Lower Extremity Amputation and Prosthetics

Incidence

More than 100,000 major lower limb amputations occur annually in the United States, and most are the result of dysvascular disease. There are more than 500,000 amputee survivors currently in the United States. There are at least 10 times more lower extremity amputations than there are upper extremity amputations. The primary cause of lower limb amputation in the age group older than 50 years is diabetes and vascular disease. The primary cause of lower limb amputation in the age group younger than 50 years is trauma. The primary cause of upper limb amputation is also trauma. The distribution and relative energy costs for lower limb amputation are outlined in Table 1.

Ideal Length

Transtibial amputations are ideally done at the junction of the proximal to middle third of the tibia, but can be as short as 1 cm distal to the tibial tubercle (Fig. 1). Transfemoral amputations are generally performed to maintain as much length as possible. Amputation above the lesser trochanter of the femur will be fitted essentially as hip disarticulation.
Rehabilitation Program

- Day 0: Amputation.
- Days 1–4: Acute hospital postoperative stay.
- Days 5–21: Preprosthetic program as outpatient or at subacute rehabilitation facility.
- Months 2 and 3: Prosthetic training with preliminary prosthesis.
- Months 3–6: Fitting of permanent prosthesis (replacement every 4–5 years).
**Medicare Functional Levels (Restrictions for Prosthetic Components)**

- Level 0: Nonambulatory.
- Level 1: Household ambulator or transfers only.
- Level 2: Limited community ambulator.
- Level 3: Unlimited community ambulator.
- Level 4: High-energy activities and recreational sports.

**Current Prosthetic Design by Level of Amputation**

**Partial Foot Amputation**

Partial foot amputation requires a custom insert in a proper orthopedic shoe with appropriate toe filler. Acceptable levels of amputations include toe amputation, ray resection, and transmetatarsal amputation. Less desirable levels include Lisfranc and Choparts level of amputation because of plantigrade migration of calcaneous from loss of dorsiflexor insertions.

**Modified Syme’s**

This is a level of amputation most commonly found in traumatic injury and not for dysvascular disease. It preserves the full length of the tibia and the end-bearing articular cartilage of the tibia, but removes the medial and lateral malleolus to obtain a flat weight-bearing surface. The purpose of a Syme’s amputation is partial end-bearing and a long lever length for good control of the prosthesis. This relies on good soft-tissue coverage, including the heel pad from the plantar surface of the foot, inserted directly onto the articular cartilage of the tibia. The prosthetic design would generally include a split foam liner inside a laminated socket. This would include partial end-bearing and partial bearing at the patellar tendon. It is commonly laminated directly to the specialized Syme’s-type prosthetic foot with no movable ankle joint but a low-profile energy-storing keel. The functional outcome at this level is very high, with running and jumping being easily accomplished.

**Transtibial Amputation**

The most common socket design for transtibial amputation is a patellar tendon-bearing total-contact socket with a soft interface material. The outer rigid portion of the socket is often of a laminated material but can also be a high-temperature thermal plastic. The soft interface materials are commonly a closed-cell foam material, such as Pelite or Bock-Lite. The foam
The suspension types can be one of four mechan-ical prostheses or silicone. The exoskeletal design allows for ease of attach-ability and, therefore, is most commonly used in children, construction workers, or for waterproof legs. The overall construction of the prosthesis may be of an exoskeletal design, where the pipe or pylon transmits the body weight from the residual limb to the foot and is then covered with a soft foam cosmetic cover. The pylon connects the socket to the prosthetic foot and often incorporates the alignment mechanisms, shock absorbers, or torque absorbers. The endoskeletal design allows for ease of adjustability. The other type is an exoskeletal design, with a hard outer shell that transmits the weight from the socket continuously down to the prosthetic foot. The exoskeletal design gives better durability and, therefore, is most commonly used in children, construction workers, or for waterproof legs.

Prosthetic feet can be divided into several different categories (see Table 2):

1. The prosthetic foot can have no motion, single axis, multi-axis, or simulated motion.
2. The foot can have energy response (bounce) or no energy response.

Functional outcome at the transtibial level can be very high if there is good soft-tissue coverage of the residual limb and good fitting of the socket. Walking with no assistive device, and running or jumping can be accomplished if there is unilateral amputation. A prosthetic device should not be used to operate a pedal on a motor vehicle and, therefore, a right lower limb amputation would require a left-side accelerator pedal to resume driving.

Table 2
Prosthetic Feet
(Examples of Commercial Products Currently Available)

<table>
<thead>
<tr>
<th>Response</th>
<th>No ankle motion</th>
<th>Simulated motion</th>
<th>Single-axis</th>
<th>Multi-axis</th>
</tr>
</thead>
<tbody>
<tr>
<td>No energy</td>
<td>SACH Foot</td>
<td>SAFE Foot</td>
<td>Single-axis Foot</td>
<td>Greisinger Foot</td>
</tr>
<tr>
<td>Energy</td>
<td>Seattle Foot</td>
<td>Luxon DP Foot</td>
<td>College Park</td>
<td></td>
</tr>
</tbody>
</table>

SACH, solid ankle cushion heel; SAFE, solid ankle flexible endoskelon; DP, dynamic pylon.
Knee Disarticulation Amputation

The socket design for knee disarticulation includes partial end-bearing and partial bearing on the distal two-thirds of the thigh. This would include a rigid outer frame and flexible inner socket. The suspension mechanisms at this level are generally a self-suspending design using a gel liner with a locking strap or a split liner with a removable medial window similar to the Syme’s amputation level. The biggest advantages at the knee disarticulation level are the full length of the femur, which allows good control of the prosthesis, and that the socket design does not need to incorporate ischial bearing and, therefore, stays out of the groin and is much more comfortable to the patient. Unfortunately, the knee disarticulation socket tends to be somewhat bulky in design and not all prosthetic knees are compatible with this design.

Transfemoral Amputation

The current transfemoral amputation socket includes a narrow medial-lateral (ML) dimension with ischial containment and total contact. Again, this would incorporate a flexible inner liner and a rigid outer frame, in addition to another soft interface material. The preliminary prosthesis would most likely include prosthetic socks as the interface material, and the permanent prosthesis would most likely include full suction of skin directly to the socket or a gel interface to provide suction into the socket. The weight-bearing is focused primarily at the ischial tuberosity and gluteal muscles, but there is significant weight-bearing across the entire muscle mass of the thigh. The preliminary prosthesis suspension mechanism includes a semi-suction design with prosthetic socks and the addition of an elastic waist belt. The permanent prosthesis is a full-suction design and no waist belt is generally required.

Prosthetic knees can be divided into roughly seven categories:

1. Manual locking knees are used primarily for marked weakness at hip extensors or multiple disabilities, including stroke or other neuromuscular disease (level 1 ambulators).
2. Stance control knees have a weight-activated locking mechanism, providing only fixed cadence ambulation for level 1 or level 2 ambulators.
3. Pneumatic knees provide adjustable swing control with variable cadence and are generally used for level 2 or level 3 ambulators.
4. Hydraulic knees provide adjustable swing and stance control with variable cadence for level 3 and level 4 ambulators.
5. Polycentric knees provide biomechanical stability from full extension to roughly 25° of flexion with fixed cadence and are generally reserved for knee disarticulation or long transfemoral amputation.
6. *Hybrid polycentric knees* incorporate pneumatic or hydraulic control mechanisms for stance stability and variable cadence, again for longer residual limbs (level 3 and 4 ambulators).

7. *Microprocessor-controlled hydraulic knees* include computer-controlled swing and stance, in addition to stumble control mechanisms to prevent falls, and are generally reserved for level 3 and level 4 ambulators.

The functional outcome at transfemoral amputation generally depends on proximal muscle strength, the residual limb length, and the overall status of the patient. With a long residual limb and normal muscle strength, a transfemoral amputee should be able to ambulate without any assistive device, but running and higher-level activities may be very demanding. Amputation of more than 50% of femur length will often require an assistive device for ambulation.

**Hip Disarticulation**

The socket design for hip disarticulation includes a custom-molded bucket that incorporates much of the pelvic structures. This would include a rigid outer frame around the involved side with weight-bearing primarily through the gluteal muscle and ischial tuberosity, and a semirigid or elastic component that wraps around the waist and pelvis on the contralateral side. A specialized hip joint is used, which stays in extension throughout the gait cycle and flexes only for sitting activities. Typically, very light-weight components are used for hip disarticulation amputation because of the lack of leverage for control of the prosthesis. A common selection of components would include a light-weight stance control knee and a single-axis or multi-axis foot. The functional outcome at hip disarticulation level is quite variable. Approximately 50% of patients at the hip disarticulation level do not use a prosthesis and ambulate with two forearm crutches, hopping on the remaining leg. The patients that do ambulate with a prosthesis will nearly always need at least one assistive device for stability. Some patients at this level would choose wheelchair mobility because of the high energy cost at this level of amputation.

**Lower Extremity Orthotics**

**Introduction**

Most lower limb orthoses are named by a universal terminology where the name describes the joints that are involved, as well as any special features. Most lower limb orthoses are custom made, but there are some that are custom fit or off-the-shelf. Most lower limb orthoses also incorporate some type of footwear and, therefore, we will discuss orthopedic shoes in the next section.
Orthopedic Shoes

Common features of an orthopedic shoe include the following:
1. Extra depth with removable innersole to accommodate an orthosis.
2. Blucher opening to allow easier access into the shoe.
3. Rounded and higher toe box.
4. Availability of very wide widths.
5. Strong heel counter to support rearfoot.

Options available for shoes include the following:
1. Crepe or leather sole.
2. High top.
3. Surgical opening.
4. Velcro closure.
5. High toe box.
6. Bunion last or contour.
7. Modifications at the heel, such as wedging, flaring, or lifts.
8. Outside buttress to support the arch.

Common indications for orthopedic shoes would include diabetic foot, dysvascular foot, orthopedic deformities, such as bunion or hammertoes, or to accommodate an orthosis.

Foot Orthosis

Generally, foot orthoses are divided into two categories: accommodative and corrective. The accommodative foot orthotic is generally soft to medium, multidensity materials that help redistribute pressure on the foot. These are often custom-made, but can be off-the-shelf if the foot has normal architecture. Common materials used are Thermocork, Plastazote, and leather. Indications would include diabetic and dysvascular foot with callous formation or ulceration. The corrective foot orthotic is often a semirigid material that helps control or change the positioning of rearfoot, midfoot, or forefoot. They should be custom-made and are fabricated from a firm Plastazote, cork, plastic, or even carbon fiber material. The indications for corrective foot orthotics include calcaneal varus or valgus, correctable pes planus, excessive pronation or supination, or chronic plantar fasciitis. Additional options for foot orthoses include a metatarsal pad to unload the metatarsal heads nos. 2, 3, and 4, or a metatarsal bar to unload 1–5.

University of California Biomechanics Laboratory Orthosis

This is a custom thermoplastic orthosis that controls the calcaneous and crosses the subtalar joint but generally stays at the level of the standard orthopedic shoe. It provides rigid rearfoot and midfoot control, and the indication is for early Charcot joint or posterior tibialis tendon dysfunction. The major drawback is the concern of tissue tolerance to such rigid control.
Supramalleolar Orthosis

This is a short, hinged ankle–foot orthosis (AFO) made of plastic or carbon to control ML instability of the ankle, short-term or long-term. It is generally tolerated better by children than adults, but can be used short-term for a variety of ligamentous or tendon sprain and strain injuries across the ankle.

Ankle–Foot Orthosis

This is a very common lower limb orthotic device that can be divided into categories of plastic or metal. The plastic design is used most often and is custom fabricated from a cast or molding of the patient’s limb. Some off-the-shelf designs may be suitable for short-term use, but custom designs are better for long-term use. The general features of a plastic AFO would include the trimlines (degree of rigidity), degrees of dorsiflexion, and foot plate design.

1. *PLS design* is the most flexible design for flaccid footdrop, and is typically set in 5–7° of dorsiflexion with very low-profile three-quarters-length footplate.
2. *Just behind the malleolus* is a less flexible design with somewhat more ML control commonly set in 3–4° of dorsiflexion. This trimline is most commonly used after stroke or other disease with moderate or low tone.
3. *Midmalleolar trimline* is most commonly used in patients with increased tone, and provides excellent ML stability with little or no flexibility in the anteroposterior plane. This can also incorporate tone reducing features in the footplate or 3-point inversion control. Because of its rigid nature, this design is set at 0–3° of dorsiflexion.
4. *Anterior trimline* provides very rigid control with no motion in anteroposterior or ML direction. This design is used for the most spastic patient and is usually set in a neutral position with a full footplate incorporating the toes to prevent curling of the toes over the edge.

Plastic AFOs can also incorporate several special features:

1. *Hinged joints*, which will allow some dorsiflexion and limited plantar flexion, but are less adjustable than metal AFO joints.
2. *Footplate designs* can incorporate three-quarter length, which stops just before the metatarsal heads for easier access into shoes, or a full length footplate with padding, which is generally used for the most spastic or most vulnerable foot.
3. *Inversion control features* include a high medial wall on the footplate and a large lateral phalange at the fibula to prevent inversion positioning of the foot in the brace.

Metal AFOs are still used for several indications, including the insensate foot, the foot with fluctuating edema, or when the need for adjustability or progressive changes in the device are indicated. The metal AFO has two
metals uprights connected proximally by a rigid calf band and extends down to the ankle joint into a stirrup, which then attaches to the shoe. The ankle joint can be of two types:

1. **Single-channel ankle joints** can provide dorsiflexion assistance and a plantar flexion stop, and are the most commonly used.
2. **Dual-channel ankle joints** can provide control both in the dorsiflexion and plantar flexion directions, and can lock the ankle joint in any selected position. Using a set screw in the ankle joint makes adjustments easy. Hybrid designs can also incorporate metal uprights to a plastic footplate, which would then allow changing the shoe on a daily basis. A very wide shoe must be used to accommodate the ankle joint and the plastic footplate.

**Patellar Tendon-Bearing Orthosis**

This device provides proximal loading of the leg to unload the foot and ankle because of disease or injury. Generally, 50% unloading is expected with this device, and more can be accomplished with the use of assistive devices in both arms. Generally, there are two types of patellar tendon-bearing (PTB) orthoses used:

1. A **bi-valve plastic clamshell** is incorporated in the upper third of the tibia similar to a PTB socket in prosthesis. Metal uprights then extend down to an ankle joint and to an orthopedic shoe. This relies on consistent limb volume, and there can be concerns about tissue tolerance owing to the plastic shell at the knee.
2. A **calf corset design** PTB orthosis includes a laced corset, which incorporates the upper two-thirds of the tibia, and can accommodate volume changes easily. This device, however, is more user-dependent in terms of putting on the device correctly. It still incorporates metal uprights to a dual-channel ankle joint and then to a stirrup and the orthopedic shoe. Both types of PTB orthoses can be used for Charcot joint to help unload and limit mobility across the foot and ankle. They can also be used for dysvascular patients with chronic ulcerations on the feet.

**Knee–AFO**

A knee–AFO (KAFO) is commonly used to control the knee and the ankle, and can incorporate a combination of plastic and metal components. The thigh component can include a plastic thigh shell with Velcro strap closure or metal uprights with thigh bands. The thigh components of both types are connected to a knee joint. There are six common types of knee joints:

1. **Drop lock** will lock at full extension or unlocks to allow full flexion.
2. **Bail lock** is a spring-loaded joint that locks automatically as the leg reaches full extension, and can be unlocked by reaching back and pulling a metal loop in the back or gently bumping against the chair. This is com-
monly used in paraplegia when two KAFOs are necessary for “hands-free operation.”

3. **Ratchet lock** has an incremental locking mechanism every 7–10° to gradually stretch the knee following contracture or spasticity.

4. **Offset knee joint** has a posterior offset axis to allow inherent stability from 0 to 30°.

5. **Trick knee** has a locking mechanism, but still allows up to 25° of flexion, even in its locked position, to mimic normal gait patterns.

6. **Stance-locking knee** is an electromechanical locking mechanism that locks the knee in extension at heel strike and releases at toe-off for normal swing phase.

KAFO designs can be all metal, plastic, carbon fiber, or a hybrid of any of these materials. KAFOs are commonly used for instability of the knee and ankle, such as stroke with hemiparesis, but also for other diseases, such as Guillain-Barré, polio, lumbar spinal injury, or severe peripheral neuropathy.

**Hip–KAFO**

A hip–KAFO (HKAFO) is a device that stabilizes the hip joint in addition to the knee and ankle joint. All of the features of the KAFO described under the previous subheading will be used, in addition to a hip joint and waist belt. Hip joints can allow free motion, limited motion, or can be locked. They are most often used for paraplegia for limited ambulation with bilateral crutches. Specialized designs include the reciprocal gait orthosis.

Hip joints can also be used in a hip abduction orthosis, which is used commonly after hip dislocation or in higher risk patients after total hip replacement. This device keeps the hip at 30° of abduction and blocks hip flexion at 70–90° to prevent dislocation.

**Upper Extremity Prosthetics**

**Introduction**

There are approximately 5000–10,000 major upper limb amputations per year, and they are most commonly caused by trauma. The most common group is males aged 15–50 years. In the younger age group of 1–15 years old, congenital deficiency and cancers can also lead to upper limb amputation. The distribution of amputation is generally two-thirds below the level of the elbow and one-third above. The levels of upper limb amputation are indicated in Fig. 2.

**Digit Amputation**

Functional issues should dictate prosthetic restoration versus reconstructive surgery at this level. Prosthetic restoration of single or multiple digits
may conflict with function of the remaining digits and may cover sensate areas of the hand or digits. Each digit has a specialized function, and its importance to the individual patient may be determined by their functional activities. The thumb is the most important digit because it opposes all other fingers to give fine motor control and gross grasp. The index and middle fingers work together to give pinch and the best fine motor dexterity. The fourth and fifth fingers work together to provide gross grasp and a strong power grip. This may be most critical to laborers or those who rely on manipulating larger objects. Hand or finger reconstruction should always be considered, including toe transplantation to replace a thumb or other major digit. Many patients will choose to use a cosmetic prosthetic device for certain social activities, but no prosthetic device may be necessary for most of their functional tasks if there is at least the thumb and one finger remaining.

**Mitt Amputation**

With mitt amputation, there is loss of all fingers and thumb with preservation of the metacarpals. This is a very awkward and difficult level of amputation because there is no good prosthetic restoration available. Reconstructive surgery options are also limited and, therefore, further amputation at the level of the wrist may provide a more appropriate functional outcome.
Partial Hand Amputation

This refers to any combination of loss of digits and metacarpals, and can be particularly devastating if there is loss of the thumb. The function is difficult to restore through the use of prosthesis, and reconstructive surgery should be strongly considered. Custom silicone restoration prostheses may give a nice cosmetic outcome, but provide little or no functional improvement. In fact, most silicone restoration prostheses will have a glove-type suspension, which will cover sensate areas and limit active range of motion (ROM) of remaining segments. Prosthetic options at this level may include a Handi-Hook device strapped to the palm of the hand and controlled through a single cable to the opposite axilla. Sometimes, a unique prosthetic device may be fashioned for a specific task or activity.

Wrist Disarticulation Amputation

This level of amputation has distinct advantages with maximum pronation and supination preserved and good leverage for lifting, pushing, and pulling activities with or without a prosthesis. However, the disadvantages include a bulky distal end and limitations on some wrist and hand components because of lack of space. There are two prosthetic options:

1. A body-powered prosthesis is most commonly used at wrist disarticulation with a hook or hand terminal device. This will include a thin wrist unit to change or reposition terminal devices, which also helps to minimize length discrepancy between the amputated limb and the intact limb. A rigid socket with soft interface incorporates approximately two-thirds of the distal forearm and yet allows some remaining pronation and supination mobility of the prosthetic device. The suspension is a figure-9 harness with a control cable from the terminal device to an axilla loop proximally around the contralateral limb. The terminal device is opened by bicipital abduction or forward humeral flexion. The terminal device options include voluntary opening hooks, voluntary closing hooks, and functional hands. Use of the terminal device for functional grasp and manipulation of an object is very good at the wrist disarticulation level, but declines steadily with more proximal levels of amputation.

2. A myoelectric prosthesis may also be fabricated at the wrist disarticulation level and would include a suction socket with surface electrodes over the forearm flexors and extensors. Muscle activity is detected by the surface electrodes to control the motorized hand or hook terminal device. Some disadvantages of the myoelectric device include an overall bulkier and heavier prosthetic device and the necessity to recharge batteries on a regular basis.
Transradial Amputation

This level is divided into three distinct lengths as outlined in Fig. 2. The long transradial amputation preserves 55–90% of radius and ulna, and represents the ideal length because it preserves most of the pronation and supination ROM, allows good leverage for lifting, pushing, and pulling activities, and allows adequate room for most electric- or body-powered wrist units and terminal devices. For most individuals, a suction socket with a myoelectric terminal device is a good option with good functional outcome and cosmesis. No harnessing is required. However, other individuals involved in more heavy-duty or outdoor activities may still prefer a cable-powered prosthesis with hook or hand terminal device and figure-9 harness. The short transradial amputation preserves 30–55% of radius and ulna length and still provides moderate stability for lifting, pulling, and pushing activities with a prosthesis. However, no pronation or supination is preserved at this level. Prosthetic options include both myoelectric control and cable control as outlined in the Subheading entitled “Wrist Disarticulation Amputation.” However, the myoelectric design may require suspension over the humeral condyles for additional support and rotational control. The cable prosthesis will now require a double wall socket with flexible elbow hinges to a triceps cuff and figure-8 harness with an additional suspension strap anteriorly.

With very short transradial amputation there is less than 30% of the radius and ulna remaining, but there must be preservation of biceps muscle insertion to maintain active elbow flexion. This is a difficult level to fit because of the limited length of the residual limb and the limited leverage for lifting, pushing, and pulling activities. The socket design must be supracondylar and may limit elbow flexion and extension. Myoelectric prosthetic control may still work at this level using a suction socket, but supplemental suspension may be necessary from an additional elastic sleeve or harness. A cable-powered prosthesis at this level may require a rigid elbow joint or step-up joint to improve elbow flexion ROM, in addition to the triceps cuff and figure-8 harness.

Elbow Disarticulation Amputation

The advantages of this level of amputation include better leverage for lifting, pushing, or pulling than transhumeral amputation. Also, the humeral condyles can be used to control internal and external rotation of the prosthesis. However, disadvantages include a bulky distal end, which makes for a bulky socket design with little or no room for elbow joints. Myoelectric
prosthetic designs may be limited at this level because of the lack of space needed for electrically controlled elbow joints. Therefore, a hybrid system using cable power at the elbow to figure-8 harness should be used along with an electronic hand or wrist rotator using the biceps and triceps muscle for myoelectric control. A cable-powered prosthesis would include a rigid socket with thin soft interface, socket trimlines below the acromion, a figure-8 harness, external locking elbow joint, and dual-control cable system. The posterior control cable will operate the terminal device and position the elbow. A second anterior cable will be used for locking and unlocking the elbow mechanism. At this level of amputation, external elbow joints must be used owing to lack of space. Proper positioning of the attachment points of the posterior control cable are critical, both on the socket and on the forearm shell. The initial pull on the posterior control cable using bicipital abduction will initiate elbow flexion. Once the elbow is properly positioned, the elbow must be locked with a “down, back, and out” maneuver of the shoulder, then further bicipital abduction or forward humeral flexion will open the terminal device. Once the object is grasped in the terminal device, it is difficult to reposition the elbow; therefore, initial elbow positioning is critical.

Transhumeral Amputation

Functional use of any prosthesis declines rapidly at this level. Similar to transradial amputation, there are three distinct levels of amputation at the humerus. Long transhumeral amputation preserves 50–90% of humeral length and is ideal for this level of amputation, with the greatest leverage for lifting, pushing, and pulling activities but allowing adequate room for appropriate electric elbow units. Prosthetic options at this level would include a full cable-powered prosthesis, myoelectric prosthesis, hybrid prosthesis, and cosmetic prosthesis. A full cable-powered prosthesis would include a rigid socket with soft interface, figure-8 harness, dual-control cables, internal locking elbow unit, rigid forearm shell, wrist unit, and terminal device. Control of the cable-powered device is the same as elbow disarticulation. Elbow flexion is first initiated by bicipital abduction to pull on the posterior control cable. Once the elbow is positioned, it could be locked with the “down, back, and out” maneuver at the shoulder. Further excursion of the posterior control cable will now open the terminal device. Because of the difficulty with repositioning the elbow once the terminal device is activated, a hybrid prosthesis with cable-powered elbow and electric controlled hand is often recommended to allow independent functioning of the elbow and the hand devices. A fully myoelectric prosthesis can be used at this level using biceps and triceps muscle sites to control elbow
flexion/extension and hand open/close. This is accomplished by signaling the prosthesis to switch from elbow to hand function with co-contraction of the biceps and triceps muscles. The disadvantages of myoelectric control at this level include increasing cost and increasing weight of the prosthetic device. *Short transhumeral amputation* preserves 30–50% of humerus, but the ability to push, pull, or lift with the prosthesis is significantly limited. The socket design will commonly include the acromion to provide extra stability and weight-bearing of the prosthesis. This will eliminate much of the active ROM of the shoulder, hence reducing excursion for a cable-powered system and limited ability to reach with the prosthesis. Prosthetic designs otherwise are similar to those described for the long transhumeral amputation. *Very short transhumeral amputation* preserves only 30% or less of humeral length. This is also commonly called “humeral neck amputation” and is functionally grouped together with shoulder disarticulation because there is no effective way to capture the movement of the humerus. It is still important to leave the short segment of humerus in place because it provides better contour of the shoulder, better cushioning of the shoulder, and the potential of residual muscles attached to the humerus, which may be used for myoelectric control.

**Shoulder Disarticulation Amputation**

This level is functionally very difficult to fit with a prosthesis because control of the prosthesis comes exclusively from proximal, trunk-based muscles for myoelectric control or scapulo-thoracic movement for cable control. The socket design will cover the entire shoulder like a cap to distribute the weight of the prosthesis. A shoulder joint with passive positioning can be used or the shoulder can be fixed in one position in the prosthesis. Generally, a myoelectric control prosthesis at shoulder disarticulation level will be difficult to control and difficult to weight-manage. Some patients will choose a hybrid design with a fixed passive shoulder joint, cable-powered elbow joint, and myoelectrically controlled hand to minimize the weight and complexity. This prosthetic device will be, at best, a helper for the remaining limb. Some patients will choose a light-weight cosmetic prosthesis or no prosthesis at all.

**Forequarter Amputation**

At this level of amputation, there is loss of the entire upper limb and scapula. There is no effective control mechanism for cable power and there are very few residual muscles for myoelectric control. Most patients will choose a cosmetic prosthesis or no prosthesis at all at this level.
Specialty Terminal Devices

There are a variety of specialized terminal devices for specific tasks. Many of them are available for cable-powered or myoelectric control systems.

1. Robotic terminal devices, such as the Greifer or Steeper, provide parallel jaws for better grip of both small and large objects.
2. Waterproof terminal devices including a myoelectric hook for active outdoor and sports use.
3. Activity-specific terminal devices can be designed for golf, skiing, photography, swimming, or even certain types of sports gloves and mitts. There is also a series of mechanic’s tools and kitchen utensils that are plugged directly into the wrist unit of the prosthesis.

Upper Extremity Orthotics

Introduction

Upper limb orthoses can be described by the joints or segments that they cross and any special design features incorporated. These should also be described as a static, dynamic, or hybrid system. A static orthosis remains fixed in one position with no movement across the joint. A dynamic orthosis increases or decreases movement across the joint. In contrast to lower limb orthoses, many upper limb orthoses can be fabricated from a kit or purchased off the shelf from a catalog or medical supplier.

Finger Orthosis

There are three common types of finger orthoses used:

1. For fracture, ligamentous injury, or inflammatory disease a static gutter splint or circumferential splint is used to eliminate motion across interphalangeal (IP) joints.
2. For contracture across an IP joint, a dynamic finger orthosis with spring wire or rubber bands is used.
3. For progressive deformity from disease, such as rheumatoid arthritis, a specialized finger orthosis called a ring orthosis can be used. This is used to control swan neck deformity and Boutonnière’s deformity.

Hand–Finger Orthosis

These are commonly used to control the digits or metacarpophalangeal (MCP) joints from a device positioned across the palmar or dorsal surface of the hand.

1. For rheumatoid arthritis at the base of the thumb or deQuervain’s ten- donitis, the thumb can be controlled with a static hand–finger orthosis stabilizing the thumb commonly called a thumb spica.
2. Median nerve injury at the distal forearm or wrist will cause loss of motor function of the thumb. A short opponens orthosis is fabricated from plastic to position the thumb opposite the fingers while maintaining first web space.

3. Ulnar nerve injury causes “intrinsic minus” hand positioning with hyperextension of the MCPs. This can be treated with a hand–finger orthosis with MCP block in slight flexion. This allows better functioning of the long finger flexors and extensors.

4. Flexion–extension contracture across the MCP joints can be treated with a dynamic hand–finger orthosis commonly called a knuckle bender using spring wire or rubber bands.

**Wrist–Hand–Finger Orthoses**

These devices range from very simple, off-the-shelf products to complex, custom-made devices.

1. The simplest and most common device to cross the wrist is the cock-up splint for carpal tunnel syndrome. This device positions the wrist in its neutral or slightly extended position to minimize pressure within the carpal tunnel.

2. Stroke patients with little or no function in the affected hand can be positioned properly with a static wrist–hand–finger orthosis, maintaining the wrist in neutral, MCPs in slight flexion, and IP joints in extension. The thumb must always be maintained in its position of opposition to the fingers.

3. Low radial nerve injury causes wrist drop and inability to extend the fingers. A dynamic wrist–hand–finger orthosis with extension positioning of the wrist and fingers using outriggers and rubber bands should be used. The patient can still flex the fingers and wrist for grasp and functional activities. However, when the patient relaxes, the rubber bands extend the fingers to open the hand.

4. With C6-level quadriplegia, active wrist extension is preserved but finger flexion and grasp is lost. A tenodesis or flexor hinge orthosis is commonly used to restore grasp or prehension. This is a dynamic wrist–hand–finger orthosis that uses active wrist extension to drive the second and third fingers against the thumb for grasp. There are several designs available both by kit and custom fabrication.

**Elbow Orthosis**

Flexion or extension contractures at the elbow are common after immobilization of the upper limb from fractures, burns, surgery, or other injury. A dynamic elbow orthosis with adjustable tension in flexion or extension is commonly used to stretch the contractures. Elbow orthoses with adjustable ROM joints are also available postoperatively to slowly restore active movement at the joint as healing occurs.
**Shoulder Orthoses**

Generally, there are two types of devices applied across the shoulder joint:

1. In acute injury or surgery, the shoulder can be fixed in nearly any position using an *airplane* or *gunslinger* type of device. This provides unloading of the weight of the limb to prevent subluxation of the gleno-humeral joint, and can allow limited or no movement for healing of soft or bony tissues.
2. Following stroke or brachial plexus injury, the gleno-humeral joint may be at risk for subluxation and chronic pain. A *non-elastic humeral cuff* or *sling* can be applied to maintain gleno-humeral positioning.

**Definitions**

*Prosthesis:* A device that replaces an absent body part.

*Prosthetics:* The field of design and fabrication of the devices to replace a body part.

*Prosthetist:* A certified practitioner who designs and fabricates a prosthesis.

*Orthosis:* A device that supports an existing body part.

*Orthotics:* The field of design and fabrication of any type of brace device.

*Orthotist:* The certified practitioner who designs and fabricates an orthosis.

**Key References and Suggested Additional Reading**


