufficient socket flexion Unstable knee 	<ul style="list-style-type: none"> Poor balance Muscle weakness Fear of knee instability 	

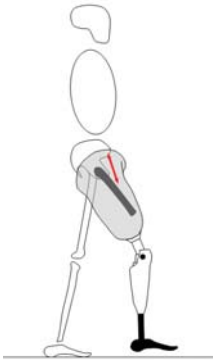
LOADING RESPONSE				
 <p>Primary Goals Knee remains stable Foot remains in line of progression</p>	Common Gait Deviations	Prosthetic Cause	Amputee Cause	C-Leg Alignment or Software Cause
	<ul style="list-style-type: none"> Knee instability 	<ul style="list-style-type: none"> Knee positioned too anterior to ground reaction force Insufficient heel compression Excessive heel height Insufficient socket flexion Foot positioned too far posterior 	<ul style="list-style-type: none"> Shoe heel too high or stiff Weak hip extensors Not actively extending limb 	<ul style="list-style-type: none"> Stance flexion damping too low
	<ul style="list-style-type: none"> External rotation of the foot 	<ul style="list-style-type: none"> Improper socket shape Insufficient heel compression 	<ul style="list-style-type: none"> Poor muscle control of limb Prosthesis donned in rotation 	
	<ul style="list-style-type: none"> Rapid toe descent 	<ul style="list-style-type: none"> Excessive heel compression 	<ul style="list-style-type: none"> Forcing extension to ensure knee stability 	

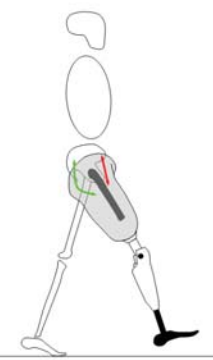
MIDSTANCE				
 <p>Primary Goals Vertical shank 2-4" gait base Trunk erect</p>	Common Gait Deviations	Prosthetic Cause	Amputee Cause	C-Leg Alignment or Software Cause
	<ul style="list-style-type: none"> Lateral trunk lean 	<ul style="list-style-type: none"> Outset foot Poor socket fit Medial brim pressure Distal lateral femur pain Short prosthesis 	<ul style="list-style-type: none"> Hip abductor weakness Painful residual limb Short residual limb Inadequate weight shift over prosthesis Hip abductor contracture 	
	<ul style="list-style-type: none"> Abducted gait 	<ul style="list-style-type: none"> Prosthesis too long Medial brim pressure Inadequate relief of distal lateral femur 	<ul style="list-style-type: none"> Habit to increase base of support Not laterally shifting pelvis Weak hip abductors Poor balance or proprioception 	
	<ul style="list-style-type: none"> Medial shank lean 	<ul style="list-style-type: none"> Excessive socket adduction 		
	<ul style="list-style-type: none"> Lateral shank lean 	<ul style="list-style-type: none"> Insufficient socket adduction 		
	<ul style="list-style-type: none"> Excessive lumbar lordosis 	<ul style="list-style-type: none"> Insufficient socket flexion 	<ul style="list-style-type: none"> Hip flexor tightness Hip extensor weakness Weak abdominals 	
	<ul style="list-style-type: none"> Excessive stance flexion 	<ul style="list-style-type: none"> Knee center too anterior to ground reaction force Excessive foot dorsiflexion 		<ul style="list-style-type: none"> Stance flexion damping too low

TERMINAL STANCE				
 <p>Primary Goals Equal step length Level pelvis</p>	Common Gait Deviations	Prosthetic Cause	Amputee Cause	C-Leg Alignment or Software Cause
	<ul style="list-style-type: none"> Excessive lumbar lordosis 	<ul style="list-style-type: none"> Insufficient socket flexion Painful ischial tuberosity 	<ul style="list-style-type: none"> Hip flexion contracture Weak hip extensors Weak abdominals 	
	<ul style="list-style-type: none"> Pelvic rise 	<ul style="list-style-type: none"> Prosthesis too long Excessive foot plantarflexion Excessive toe lever 		
	<ul style="list-style-type: none"> Pelvic drop 	<ul style="list-style-type: none"> Prosthesis too short Excessive foot dorsiflexion Insufficient toe lever Knee alignment unstable 	<ul style="list-style-type: none"> Long sound side step 	
	<ul style="list-style-type: none"> Rapid knee extension 	<ul style="list-style-type: none"> Excessive foot plantarflexion Excessive forefoot lever 		<ul style="list-style-type: none"> Stance extension damping too low

PRESWING				
 <p>Primary Goals Smooth hip flexion Smooth knee flexion Socket remains secure on residual limb Foot tracks in line of progression</p>	Common Gait Deviations	Prosthetic Cause	Amputee Cause	C-Leg Alignment or Software Cause
	<ul style="list-style-type: none"> Insufficient knee flexion 	<ul style="list-style-type: none"> Prosthetic knee too far posterior (stable) Foot excessively plantarflexed Excessive knee resistance 		<ul style="list-style-type: none"> Knee angle threshold too low Maximum toe load too high Initial swing flexion damping too high
	<ul style="list-style-type: none"> Excessive knee flexion 	<ul style="list-style-type: none"> Prosthetic knee too far anterior (unstable) Excessive foot dorsiflexion Insufficient knee resistance 		
	<ul style="list-style-type: none"> Medial or lateral heel whip 	<ul style="list-style-type: none"> Excessive knee axis rotation Socket contours do not accommodate muscle contraction 	<ul style="list-style-type: none"> Socket rotated Suspension belt donned and worn improperly 	
	<ul style="list-style-type: none"> Posterior pelvic rotation 		<ul style="list-style-type: none"> Inadequate pelvic rotation 	

INITIAL SWING				
 <p>Primary Goals Maintain level pelvis Control heel rise</p>	Common Gait Deviations	Prosthetic Cause	Amputee Cause	C-Leg Alignment or Software Cause
	<ul style="list-style-type: none"> Excessive heel rise 	<ul style="list-style-type: none"> Insufficient knee resistance 	<ul style="list-style-type: none"> Excessive use of hip flexors 	<ul style="list-style-type: none"> Dynamic factor too low Knee angle threshold too high
	<ul style="list-style-type: none"> Insufficient heel rise 	<ul style="list-style-type: none"> Excessive knee resistance 	<ul style="list-style-type: none"> Insufficient use of hip flexors 	<ul style="list-style-type: none"> Knee angle threshold too low Maximum toe load too high Initial swing flexion damping too high Dynamic factor too high
	<ul style="list-style-type: none"> Prosthetic side pelvic drop 		<ul style="list-style-type: none"> Insufficient pelvic stabilization 	

MIDSWING				
 <p>Primary Goals Toe clearance Knee and foot track line of progression</p>	Common Gait Deviations	Prosthetic Cause	Amputee Cause	C-Leg Alignment or Software Cause
	<ul style="list-style-type: none"> Inadequate toe clearance 	<ul style="list-style-type: none"> Prosthesis too long Inadequate suspension Excessive knee resistance 	<ul style="list-style-type: none"> Inadequate pelvic stability 	<ul style="list-style-type: none"> Swing extension damping too high
	<ul style="list-style-type: none"> Circumduction 	<ul style="list-style-type: none"> Excessive knee resistance Mechanical extension assist too strong Inadequate suspension 	<ul style="list-style-type: none"> Weak hip flexors 	<ul style="list-style-type: none"> Initial swing flexion damping too high Maximum toe load too high Knee angle threshold too low
	<ul style="list-style-type: none"> Vaulting 	<ul style="list-style-type: none"> Prosthesis too long Inadequate suspension Excessive knee friction 	<ul style="list-style-type: none"> Patient insecurity Habit Limb not completely in socket Weak hip flexors 	<ul style="list-style-type: none"> Maximum toe load too high Dynamic factor too high Initial swing flexion damping too high Knee angle threshold too low

TERMINAL SWING				
 <p>Primary Goals Smooth deceleration to full extension Equal step length</p>	Common Gait Deviations	Prosthetic Cause	Amputee Cause	C-Leg Alignment or Software Cause
	<ul style="list-style-type: none"> Terminal impact 	<ul style="list-style-type: none"> Insufficient knee resistance Mechanical extension assist too strong 	<ul style="list-style-type: none"> Deliberate rapid hip extension to ensure full knee extension 	<ul style="list-style-type: none"> Swing extension damping too low Dynamic factor too high
	<ul style="list-style-type: none"> Increased prosthetic step length 	<ul style="list-style-type: none"> Insufficient socket flexion 	<ul style="list-style-type: none"> Sound side hip flexion contracture 	
	<ul style="list-style-type: none"> Decreased prosthetic step length 	<ul style="list-style-type: none"> Excessive socket flexion Insufficient knee extension 		<ul style="list-style-type: none"> Knee angle threshold too high Dynamic factor too low Swing extension damping too high

GENERAL				
<p>Primary Goals Equal arm swing</p>	Common Gait Deviations	Prosthetic Cause	Amputee Cause	C-Leg Alignment or Software Cause
	<ul style="list-style-type: none"> Uneven arm swing 	<ul style="list-style-type: none"> Poor socket fit Socket pain 	<ul style="list-style-type: none"> Inadequate pelvic and trunk rotation Poor balance Patient insecurity 	

16. Amputation Related Pain

Pain, for the individual with limb loss, is often a very real part of daily life. Pain can complicate and delay the rehabilitation process, therefore it is important that the physical therapist understand the different types of pain that an amputee may experience. Pain associated with amputation is typically categorized into phantom limb sensation, phantom limb pain, and residual limb pain. Recent amputees must also deal with pain from the injury or disease, the amputation surgery, and the recovery process. The extent to which the physical therapist can recognize and assist the patient address the complex and various presentations of pain may have a significant impact on the amputee's ability to participate in physical therapy. Individuals with lower limb amputation also have high incidence of low back pain, and therapy programs to address back pain, while not discussed in this chapter, may need to be incorporated into the overall treatment plan.

Describing Pain

Articulating an accurate description and assessing the severity of uncomfortable sensations and pain is difficult. When talking with patients, it can be helpful to ask them to be as detailed as possible in order to characterize the sensations. Ask, "Is the feeling constant, or does it come and go? Does it occur frequently, or rarely? How long does it last? Do you experience it at certain times of day more than others? Would you describe it as intense, or is it kind of "in the background"? Is it a sharp pain, or a dull sensation? Is it an itch? Is it a burning sensation? Is it bothersome, or not?" The physical examination of the limb, specifically palpating for tender or painful areas and trigger points that reproduce the pain helps to differentiate residual limb pain from phantom limb pain. The patient's history of pain and physical examination will be useful in understanding what type of pain the amputee is experiencing.

Because pain can be experienced differently by each individual, measuring and quantifying pain can be very difficult. A scoring system can often be useful in helping the person with limb loss and the health care provider come to an understanding about the severity of the pain. The most typical way to rate the severity of pain is by asking: "On a scale of zero to 10, with zero being no pain to 10 being the worst pain you can imagine, how would you rank the pain you're feeling?" This simple scale helps to approximate an entity that truly is impossible to measure.

This type of scoring system can be a beneficial tool for continued assessment of a person in a treatment program. If a person rates pain as a 7 or an 8, and after a period of medication or treatment he or she says the pain level has dropped to a 4 or 5, improvement can be documented. However, it is impossible to discern whether the intensity of the pain is less or if the nature of the pain has changed. A scoring system can be useful, but it should not be the sole determinant for measuring pain.

Phantom Limb Sensation and Phantom Limb Pain

The word phantom implies "imaginary" or "ghostlike," but phantom sensation and phantom pain are very real. These phenomena may manifest in different forms, feelings, and sensations, some of which are painful (phantom pain) and others of which are not (phantom sensation).

Phantom limb sensation is the perception that some or all of the amputated limb is intact. Phantom sensation is often "in the background," its intensity varies little, and the amputee may not be aware of it except when consciously paying attention to it. Phantom sensations may include touch, pressure, temperature, itch, position sense, and posture. Some amputees report that the amputated foot itches, that it feels like the ankle is turned around backward, or that they can feel the big toe and it is hot. Positional sensation is a type of phantom sensation that refers to a sensed anatomic position of the toes, ankle, or knee. The amputated body part may be felt to be in a flexed, extended, varus or valgus position. Positional phantom sensation can also refer to the location of the hand or foot in relation to the amputation site. Over time, a common description is a sensation of telescoping, where the phantom hand or foot is perceived as moving closer to the amputation site.

Much research has been focused on phantom sensation and its prevalence. In one 2-year prospective study, 52 of 58 patients (90%) reported phantom sensations at some time during the study.²⁵ Over time, the prevalence of the sensations did not decrease, but the frequency and duration did. In another study of 255 adults with lower limb amputations who had been amputees an average of 14.2 years, 201 (79%) reported phantom sensations.²⁶ The study also showed that phantom sensations typically do not go away but rather become chronic.

More disturbing to amputees than phantom limb sensation is phantom limb pain, pain that seems to originate in the amputated part. Phantom limb pain typically is more episodic and intermittent than is phantom limb sensation. Few amputees describe phantom pain as constant pain. It usually comes in bursts, striking quickly. Amputees describe phantom limb pain in many different ways, using terms such as burning, shooting, stabbing, throbbing, or "like an ice pick is being driven through the foot." Amputees who sustained traumatic amputations may describe the pain as being like the pain they felt during the injury.

The duration of episodes of phantom limb pain varies, ranging from a few seconds or minutes to sometimes much longer. The results of published studies suggest that phantom limb pain occurs in 55% to 85% of amputees.²⁵⁻³⁰ Phantom limb pain typically occurs soon after amputation, as early as within the first days after surgery.^{31,32}

Individuals with limb loss often report that the phantom limb pain is most intense in the hand or the foot. This may be because the amount of brain cortex that perceives pain is not proportional to the size of the body part. The portion of the brain cortex devoted to the sensation of the hands and feet is large in proportion to the rest of the body. Because more

brain area is devoted to these body parts, it may explain the prevalence of phantom pain that seems to originate in the hands and feet.

Etiology of Phantom Limb Sensation and Pain

In the past, phantom limb pain has been characterized as a symptom of a psychological or personality disorder. More recently, it has been viewed as a common physiologic response to limb loss. Interestingly, as theories about the etiology of phantom limb pain have shifted from a primarily psychological to a physiologic focus during the last few decades, theories about other types of chronic pain have broadened from an almost exclusively biomedical approach to one that incorporates psychosocial variables. The general literature now views chronic pain as a multidimensional experience that involves not only sensory and physiologic processes but also psychosocial, behavioral, and environmental factors.

Several mechanisms have been hypothesized to explain the development of phantom limb pain.^{33,34} Although persistent peripheral nerve discharges have been recorded after amputation, most evidence suggests that a central abnormality is present in patients with phantom limb pain. Some authors³⁵⁻³⁷ suggest that hyperirritable foci develop in the dorsal horn of the spinal cord after peripheral nerve transection, possibly as a result of the loss of high-threshold input to the dorsal horn neurons. There are likely also central factors proximal to the spinal cord, since severe phantom limb pain has been reported to be unresponsive to cordotomy (surgical sectioning of the spinal cord) and can be unmasked by spinal anesthesia. Whatever central changes develop, the initiating event in the development of phantom limb pain is likely peripheral. The massive afferent barrage at the time of injury or amputation may set up central processes that later generate pain, or the sudden loss of peripheral input may trigger central changes that result in the elimination of normal sensory nerve impulses.

Residual Limb Pain

Residual limb pain is also an issue for some amputees. Residual limb pain should be distinguished from phantom limb sensations or phantom limb pain as pain that occurs in the remaining part of the amputated limb. Typically, the location can be identified and palpation or mechanical stimulation of the site can reproduce the pain. Like phantom limb pain and phantom limb sensation, residual limb pain is fairly common, with a reported prevalence of 48 % to 74%.^{26,32,37,38} Residual limb pain can originate from a number of sources, including chronic wounds, neuromas, bone spurs, heterotopic bone formation, cysts, overuse, and the prosthetic socket. The patient should be referred to his or her physician to determine the etiology of and proper management for residual limb pain.

Medical Management of Chronic Pain

Many different treatments have been suggested to treat chronic pain in amputees. These have primarily focused on treating phantom limb pain. Attempted treatments have

included surgical, pharmacologic, medical, psychological, and alternative medical options. No single treatment has been found to be the most effective in all situations. Each patient is unique, and an amputee may benefit from one or a combination of several approaches.

Tricyclic Antidepressants

Tricyclic antidepressants (TCAs) have long been used to treat phantom limb pain, but scientific data to support their use is lacking. A 1992 meta-analysis of 39 placebo-controlled trials concluded that antidepressants were beneficial for relieving a variety of types of chronic pain, but these studies did not include patients with pain after limb loss.³⁹ Another study found TCAs to be effective in the treatment of painful peripheral neuropathies.⁴⁰ Given that amputation requires the severing of multiple peripheral nerves, it is plausible that TCAs may be helpful in treating amputation-related pain as well. Only one randomized controlled clinical trial examined the efficacy of TCAs for relieving chronic amputation-related pain.⁴¹ This study of 39 adults with either phantom limb pain or residual limb pain compared the effects of amitriptyline to an active placebo (benztropine mesylate) and found no significant benefit for either type of pain.

Anticonvulsants

Anticonvulsants, also called anti-seizure drugs, have long been prescribed for phantom limb pain because of their effectiveness in calming excited nerves. Clinical reports suggest that these drugs may minimize the number of episodes of phantom pain. Two double-blinded, placebo-controlled, crossover studies of gabapentin for phantom limb pain have been completed. Bone, Critchley, and Buggy⁴² reported on the use of gabapentin for phantom limb pain. They found that in the 14 amputees who completed the 6-week trial, gabapentin resulted in significantly greater reduction of pain intensity compared with placebo. In contrast, Smith and associates⁴³ studied the use of gabapentin in 24 amputees and found no significant reduction in pain intensity during the gabapentin phase than during the placebo phase, although a greater proportion of patients did report a meaningful pain reduction during the gabapentin phase. It should be noted that baseline pain intensity was greater for patients in the first study. This research suggests that gabapentin may be effective for certain subgroups of patients, but more clinical trials are needed.

Non-narcotic Analgesics

The most commonly used medications for any type of chronic pain are non-narcotic analgesics. Acetaminophen and anti-inflammatory drugs are the main medication in this category. To date, no known research has been conducted specifically on the efficacy of nonnarcotic analgesics for amputation-related pain. These medications may serve as a good starting point for a treatment program because they are unlikely to be harmful to the patient.³⁵

Narcotic Analgesics

The role of opioids in the management of chronic neuropathic pain and the consequences of long-term use remain controversial.⁴⁴ One study found that most patients with chronic nonmalignant pain have concerns about addiction and

dependence with narcotic use.⁴⁵ Narcotics are very effective in the short term and are recommended during the immediate postoperative period. While not proven in the literature, many believe that effective control of acute pain may even reduce the risk of developing chronic pain.³⁵

Long-term use of narcotics, however, may result in dependence on the drug. As tolerance to the drug increases, larger doses are required to achieve that same level to control the pain. Addiction may result in withdrawal symptoms when the narcotic is not taken. Tolerance and addiction can lead to greater disability and depression over time.³⁵ In addition, narcotics usually do not eliminate the pain but only calm the patient's reaction to the pain, making the pain seem less bothersome. Traditional narcotics (e.g. morphine and demerol) have a fast onset and a high initial peak effect, but they wear off quickly, and the pain recurs. Additionally, common side effects include constipation, sedation, and nausea.⁴⁶ Narcotic use is also associated with an array of safety risks, such as drowsiness, decreased reaction time, impaired judgment, and, in large doses, inhibited respiration, which may make breathing difficult or impossible.

New, longer-acting narcotics (eg, oxycontin) take effect more slowly and linger in the patient's system for an extended time, possibly minimizing tolerance to the drug. A recent study found preliminary evidence that opioid medication may reduce cortical reorganization in patients in whom the reorganization is not yet irreversibly chronic. In this double-blinded crossover trial, 12 patients took oral retarded morphine sulphate (MST) for phantom limb pain. Five patients reported significant reduction in pain (50% decrease) over the 4-week trial. In addition, reduced cortical reorganization was found in 3 of the patients, concurrent with reductions in pain intensity.⁴⁷ Although this appears to be a promising line of research, larger clinical trials are needed that can also examine long-term consequences of narcotic use in patients with phantom limb pain. For now, clinicians must balance the needs of the patient with the potential for dependence over time. If drug intake increases or activity levels decrease, the patient should be titrated off the narcotic medication.

Transcutaneous Electrical Nerve Stimulation

Transcutaneous Electrical Nerve Stimulation (TENS) therapy relieves pain by overriding pain signals in nerve fibers with constant, low-level electrical stimulation through the skin. The intensity can be controlled so that the person receives constant stimulation, pulsations, or intermittent bursts. TENS therapy typically is used early in the postoperative period and is very helpful for some people, especially in the short term.

Many people discontinue TENS therapy after a few months; the reason for this is not known. It may be that the treatment becomes less effective over time, or perhaps the symptoms diminish with time and therapy, and the TENS treatments are needed less.

Biofeedback

The theory behind the use of biofeedback to relieve phantom limb pain is that anxiety and tension may aggravate the pain, causing muscles to tighten. In biofeedback therapy,

electrodes attached to the residual limb produce a signal when muscle tension is present, alerting the amputee to relax the muscle until the signal stops. Eventually, the amputee may learn to recognize the signals of tension without the use of equipment.

Manual Massage

Massage is one of the oldest and most popular forms of hands-on therapy. Touching and rubbing a painful area can relax the muscles, stimulate the nerves, improve blood flow, and provide relief. One form of massage is shiatsu, a Japanese practice in which moderate to deep pressure is applied to key parts of the body with fingers, thumbs, palms, knuckles, and even elbows or feet. Shiatsu and other forms of massage may be performed on a regular basis as part of a therapy program.

Acupressure and Acupuncture

Two traditional Chinese techniques, acupressure and acupuncture, have been gaining a growing number of adherents in western countries. Both techniques are based on the concept that energy travels through the body along pathways called meridians and that blocks in that energy flow can result in discomfort or even disease. To promote energy flow, the acupressure specialist presses "acupoints" on the body. With acupuncture, slender needles are inserted along the energy pathways to interact with energy flow and potentially reduce phantom or residual limb pain.

Eye Movement Desensitization and Reprocessing

Eye Movement Desensitization and Reprocessing (EMDR) is a technique in which patients follow a light or moving object with their eyes as they think about a traumatic incident in their lives. EMDR practitioners say the rapid eye movement stimulates the brain to reprocess painful memories and activate emotional mechanisms to help cope with traumatic episodes and their aftermath. It has been used primarily to treat post-traumatic stress disorder. EMDR has some anecdotal evidence to support the treatment of chronic pain.⁴⁸ However, scientific trials using EMDR to specifically treat amputation pain such as chronic residual limb pain or phantom limb pain have not been published.

Magnets

The use of magnets to treat pain is controversial.⁴⁹ Advocates claim that placing magnets over the affected area relieves pain, perhaps by improving blood flow in the residual limbs, which could have a positive effect on phantom limb pain. There is little literature to document the altered physiology, however. Magnets and certain metals, by themselves or when woven into the fabric of clothing, may help to minimize problems caused by electromagnetic fields. While it remains unproven that electromagnetic fields cause or increase pain, proponents of magnet therapy believe that elimination of electromagnetic fields decreases pain. Of three controlled human studies, one found some improvement in knee pain, while two studies found no improvement in heel or in back pain.⁵⁰⁻⁵² One additional explanation is that magnets affect depression, which indirectly improves the perception of pain. A study published in the journal *Psychiatric Annals* reported

success in treating some cases of severe depression when powerful electromagnets were applied to a person's head.⁵³ Alleviating depression is beneficial. When an individual feels better emotionally, an indirect perception of improved physical well being and less pain may result. However, it must be restated that little scientific evidence is available to support claims of the healing properties of magnets.

Attitude and Understanding Pain

Finally, the amputee's attitude and understanding of the emotional issues associated with amputation can be an

important factor in the experience of pain. Losing a leg in a waterski accident as a nursing student led to Delores Malchow's work with amputees. By comparing limb loss to the loss of a loved one, Malchow gives health care providers insight in how to better care for individuals with limb loss.⁵⁴ It may not always be possible to relieve an amputee's specific type of pain, but the pain need not dictate the amputee's attitudes, behaviors, or quality of life. Supportive reassurance, as teaching individuals improved problem solving skills and self-efficacy skills might assist coping and managing life in the presence of chronic pain.

17. Peer Visitors and Support Groups

A significant recent development in health care is the new emphasis on patient empowerment and the consumer movement. One aspect of this trend was articulated by Marcia Sherer in an address to the American Psychological Association in 2002 when she said, "The expansion of rehabilitation's sphere of concern and involvement has meant an evolution from a philosophy of a normalization (people with disabilities should strive to be like people without disabilities) to empowerment (people with disabilities have the right to be self-determining and to make their own choices about their lives and to achieve the Quality of Life each believes is personally best)."⁵⁵

The practice of physical therapy embodies this philosophy of patient empowerment in that its goal is to enable the individual to progress to a level of function that provides the highest possible quality of life. During rehabilitation, individuals become empowered, evolving from seeing themselves as patients to being participants in their own care.

The concept of quality of life, though largely subjective, commonly includes being satisfied with various aspects of life, including work, social, emotional, and physical aspects. For those faced with physical disabilities, one goal is regaining full physical function. To achieve a satisfactory quality of life, however, physical function alone is not sufficient. Emotional and social issues also must be addressed if rehabilitative success is to be achieved.

Amputation, limb loss, or limb difference is a life-altering experience regardless of the age at which it occurs because it inevitably involves a challenge to the individual's sense of personal individuality and ability. The goal of physical therapy is to help amputees achieve a new sense of physical individuality and ability following limb loss, including fostering emotional well-being and a positive self-image. One of the most effective ways for the physical therapist to achieve these goals is to refer the amputee to resources such as peer visitors and support groups. The social support provided by peer visitors and support groups is recognized as a key element to an amputee's successful adjustment to limb loss.⁵⁶

The Amputee Coalition of America

More than 1.2 million amputees live in the United States,⁵⁷ and the number is growing because of the increasing prevalence of contributing causes such as cancer, diabetes mellitus, and traumatic injury.⁵⁸ At the same time, more postoperative care is occurring in outpatient settings, as patients spend less time in the hospital postoperatively.⁵⁹ This means that increasing numbers of amputees are likely to rely on physical therapists as significant sources of education and information regarding their care and well-being throughout rehabilitation.

It is unrealistic, however, to expect the physical therapist to become an expert in amputee rehabilitation. The role of the physical therapist is to identify reliable resources to which they may refer the amputee when questions and concerns arise during the rehabilitation process. One valuable resource is

the Amputee Coalition of America (ACA). The ACA enhances the efforts of other health care providers by introducing unique approaches and resources for a more comprehensive rehabilitation model. Through grassroots efforts, the ACA reaches out to people with limb loss, empowering them through education, support, and advocacy.

The ACA was founded in 1986 by Mary Novotny, with the goal of helping amputees cope with limb loss through information and education. Its original mission was to educate and provide a voice for amputees. As the ACA has grown, it has enlarged its efforts to include a wide variety of education and outreach efforts, ranging from professional training for health care professionals to the highly regarded Peer Visitation Network.

Peer Visitors

Through various partnerships with research institutions and prosthetic device manufacturers, the ACA has identified several keys for surviving limb loss. Paramount among them is the need for recent amputees to learn about life with limb loss from experienced amputees: to share feelings with their peers and learn from them what to expect and how to get through everyday life as an amputee. To meet this need, the Peer Visitation Network was created.

Peer visitation can be of great benefit to the process of rehabilitation, helping the amputee retain a high quality of life following limb loss. Skilled peer visitors are amputees who can compassionately and accurately share their experiences related to amputation and in so doing comfort the recent amputee and provide him or her with a positive model of adjustment to limb loss. Whereas physical therapy provides the amputee with tools for physical self-sufficiency, the peer visit provides the amputee with the emotional support needed to deal with the physical and social challenges that are inevitable throughout the rehabilitation process.

The Peer Visitor Concept

The ACA defines a peer visitor as follows: "A Peer Visitor is someone who has experienced a life changing event (limb loss, or congenital limb deficiency), is living a full and productive life, and has completed a training program preparing him/her to visit another individual and his/her family facing a similar experience." A Peer Visitor volunteers to serve as a role model, offer emotional support, and provide information about the resources available locally and nationally. Likewise, "a Peer Visitor is NOT a professional counselor, therapist, advice-giver, or problem solver. Peer Visitors are sensitive listeners who will use their developed skills in communication to facilitate the recent amputee's own recovery and self-exploration so that they may make good decisions for themselves." Peer visitors can demonstrate:

- That others experience similar feelings of loss and grief
- What it is like to perform daily activities with limb loss
- How a prosthesis is used

- What problems to expect and how to cope with them
- How to handle returning to work and school, driving, and other daily activities
- Where to locate assistance
- How to deal with changes in personal relationships
- How family members cope with amputation.

ACA peer visitors receive 8 hours of training by volunteer trainers. The training concludes with an interview and test that each candidate must pass to become certified. An effective peer visitor should have:

- Openness and the ability to put people at ease
- A personal support system
- Good listening skills
- An understanding of which activities are off limits for peer visitors
- The ability to discuss the amputee's situation and make appropriate referrals
- Knowledge of how to separate the amputee's physical and emotional pain from the peer visitor's own life
- The ability to identify crisis situations and situations that are outside the role of the peer visitor and make appropriate referrals
- The ability to provide own transportation (but the peer visitor must never transport the recent amputee because of liability issues)
- An understanding of the amputee's demographics before making contact
- An understanding of the recovery process and the role of the peer visitor in that process
- The ability to communicate with compassion
- An understanding of acceptable procedures for visits in various settings: in the hospital, in the home, over the telephone
- An understanding of the importance of asking for assistance when needed
- An appreciation of the limits of the peer visitor role; peer visitors will refer to trained professionals as necessary
- An absence of any conflict of interest that might impair judgment and place the amputee at risk of exploitation
- Respect for the values of others.

ACA peer visitors must recertify every 3 years. Also to maintain their certification, they must submit their ongoing peer visitation schedules to the ACA for tracking purposes.

Peer visitors should be regarded as resources for the physical therapist to use for the benefit of the amputee. In addition, educational materials such as books and videos are also available through peer visitation and the ACA. Knowing how to incorporate a peer visitor into the care model is an important responsibility for the physical therapist working with an amputee.

Timing of Peer Visitation

Ideally, peer visitation should begin shortly after the amputation or, for patients who are anticipating amputation surgery, even

before the amputation. According to Sperber-Ritchie, "Early involvement (such as supportive or peer counseling) should begin within one week of the injury... peer support enables (patients) to express their emotional reactions and gain a sense of comfort and security... Outcomes of such psycho-educational sessions include lowering distress...strengthening the immune system, controlling pain...raising self-esteem and optimism, and resolving the many problems of daily adjustment... Social support is of critical importance and ...a peer visitation program... is an excellent route to this goal."⁶⁰

With today's shorter hospital stays and faster recovery tracks, it is not always possible to accomplish such early support during the hospital stay. Peer visitation can take place just about anywhere, however—in the hospital, in the amputee's home, over the phone, or even through email. Experienced peer visitors are used to visiting in just about any environment, including private areas of physicians' offices, in treatment rooms, and even in restaurants.

Referral to Peer Visitation

Peer visitation is usually initiated through a referral by a health care provider, friend, or family member. As with all support services, for peer visitation to be effective, the amputee must be open to it and must not be forced into participating. Peer visitation is never successful if it is provided against the amputee's wishes.

To refer a patient to an ACA-certified peer visitor, the physical therapist should contact the regional, state, or national ACA. If a referral is made to another volunteer network, the physical therapist should make certain that the organization certifies its peer visitors and that it adheres to standards of integrity and confidentiality. Working with organizations that certify their volunteers also allows for tracking the success and appropriateness of the peer visitations.

When the ACA receives a call for a referral, a representative will match a peer visitor from the network with the recent amputee. The recent amputee and peer visitor are matched by characteristics such as geographic location, age, background, and etiology of amputation. Similarities in life circumstances put the amputee at ease, making it easier to share experiences. A primary goal is to provide a face-to-face visit, so for geographic reasons, most matches are identified through the local ACA peer visitor networks. Peer visitors are most effective when given complete information, including:

- Name and age of the amputee
- Location of the amputee
- Method of preferred contact
- Date, cause, and level of amputation
- Any medical condition that may affect the effectiveness of the visit (eg, hearing impairment)
- Emotional state
- Types of information that may have been requested by the amputee or family
- Other background information that might be helpful to initiate conversation
- Confirmation that the peer visit was requested and/or approved by the amputee in advance.

Complete information helps the peer visitor prepare for the visit. It also increases the likelihood that the visit will support the rehabilitation process and, most importantly, the emotional needs of the amputee. In some settings, HIPAA regulations may hinder this information exchange. The peer visitor will strive to achieve the best quality peer visit possible, given the guidelines of the facility.

Elements of a Well-Conducted Peer Visit

The peer visit ideally involves only one peer visitor and one recent amputee or soon-to-be amputee. Typically, the visit takes place in a private and mutually comfortable setting. The information shared is kept confidential between the two participants. Usually no health care professionals are involved in the interaction, although depending on the particular circumstances of the prescribed care, a trained health care provider may be present, especially in a hospital setting.

The peer visit does not include endorsement of any particular product or practitioner or of any specific medical procedure or treatment. Certified peer visitors do not confirm treatment plans, argue with medical practices, or advise on medical treatment or medication. The peer visitor should provide emotional and social support only.

Peer visits may last from 20 minutes to 2 hours, depending on the situation and the comfort level of the amputee. The ultimate goal is to provide an opportunity for the new amputee to foster self-exploration and personal growth as an amputee.

The Poorly Conducted Peer Visit

Although most peer visits are well conducted and benefit the recent amputee, bad peer visits do happen. A poorly conducted visit may simply provide no benefit to the amputee or, at worst, may leave the amputee with incorrect information and expectations.

Bad peer visits generally occur as a result of poor preparation, incomplete or incorrect information about the amputee's circumstances, and logistical constraints such as lack of time or privacy. Occasionally, a bad peer visit results from a simple personality clash.

In a different category is the "ugly" peer visit, in which the amputee feels worse than before the visit because of the interaction with the peer visitor. Such visits are generally conducted by a volunteer amputee who has not undergone training and certification as a peer visitor, does not subscribe to the tenets of mutual respect and the purpose of peer visitation

or has his or her own agenda for being a peer visitor. Ugly visits also may occur if the peer visit was not requested or accepted by the amputee. Thankfully, these types of visits are rare, but the characteristics of ugly peer visits are important to know.

The Support Group

Support groups can be an invaluable resource for amputees. Support groups offer opportunities for the amputee to observe others who are successfully coping with limb loss, learn new coping strategies, and discuss and practice coping techniques in a supportive atmosphere

Some amputees may use a support group in addition to a peer visitor, whereas other recent amputees may not be interested in a peer visit but still would like to share experiences with a group of amputees. In a support group, amputees may not feel pressured to state their feelings or participate directly; instead, they are able to listen and learn from others' experiences.

More than 200 amputee support groups are registered in the United States.⁶¹ Some are led by amputees from the local community, whereas others are led by trained health care providers. Support groups are voluntary organizations that are internally supported and funded.

No two support groups are exactly alike. The topics discussed are determined by the individuals in the group. Groups meet as often as weekly or as infrequently as every other month. Some support groups offer structured meetings with set times and speakers, whereas others are more informal. All these variations can be successful as long as they meet the needs of the members.

There are certain similarities among support groups, however. One similarity is that thoughts and feelings shared within a support group are considered confidential. Also, most support groups do not include health care professionals as regular participants. The goal is to provide a safe setting in which amputees can share and learn from one another's experiences and adjustments to limb loss. Contact information for amputee support groups can be obtained through the ACA.

Summary and Conclusions

As health care delivery continues to change, physical therapy is assuming an ever greater role in the recovery process. The physical therapist can truly affect the amputee's social, emotional, and physical adjustment to limb loss by linking recent amputees to resources such as peer visitors and support groups.

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