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Gait Analysis for the Enhancement of AKA Gait Patterns

Krista Lausen
University of North Dakota

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GAIT ANALYSIS FOR THE ENHANCEMENT OF AKA GAIT PATTERNS

by

Krista Lane Lausen
Bachelor of Science in Physical Therapy
University of North Dakota, 1995

An Independent Study
Submitted to the Graduate Faculty of the
Department of Physical Therapy
School of Medicine
University of North Dakota
in partial fulfillment of the requirements
for the degree of
Master of Physical Therapy

Grand Forks, North Dakota
May
1996
This Independent Study, submitted by Krista Lane Lausen in partial fulfillment of the requirements for the Degree of Master of Physical Therapy from the University of North Dakota, has been read by the Faculty Preceptor, Advisor, and Chairperson of Physical Therapy under whom the work has been done and is hereby approved.

(Chairperson, Physical Therapy)

(Faculty Preceptor)

(Graduate School Advisor)

(Chairperson, Physical Therapy)
PERMISSION

Title          Gait Analysis for the Enhancement of AKA Gait Patterns

Department     Physical Therapy

Degree         Master of Physical Therapy

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Signature  Krista Lauson

Date   12-15-95
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ACKNOWLEDGMENTS

I would like to acknowledge and thank the following people for their involvement in my education and life: Bev Johnson, my preceptor and advisor, for her continual encouragement and guidance; Carole Dallman, my mom, for her devotion to my education, her caring way, and constant faith; David, for his patience, perspective, and love. I never would have made it without you.
ABSTRACT

The amputation of a body part is both a physically and psychologically traumatic event for an individual. There are a number of gait deviations that often occur when a person has had a lower extremity amputation, especially when that amputation is above the knee. The entire locomotor mechanism of the body is altered by this change. The person must then adjust and relearn how to accommodate for the loss.

This literature review will discuss specific causes of certain gait deviations to determine whether the deviation is due to a musculoskeletal deficit or habit pattern on the part of the patient or whether it is due to a prosthetic malalignment. The appearance of each deviation, when to observe each pattern, and how the physical therapist can help to enhance the overall gait pattern will be discussed. The purposes of this literature review are to help the physical therapist identify gait deviations that frequently occur with an above knee amputation, to recognize the primary or secondary causes of gait deviations, and to decide what action must be taken to enhance the gait pattern. It is a brief, yet comprehensive overview of the physical therapist’s role in the gait enhancement of patients who have had an above knee amputation.
CHAPTER I

INTRODUCTION

The amputation of a body part is both a physically and psychologically traumatic event for an individual. There are four basic categories that lead to causes for amputations. They are, from highest to lowest incidence: disease (such as diabetes, arterial sclerosis, and Beurger’s disease), trauma (such as auto accidents, farming accidents, fire arms, freezing, electrical burns, and power tool accidents), tumors, and congenital amputations and malformations. Obviously, the longer an individual lives, the greater the chance of developing a disease or having an accident that may necessitate the removal of part or all of a limb. Thus, it is easy to see that the greatest number of individuals with amputations belong to the geriatric population.

When part of a lower extremity has been amputated, the loss not only alters the person’s physical appearance, but also alters the entire locomotor mechanism of the body. The body must then adjust and relearn how to accommodate for the loss. Often, there are physical gait deviations that occur when a person has had an above knee amputation. How quickly, efficiently, and effectively that person regains his or her optimal functional level depends in part on how well the interdisciplinary team, including the person with the amputation,
works together. The physical therapist (PT) is an integral part of this team and can teach valuable strategies for enhancement of the patient's gait pattern.

Several factors come into play in the decision to fit a person with a prosthesis. Primarily, the person must be open to the idea and must want to have a prosthesis. The person must be psychologically prepared to accept such a responsibility and must mentally understand the commitment and determination required to master use of the prosthesis. Physically, the candidate must demonstrate adequate strength, flexibility, and endurance to functionally utilize the prosthetic device. The patient must also have a stump that is able to tolerate the socket without skin breakdown. All of these factors are taken into consideration when the interdisciplinary team members are deciding appropriateness for prosthetic fitting.

The team concept is the ultimate approach for the rehabilitation of any patient. Team members for a person with an amputation usually include a physician, a physical therapist, an occupational therapist, a prosthethist, a social worker, and a vocational counselor. Others may include a nurse, a dietician, a psychologist, and an administrative coordinator. Some patients may also require the services of a hospital chaplain. The team regularly exchanges information in attempts to keep all participants in the rehabilitation hospital well informed.

The PT is involved with the patient in several areas. The physical therapist works with the patient on a daily basis, works with the prosthethist when
the patient initially receives the prosthesis, and works with the prosthetist again whenever modifications to the prosthesis are needed. The prosthetist helps ensure the best fit and alignment of the prosthesis. The physical therapist and certified prosthetist must have a good working relationship to allow the free flow of information and exchange of ideas. The best interest of the patient must always come first.

The purposes of this literature review are to help the physical therapist identify gait deviations that frequently occur with an above knee amputation, to recognize the primary or secondary causes of gait deviations, and to decide what action must be taken to enhance the gait pattern.

This literature review is needed for several reasons. First, it will educate PTs on how to identify gait deviations. Second, it will make PTs a strong asset to the interdisciplinary team by increasing the awareness and skill level of the therapist. Third, it will make PTs aware of opportunities to observe the patient and bring concerns to the team. Lastly, to efficiently serve rural communities, the physical therapist must be able to decide if the problem is due to musculoskeletal deficiencies that can be solved in the immediate environment or if it is necessary for the individual to make what might amount to a costly, time consuming, and inconvenient visit to a prosthetic clinic, a site which could be hundreds of miles away.

The latter condition, although an undesirable geographical nuisance, does exist in many areas. Having the skills to determine what problems are
causing gait deviations with above knee amputations will help the physical therapist decide most efficiently, with support from the interdisciplinary team, how to treat and how to refer appropriately in each individual circumstance.
CHAPTER II
PROSTHETIC COMPONENTS

To properly evaluate a patient's gait pattern, it is necessary for the physical therapist (PT) to have a basic knowledge of the components and mechanics of the prosthetic device. This chapter will review the two primary above knee (AK) socket designs, various knee designs, and a number of ankle/foot mechanisms. The intent is not to teach the physical therapist how to modify the prosthetic device, but simply to provide an understanding of certain prosthetic options.

Socket Design

There are two basic A-K socket designs that will be discussed. They are the quadrilateral socket and the ischial containment socket.

The Quadrilateral Socket.—

According to Hall,\(^4\) any prosthesis must meet criteria to properly support and stabilize the patient. The following fundamental criteria must be met:

1. the socket contour must allow relief areas for functioning muscles
2. stabilization is most effective in areas where there is no functioning muscle
3. to achieve greatest muscle power, the muscles should be stretched to slightly greater than rest length, if at all possible

4. pressure is tolerated over neurovascular bundles, such as Scarpa’s triangle, if applied appropriately

5. force is best tolerated if it can be applied over a large surface area.

Since the 1960s, the quadrilateral socket has been the socket of choice for prosthetic management. It was first introduced by the University of California at Berkeley. The name quadrilateral comes from the appearance of the socket brim when viewed from above. The four walls, each of which serves a specific purpose, form the sides of the quadrilateral socket.

The posterior wall of the socket is the weight bearing shelf for the ischial tuberosity and gluteal musculature. If the socket is contoured correctly, the posterior brim will provide support throughout the entire gait cycle. Correct biomechanical position is maintained by stabilization from the anterior, medial, and lateral socket walls. The medial one-third of the anterior wall is especially important in providing proper counter-support to the posterior wall. Moving distally from the proximal brim of the posterior wall, there is a slight anterior slope. The slope accomplishes two things: it allows a better fit for the remaining thigh musculature and it keeps the stump in a slight amount of flexion to stretch hamstring and gluteal muscles. This stretch helps facilitate powerful hip extension. There is often an amount of flexion built into the socket when it
is fabricated to provide stretch. "Amount of initial flexion increases as the amputee's ability to extend his hips decreases."\(^7\)\(^{(p511)}\)

The medial wall functions to stabilize the limb against the lateral wall.\(^4,6\) The line created by the medial brim should be parallel to the patient's line of progression when ambulating.\(^1\) The line of progression is the course of movement the patient takes with forward walking. There may be a slight decline of the medial brim as you move posterior to anterior. This creates an open space for the pubic ramus.\(^1\) However, according to Hall,\(^4\) the medial brim may stay horizontal and is turned at a 90 degree angle to the posterior brim. The wall drops distally, in a straight vertical direction, for several inches. It then follows the contours of the residual limb as it moves distally.\(^4\) This helps to assure total contact of the stump within the socket. The adductor muscles are not functional and can be compressed by the socket.\(^4\) A good stump shaping program is necessary to decrease the probability of developing an adductor roll.\(^1\) If an adductor roll develops, proper fit and stabilization of the prosthesis is difficult to both attain and maintain.

Fabrication of the medial wall to the correct width is another important consideration. If the width of the brim is too narrow, it will become painful to the patient.\(^1\) If the patient complains of a sharp, painful area where the medial brim meets the skin, the width may be too narrow.

As stated earlier, the anterior wall is very important in maintaining proper position of the socket on the stump. It may be one-half inch higher than the
A distinguishing characteristic of the anterior wall is its many built-in pressure reliefs. The many functioning muscles that are contained by the anterior wall must be given enough area to contract and relax. An area that is capable of tolerating pressure is Scarpa's triangle. Scarpa's triangle (also known as the femoral triangle) is bordered by the inguinal ligament, medial border of the sartorius, and the medial border of the adductor longus. The neurovascular bundle is located within Scarpa's triangle. The anterior wall is used to counteract the force of the posterior wall.

"The prime function of the lateral wall is stabilization of the femoral shaft, which, in turn, stabilizes the pelvis when the amputee rests his full weight on the ischial tuberosity." The longer the lever, the greater the force that can be generated. An individual with a short residual limb may be given a prosthesis with a higher lateral wall to allow greater leverage. Conversely, an individual with a longer residual limb may have a prosthesis with a lateral wall that is lower.

The lateral wall is fabricated in an adducted position. Again, this puts the hip abductors on a slight amount of stretch, permitting them to be in a stronger position. This is quite important in stabilizing the hips during ambulation.

The anterior and lateral wall heights should be equal at the antero-lateral junction. The lateral wall is then contoured to comfortably fit the gluteus maximus, vastus lateralis, and tensor fascia lata. According to Shurr and
Cook, the lateral wall should always remain higher than the posterior wall at the postero-lateral corner.

There may also be a pressure relief built into the distal part of the socket that contacts the femur. This is because of the sensitivity that frequently occurs when the distal femur encounters pressure.¹ ⁴

The quadrilateral socket design includes:

1. weight bearing mostly over the ischial tuberosity
2. the socket fabricated in slight flexion and adduction
3. the adductors flattened to allow a better fit
4. pressure relief channels built into the socket for the hip flexors and extensors
5. a socket contour independent of the hip abductors because they are superior to the socket brim.⁴

Some clinicians find that the quadrilateral socket, which is narrower in the antero-posterior (A-P) than the medial-lateral (M-L) direction, contributes to certain gait deviations.⁶ Sabolich believes that the bigger M-L distance allows movement of the ischial tuberosity over the posterior wall. These extraneous movements contribute to several gait deviations. The deviation most commonly noted is lateral trunk leaning.⁸

An alternative to the quadrilateral socket, the ischial containment (IC) socket, has been developed. Other names that refer to the IC socket are the Long’s Line prosthesis, the contoured adducted trochanteric-controlled
alignment method (CAT-CAM) socket, the normal shape-normal alignment (NSNA) socket, or the narrow medial-lateral (M-L).9

The Ischial Containment Socket.—

Esquenazi, et al9 reported several advantages of the ischial containment concept. The narrower M-L dimension helps to keep the femur adducted, thereby decreasing movement of the ischial tuberosity. There is less pressure over the neurovascular bundle in the femoral triangle and it provides a better fit for a short stump. However, it is more difficult to fabricate and is more costly than the quadrilateral socket.5 It is important to note that objective research has not been conducted to substantiate the advantages and disadvantages of this socket.9,10

The posterior brim of the IC socket is approximately four centimeters higher than the ischial tuberosity.10 Hence the name, ischial containment, was developed. The IC socket is a total contact socket with a lateral wall that extends proximally above the greater trochanter.11 Unlike the quadrilateral socket, where the ischial tuberosity rests on the brim of the posterior wall, the ischial tuberosity is contained within the walls of the prosthesis.11 Weight bearing is through the entire contact of the socket. With this socket, the femur is aligned in adduction. Because of this increased adduction angle, some weight bearing may be through the lateral border of the femur.8
A three-point system exists to keep the ischial tuberosity in position. The proximal lateral wall and the distal lateral wall, which are built to keep the femur in adduction, provide a medial force. The ischial tuberosity provides a lateral counter-force to "lock the femur into adduction and reduce motion that can occur when the ischium is free to shift about."\(^8(p19)\)

According to Sabolich,\(^8\) the increased anterior-posterior (A-P) dimension has not negatively affected stabilization. An increased A-P dimension allows the musculature to contract and expand naturally, without the restrictions imposed by a quadrilateral socket that is much narrow in the A-P dimension.\(^8\) Likewise, the bony resistance of the ischial tuberosity against the posterior wall is more definitive than the resistance provided by the quadrilateral socket.

A problem identified in the literature is lateral migration of the socket brim when the ischial tuberosity comes out of the socket. The medial brim then becomes a painful area to the patient. The etiology of this problem rests with a medial-lateral dimension that is too narrow, causing the socket to be too tight.\(^8\)

An advantage of having the IC socket with regard to short above-knee amputations is that the higher lateral brim allows better containment of the residual soft tissues.\(^8\) Another advantage, especially affecting the geriatric population, is increased blood flow to the residual limb.\(^8\) This is due to the increased A-P dimension and the decreased pressure on Scarpa's triangle.
Subjective reports from individuals who have experienced both the quadrilateral and IC socket favor the IC socket. They claim to have decreased use of energy, less pain, and easier initiation of movement with the IC socket. 8

Knee Components

Depending on the level of activity and skill of the patient, different degrees of mobility are needed in the knee component of the prosthesis. The major categories for knee mechanisms include: constant friction, locked, hydraulic and pneumatic, and polycentric knees. 12 The various knee components will be briefly described in order to provide a basic understanding of their mechanics.

Constant Friction.—

The constant friction knee system "keeps the shank from swinging too fast as the user swings the artificial leg through the next step." 13(p60) A bolt that connects the socket to the shank provides mechanical friction. 13 In this knee, the user can safely walk at one speed without fear of buckling. Adjustment of the bolt will accommodate a change in walking speed. 1

Another version of the constant friction knee, the “safety” knee, utilizes two bolts that rotate around each other to act as brakes that keep the knee from buckling. This is a very popular design among the elderly population. 13 This design may also be referred to as the “locking” knee (which is different from the locked knee) or the “weight activated stance control.” 1(p89) It will remain locked while the extremity is weight bearing and will flex when weight bearing is
relieved. This knee design does not have to be in full extension to lock, thereby allowing a small margin of variation in knee extension during ambulation.

The friction control knee devices are used more commonly than other devices. This is due to their high degree of dependability and their simplicity. The above mentioned friction devices are known as single axis knees.

Locked Knee.—

The locked knee unit is designed to have optimal support during stance phase. It is locked in extension at all times, with the exception of being flexed during sitting. There is usually a cord on the proximal-lateral portion of the socket that can be pulled to unlock the knee. The inherent stability of this unit may accentuate certain gait deviations. These may include hip hiking, vaulting, or circumduction. To help minimize these deviations, the overall length of the prosthesis may be shortened.

Engstrom and Van de Ven refer to a similar knee mechanism, the semi-automatic knee lock (SAKL), which locks the knee in extension with a spring loaded mechanism. It, too, is capable of flexing while sitting.

Hydraulic and Pneumatic Knees.—

Hydraulic and pneumatic knees are prescribed for a person with an amputation who continues to lead a very active lifestyle. Several variations of this device are available. Some allow for only swing-phase control, while others allow swing and stance-phase fluid control. A hydraulic mechanism utilizes oil to
control movements and a pneumatic mechanism utilizes air to control movement.\textsuperscript{1,11} The hydraulic and pneumatic devices allow the patient to vary the walking speed without physically adjusting the prosthesis.\textsuperscript{1,11,13}

The swing-phase control must initially be set to allow proper resistance during heel rise and to promote adequate knee extension. Most swing-phase fluid control units do not have a stance-phase lock.\textsuperscript{1} Knee stability is maintained both through the alignment of the prosthesis and through muscle control by the patient. The hydraulic and pneumatic units add weight to the prosthesis, and the price is increased.

Units that permit both swing and stance-phase fluid control allow the patient to quickly vary the walking speed and to descend stairs or ramps easily.\textsuperscript{1} The knee does not lock, but gradually yields to flexion or extension, depending on pressure applied to that extremity. As stated by Shurr and Cook,\textsuperscript{1} "This gradual knee flexion allows the amputee to essentially 'ride' the hydraulic cylinder down the steps one at a time and to follow the prosthetic step with a normal step on the sound side."\textsuperscript{1}(p93)

It is also possible to quickly release the knee extension before sitting with a swift hyperextension of the hydraulic or pneumatic knee unit. When the knee unit allows swing and stance-phase control, an optional feature may be the ability to disengage the stance phase control. Stability would then rely on the alignment of the prosthesis. Another option is the ability to lock the knee at a
specific angle. This is functionally convenient when a person wants to drive a car.\textsuperscript{1}

Polycentric Knees.—

According to Radcliffe,\textsuperscript{14} "A polycentric knee mechanism is any device where the instantaneous center of rotation of the knee changes its position as the knee flexion angle increases or decreases."\textsuperscript{14(p149)} This polycentric knee system allows greater stability at heel-strike and through stance-phase.\textsuperscript{7,13} Stability decreases at toe-off to make swing-phase easier.\textsuperscript{7} This unit is limited to about 100° of knee flexion.\textsuperscript{13} According to Wilson,\textsuperscript{13} swing-phase control of the knee is provided by hydraulics or by friction.

The polycentric design may be referred to as the four-bar polycentric knee or linkage system.\textsuperscript{11,13} Two bars on each side of the knee joint attach the socket to the shank.\textsuperscript{15} This allows freedom of the knee joint to rotate. There are many variations for aligning the four bars, which change the center of rotation to allow subtle changes in the gait pattern.\textsuperscript{14} Their description is beyond the scope of this paper. Advantages of the polycentric knee include improved appearance of the gait pattern, stability during stance or standing, and lower energy expenditure.\textsuperscript{15}

Foot and Ankle Mechanics

Any person who has an above-knee amputation (AKA) and receives a prosthesis will have the option of many different designs of prosthetic feet. The patient's activity level and financial situation must be taken into consideration.
The prosthetic limb's cosmetic appearance and ease of operation will impact the design as well. Durability and weight are also considered.\(^{16}\) Regardless of the type chosen, it is desirable for the foot and ankle to mimic the normal foot/ankle mechanism. The foot "provides a stable weight-bearing base of support, permits impact absorption, and generates dynamic propulsion essential for normal locomotion"\(^{16(p299)}\) in the non-amputated limb. The degree to which these elements can be satisfied partly depends on the device.

The next section will discuss general design characteristics of specific foot and ankle systems. It is important to recognize that this is an ever-changing arena and that continuing education is necessary to stay current. There are four broad categories of prosthetic ankle/foot design.\(^{11}\) They are the solid ankle cushioned heel (SACH), the uniaxial ankle, multiaxial ankle, and energy storing prosthetic feet. Following is a description of each category.

The Solid Ankle Cushioned Heel (SACH).

The SACH does not have an ankle joint.\(^{11}\) This is "the most commonly prescribed prosthetic foot used today in the United States."\(^{1(p59)}\) A heel cushion of varying densities is used to absorb shock at heel-strike and to simulate normal ankle motion. Flexion at the forefoot accommodates movement at toe-off.\(^{11}\)
Uniaxial Ankles.—

One plane of motion is allowed with this design. Plantarflexion and dorsiflexion are each controlled by a plantarflexion bumper or dorsiflexion bumper, respectively. This design also allows flexion of the forefoot at toe-off.

Multiaxial Ankles.—

Multiaxial ankles are designed to allow motion in up to three planes. Capabilities include plantarflexion-dorsiflexion, inversion-eversion, and transverse rotation. This system is capable of accommodating more easily to uneven terrain.

Energy Storing Prosthetic Feet.—

This category enables a smoother gait pattern and a higher level of activity. Often, a spring loaded mechanism creates a more dynamic foot that is more reactive to its environment. This category may also be referred to as dynamic elastic response (DER).

Following is a list describing foot/ankle components. All information is taken from Esquenazi and Torres. See Tables 1 and 2 for recommended foot/ankle components for persons with above-knee amputations.

Carbon Copy II.—This is a solid ankle design which allows dynamic activity. It is relatively wide and has a poor cosmetic appearance, but is very stable. The Carbon Copy II ankle has the capacity to operate at two activity levels, one for functional activities and the other for more intense activity.
Table 1.—Recommended Foot/Ankle Components for Sedentary Individuals

<table>
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<tr>
<th>EXCELLENT</th>
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<th>GOOD</th>
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<tr>
<td>Multiflex</td>
<td>Graph-lite</td>
<td>Carbon Copy II</td>
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<tr>
<td>Seattle Light</td>
<td>Quantum</td>
<td>Dynamic</td>
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<td>S.A.F.E. I &amp; II</td>
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<td></td>
<td></td>
<td>Seattle Light with Ankle</td>
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* Cost not considered.
Table 2.—Recommended Foot/Ankle Components for Active Individuals

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<tr>
<th>EXCELLENT</th>
<th>VERY GOOD</th>
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<tr>
<td>Carbon Copy II</td>
<td>Dynamic</td>
<td>Flex-Walk</td>
</tr>
<tr>
<td>Flex Foot</td>
<td>Graph-Lite</td>
<td>Quantum</td>
</tr>
<tr>
<td>Sabolich</td>
<td>Greissinger</td>
<td>RAX</td>
</tr>
<tr>
<td>Spring-Lite</td>
<td>Multiflex</td>
<td>S.A.F.E. I &amp; II</td>
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<tr>
<td></td>
<td></td>
<td>Seattle Light with Ankle</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Seattle Light</td>
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* Cost not considered.
It is very light and is a recommended design for people with above-knee amputations (AKA).

**Flex-Foot.**—This is a system that uses a carbon-graphite and pylon design to release energy at toe-off. The energy in this system is stored during the patient’s stance-phase. Weight and activity of the person are taken into consideration during custom fabrication. Fabrication is difficult, which increases the price. This design suits the very active AKA well.

**Flex-Walk.**—This mechanism is much like the Flex-Foot. However, it is suited for a less active lifestyle or for those with a longer stump. It costs less than the Flex-Foot. The Flex-Walk is lighter than the Flex-Foot because it is shorter than the Flex-Foot.

**Graph-Lite.**—This system allows a multiaxial movement protected by four bumpers and a multi-directional pin. It is light, has an acceptable cosmetic appearance, allows a stable knee, and lets the person travel on uneven surfaces. Easy adjustment of the heel height is an additional benefit.

**Greissinger.**—This system, too, is multiaxial. It lets the patient plantarflex and dorsiflex, invert and evert, and rotate in the transverse plane. This is a high-maintenance design, requiring frequent replacement of parts. It is large, noisy, and heavy. However, for the patient with good balance, it allows ambulation over various terrains. Due to the increased distal bulk, the mass of the prosthesis may be noticeably disproportional to the remainder of the prosthesis.
Multiflex Ankle-Foot.—This system also allows motion in three planes (plantarflexion-dorsiflexion, inversion-eversion, and transverse rotation). The design of the Multiflex Ankle-Foot allows walking on uneven terrains and torque absorption. Varying heel heights are available with this system.

Quantum Modular Foot.—This endoskeleton design uses two springs in the foot module, according to shoe size, body weight, and relative activity level. It is a dynamic system that allows ambulation on irregular surfaces. Cosmetically, the endoskeleton can be covered to improve appearance.

RAX.—This Swedish design uses air-filled chambers to store and release energy. It is a light-weight design that allows inversion-eversion and transverse rotation.

Sabolich.—This design is fabricated specifically for each patient, considering activity and weight on an individual basis. The Sabolich foot stores energy from heel-strike to mid-stance, holds it, and the design of the forefoot allows release of the energy at toe-off.

Stationary Attachment Flexible Endoskeleton Foot (S.A.F.E.).—This is a dynamic solid ankle design. It allows shock absorption and permits ambulation on irregular terrains. It can be made waterproof to decrease maintenance or non-waterproof which will decrease weight. Compared to the SACH, it is heavier. The S.A.F.E. design is fabricated with toes.

Seattle Foot.—This design mimics the human foot in appearance. "A cantilevered Delrin spring keel and Kevlar reinforced toe-pad are encased in a
human-looking polyurethane mold. It is capable of storing energy and releasing that energy at push-off. Design specifications are made according to the weight and activity level of the consumer. Stability is questionable, due to its high arch and decrease in M-L dimension. To some, it appears wide and heavy.

A female version of the Seattle Foot is on the market.

Seattle Lightfoot.—As the name implies, this dynamic design is lighter (by about one-half) than the regular Seattle foot. The arch is lower, allowing increased medial-lateral stability, and may contribute to better shoe fit. It is used with the Seattle ankle to provide plantarflexion and dorsiflexion.

Spring-Lite.—It is similar to the Flex-Foot in utilizing the carbon-graphite and pylon mechanics, but is cosmetically more pleasing. Alignment is challenging and fabrication is expensive.

Otto Bock Dynamic Foot (1D10).—This is a design related to the SACH. It is lightweight, absorbs energy, but has only a small dynamic capability.
CHAPTER III

PROSTHETIC GAIT DEVIATIONS

"One of the aims of prosthetic fitting is to restore as much of the normal pattern of movement as possible." This, combined with proper fitness of the amputee, will help regain the ideal walking pattern. There are a number of common above knee amputation (AKA) gait deviations that the practicing physical therapist (PT) should be able to recognize. These include lateral trunk bending, abducted gait, circumduction of the prosthetic limb, medial and lateral whips, rotation of the foot on heel strike, uneven heel rise, terminal swing impact, foot slap, uneven step length, lordosis, and vaulting.

The focus of this chapter is to review the appearance and causative factors of each deviation. PT interventions in regard to remediation and prevention of the deviation will also be discussed.

Lateral Trunk Bending

Appearance.—

This deviation is best viewed when observing the patient from behind. It occurs during the stance phase on the prosthetic limb. The patient will laterally bend the trunk, usually toward the side of the prosthesis.
Amputee Causes.—

If the amputee has weak hip abductors, he will try to prevent hip drop on the sound side by shifting his center of gravity (COG) toward the prosthetic side. This COG shift causes a lateral bend of the trunk toward the prosthetic side to compensate for pelvic drop with the swing side limb (which is the sound side).\textsuperscript{20} According to Engstrom and Van de Ven,\textsuperscript{11} weak hip abductors will cause lateral side bending away from the prosthetic side. This is simply an uncompensated hip abductor gait pattern.

Another amputee cause of lateral trunk bending toward the prosthetic side is a hip abduction contracture. If this is suspected, proper assessment begins with placing the patient in supine, keeping the anterior superior iliac spines (ASIS) level to ensure a level pelvis, and using the ASIS axis as a marker for one arm of the goniometer. The PT then keeps the moveable arm in line with the femur and asks the patient to adduct.\textsuperscript{23} Less than full range of motion may indicate a hip abduction contracture. Normal range of motion (ROM) for adduction is $0^\circ$ to $20^\circ$-$30^\circ$ abduction.\textsuperscript{24}

Other amputee causes include a painful stump, a very short stump that fails to provide a sufficient lever arm for the pelvis, and habit patterns, which all lead to a lateral lean toward the prosthetic side.\textsuperscript{11,20-22} Poor balance may also cause the patient to have a lateral lean.\textsuperscript{22}
Prosthetic Causes.—

An abducted socket will cause a lateral lean away from the prosthetic side.\textsuperscript{11} Causes of lateral trunk bending toward the prosthetic side include the following: poor support of the lateral femur by the socket wall, a short prosthesis, or a medial socket brim that is too high and causes pain.\textsuperscript{11,20-22} Alignment of the socket in too much adduction causes lateral trunk bending away from the prosthetic side.\textsuperscript{11}

PT Intervention.—

Before the physical therapist sends the patient to the prosthetic clinic, the patient's musculoskeletal system and habit patterns should be screened to find problem areas. Manual muscle testing of the hip abductors should be conducted, range of motion (ROM) should be checked for contractures, and sensory tests of the stump to note problematic areas should be completed. For this deviation, as well as all others that follow, the PT should do a thorough job of assessing the deviation, but also should solicit the support of interdisciplinary team members as needed.

Abducted Gait Pattern

Appearance.—

This gait pattern is characterized by walking with a wide base of support, along with increased movement of the pelvis and trunk.\textsuperscript{11,20} The prosthetic limb is held away from the midline of the body at all times.\textsuperscript{11,20-22} Lateral trunk
bending is frequently seen with this deviation. This pattern is most easily observed from behind the patient during double limb support.20

Amputee Causes.—

A hip abduction contracture (assessment was described in the above section), habit pattern, and insecurity are factors that will contribute to this deviation.11,20-22 Other anatomic causes include an adductor roll, which usually results because of poor post-amputation care.11,21 The adductor roll is a physical obstruction to proper fit of the prosthesis and may cause pain that may be relieved by having a wide base for walking. Poor balance necessitating a wider base of support may also lead to an abducted gait pattern.25 The wider base of support will lead to increased confidence, in which case the circumducted gait may be done intentionally.

Prosthetic Causes.—

Prosthetic causes include the prosthesis being too long, excessive abduction built into the prosthesis, pressure on the pubic ramus caused by a high medial wall, and poor support of the lateral femur due to poor contour of the lateral socket wall.11,20-22 The amputee compensates for these prosthetic problems by being forced to abduct the limb. Pain may also be a factor in eliciting this gait deviation.

PT Intervention.—

Whenever anatomic or prosthetic causes elicit a gait deviation, such as a wide walking pattern, energy consumption increases.21 Extraneous movements
may be necessary to prevent pain, prevent falling by keeping the COG over the BOS, and to increase confidence during ambulation by widening the BOS.\textsuperscript{21} But, because of the extra energy consumption, attempts should be made to remedy the deviation.

Early intervention, such as shaping the residual limb, is necessary in the prevention of adductor rolls. A pre-prosthetic exercise program to promote patient confidence, eliminate habit patterns, increase balance control, and keep muscles balanced to prevent contractures is very important. Weight shifting activities in the seated position will help to improve balance and stimulates motor control. These same activities will begin to improve the patient’s confidence.\textsuperscript{25}

Circumducted Gait

Appearance.—

Like the two previous deviations, a circumducted gait pattern is best viewed from behind the patient.\textsuperscript{20} During swing phase of the prosthetic limb, the limb follows a laterally curved line.

Amputee Causes.—

An abduction contracture of the hip may contribute to this deviation.\textsuperscript{11,21,22} This, along with habit pattern, weakness, or poor utilization of the knee joint, will cause the patient to circumduct the prosthetic limb.\textsuperscript{11,20,21} The weak muscles that contribute to this are the hip adductors (adductor longus, magnus, and brevis; gracilis; and pectineus).\textsuperscript{11,23} When these muscles are weak, a muscle imbalance is created that leads to hip abduction and external rotation contractures,
especially in short above-knee stumps. Poor utilization of the knee joint may also cause this pattern. Ineffective use of knee flexion is often contributed to inadequate education of the mechanics of the particular knee joint. Education is needed to give the patient a good understanding of how the knee works and what the mechanism is to promote knee flexion.

Prosthetic Causes.——

The most common cause of circumducted gait is the prosthesis being too long. Two factors contribute to the manifestation of this pattern. The first is too much mass in the thigh or shank section. This adds extra length and may surpass the length of the sound limb. Secondly, the socket may be too large or too small. If it is too large, the socket will have poor fit and may piston during a gait cycle. During swing phase, the prosthesis will slip off the stump, in essence causing the limb to lengthen. If the socket is too small, the amputee will be unable to comfortably fit the stump into the socket. In this case, there will be extra space at the bottom of the socket and will basically cause the limb to be too long.

Other prosthetic causes include improper knee motion. If the knee extension aide, a device that promotes knee extension and resists knee flexion, is too taut, it will facilitate a circumducted gait. Functionally, the knee extension aide acts much like the quadriceps in limiting knee flexion and promoting knee extension. However, if the knee extension aide is maladjusted, it might keep
the knee extended throughout the beginning of swing phase, causing a person to circumduct to prevent dragging the foot.

If the knee friction is too great or too small, it may cause circumduction because it will not allow the knee to swing properly. Friction in a prosthetic knee is usually accomplished by a clamp around the knee bolt. If friction is too great, it makes it difficult to flex the knee resulting in a circumducted gait pattern. This will keep the foot from dragging on the floor or ground.

Another cause attributed to the knee joint is the manual knee lock, which keeps the knee extended throughout the gait cycle. With this type of knee component, it simulates a stiff knee gait. The typical response will be to circumduct the entire leg to keep from stubbing the foot on the floor.

The ankle component may also be a cause of circumduction if the ankle is set in too much plantarflexion. This will cause a longer overall length of the prosthesis, so the person with the amputation must circumduct to prevent toe drag.

PT Intervention.—

To assist the patient in avoiding this pattern, adequate education in the proper mechanics of the knee and ankle components is necessary. Of course, the prevention of hip contractures and proper muscle balance is undeniably as important. Because habit may contribute to this problem, the patient may have to work very hard to overcome the practice.
Medial Whip

Appearance.—

The best position for the PT to observe a medial whip is watching the patient as he walks away.\textsuperscript{20} The observer will note medial movement of the heel at heel off and the very beginning of swing phase.\textsuperscript{11,20}

Amputee Causes.—

Some sources, such as Edelstein,\textsuperscript{21} do not attribute whips to the amputee. Engstrom and Van de Ven\textsuperscript{11} do not contribute causes to the amputee during a stiff knee gait. However, when there is a free knee gait, Engstrom and Van de Ven\textsuperscript{11} will attribute this deviation to faulty walking habits due to stump pain or to problems in the remaining extremity. Kumar\textsuperscript{22} agrees that the only amputee cause is habit pattern. Berger\textsuperscript{20} states that weak and flabby musculature, along with poor socket design, allows free rotation around the femur which will allow a medial whip to occur.

Prosthetic Causes.—

A poor socket contour, or malrotation of the knee joint (internally rotated knee bolt) which in effect gives an externally rotated knee, may cause this deviation.\textsuperscript{11,20,22} Another prosthetic cause may be due to poor socket suspension and no auxiliary suspension.\textsuperscript{20} In this case, poorly conditioned muscles intensify the problem. Also, tightness of the socket on the stump may cause pressure during muscle activity and cause the prosthesis to rotate at heel off.\textsuperscript{20}
general, Engstrom and Van de Ven\textsuperscript{11} cite genu valgus and varus as causes for medial or lateral whips.

PT Intervention.—

Decreasing pain in the residual limb, strengthening flabby musculature, and preventing habit formation are all areas that the PT can influence. With this gait pattern, most deviations will be due to inadequate prosthetic design.

Lateral Whip

Appearance.—

In presentation, the lateral whip is similar to the medial whip in all respects except in that the heel moves laterally at heel off and not medially as in the medial whip. A lateral whip is best observed as the patient walks away from the therapist.\textsuperscript{20}

Amputee Causes.—

The anatomical or amputee causes of the lateral whip are the same as those noted for the medial whip. Most frequently, the source of this deviation is due to poor habits, when the prosthesis is not at fault.\textsuperscript{11}

Prosthetic Causes.—

Very similar reasons exist for lateral whip and medial whip. Malrotation of the knee unit is set by an externally rotated knee bolt which causes excessive internal rotation of the knee joint.\textsuperscript{11,20-22} Similarly, a poorly contoured prosthesis, a loose or tight fit, and incorrect alignment at toe off may cause this deviation.
Again, excessive valgus or varus at the knee contributes to medial or lateral whips.¹¹

PT Intervention.—

The PT’s primary concern is to prevent habit formation, reduce pain in the stump, and strengthen flabby muscles. The PT must know the components of the prosthesis so he/she can provide a differential diagnosis.

Rotation of the Foot on Heel Strike

Appearance.—

The name of this deviation as an explanation is complete, except to say that the rotation is usually outward.¹¹,²⁰-²² The best position to observe this deviation is from the front as the patient approaches the PT.²⁰

Amputee Causes.—

Typically, the muscles active at heel strike with the AKA are the hip extensors and medial rotators.¹¹ Excessive weakness of these muscles, which lead to poor stump control, cause this deviation. Kumar²² also lists vigorous extension of the hip at heel strike as a cause. The vigorous hip extension on the part of the amputee is an attempt to verify complete knee extension as a safety measure.

Prosthetic Causes.—

A hard heel cushion or plantarflexion bumper in the foot component may cause this deviation. A heel cushion (or heel wedge) is a part of a prosthetic foot that compresses at heel-strike and during early foot flat. If it is too hard, it
may cause a problem with knee instability. The patient may compensate by forcefully using the hip extensors to extend the knee, causing the foot to rotate. A plantarflexion bumper is a rubber pad located in the foot that controls the degree of plantarflexion that is mechanically allowed.

Another prosthetic cause includes too much toe out built into the prosthesis itself or a poorly fitting prosthesis. If it is either too loose or too tight, the amputee may exhibit this deviation.

The patient can be a good source of information. Subjective information comes from the patient, such as “I can feel my leg slipping in and out” or “it is squeezing my leg.” These are good indications that the problem lies within the prosthesis. On the other hand, if the manual muscle tests identify weak musculature or the patient is forcibly extending the hip at heel strike to ensure good contact, the problem is probably with the patient.

PT Intervention.—

Specifically strengthening the hip extensors and medial rotators of the hip will help to avoid this deviation. A manual muscle test will help to identify if these muscles are the cause of the problem.

Uneven Heel Rise Appearance.—

This pattern is best observed from the side as the patient walks back and forth in front of the PT. Its distinguishing characteristic, as the name implies, is
an uneven heel rise (usually with the prosthetic heel rising higher than the non-prosthetic heel) during the early part of swing phase when the knee flexes.\textsuperscript{11,20-22}

Amputee Causes.—

Engstrom and Van de Ven\textsuperscript{11} do not claim any amputee causes (or prosthetic causes) when the patient has a stiff knee gait. However, when there is a free knee gait, excessive hip flexion may cause too much flexion to occur in the prosthetic knee.\textsuperscript{11} In this case, the prosthetic heel will rise higher than the non-prosthetic heel. It can be assumed that weak hip flexion may be a cause for a low heel rise on the prosthetic side. Some degree of fear and insecurity may also elicit this deviation.\textsuperscript{20} The amputee will walk with little knee flexion, probably at a slower pace, and the result will be a low heel rise on the prosthetic side.

Prosthetic Causes.—

There are many prosthetic causes for this deviation. However, Engstrom and Van de Ven\textsuperscript{11} list prosthetic causes only when there is a free knee gait, not when there is a stiff knee gait.

If the prosthetic knee flexes with too much ease, due to decreased knee friction, this deviation will be evident because the shank will rise too high.\textsuperscript{11,20-22} Also, an insufficient extension aid will cause this problem during swing phase.\textsuperscript{11,20-22} In essence, the foot will stay high for too long a period of time because of the lack of assisted knee extension. Low heel rise will be seen when knee friction is set too high preventing easy movement or when the extension
aid is too strong which makes the knee extend too early and with excessive force at times.\textsuperscript{20}

**PT Intervention.**—

Proper gait training and education of the patient will help decrease the chance of having this deviation due to anatomical or amputee causes. Also, proper strengthening and re-education of the hip flexors will help to prevent this problem. Proper strengthening will let the patient have better control of the knee component. Once again, the PT should have a good working knowledge of the mechanics of the prosthetic knee joint, and prosthesis as a whole, to properly evaluate this gait deviation.

**Terminal Swing Impact**

**Appearance.**—

This deviation is best seen from the side of the patient. The time to note its existence is at the very end of swing phase.\textsuperscript{20} Often, an audible click can be heard when it occurs. It is caused by the shank moving forward too quickly during swing phase and the sudden stop that occurs at full extension, just before heel strike.\textsuperscript{11,20-22}

**Anatomic Causes.**—

A person with an AKA may fear knee buckling of their prosthesis. In an attempt to keep this from happening, the amputee will forcibly extend the knee joint to make sure it is in the proper position to support the body weight through stance phase.\textsuperscript{11,20,22} The forcible extension of the knee is exaggerated by hip
extension on the prosthesis.\textsuperscript{11,21,22} Berger\textsuperscript{20} states that this knee extension is facilitated by abrupt extension of the hip as the knee, nears full extension.

Other causes may be lack of confidence in ability to control fine movement of the prosthesis; therefore, movements are exaggerated.\textsuperscript{11} Habit, as with many of the deviations, may also be a cause.\textsuperscript{11}

Prosthetic Causes.—

Insufficient friction in the prosthetic knee allows the knee to swing freely with little resistance.\textsuperscript{11,20-22} This may allow rapid forward movement of the shin piece with the resultant audible sound when full knee extension is reached. This deviation may also be due to a knee extension aid that is too strong.\textsuperscript{11,20-22} It will pull the knee into extension with more force and give a strong terminal impact of the knee.

PT Intervention.—

To remedy this deviation, gait and prosthetic education is needed. The patient’s confidence and necessary knowledge must be balanced with the proper alignment and design of the prosthesis. It is important to note that this deviation frequently occurs along with a prosthetic step that is too long.\textsuperscript{11}

Foot Slap

Appearance.—

Foot slap is characterized by a rapid descent of the anterior portion of the prosthetic foot or rapid plantarflexion of the foot which is often heard as a slap
The best place for the observer to be is at the side of the patient, just after heel strike. 

Amputee Causes. —

Foot slap may occur when the patient wants to assure extension of the knee and has a coinciding action of forcibly driving the prosthetic foot down. This may also be a habit that the amputee must recognize in order to correct it.

Prosthetic Causes. —

If the plantarflexion bumper is too soft, it does not allow enough resistance to foot motion from initial contact to foot flat. Edelstein notes that this deviation is not dangerous for the patient, but does contribute to asymmetry of the gait pattern.

Another cause, related to either the amputee or the prosthesis, is wearing an incorrect shoe for the prosthetic foot. Changing heel heights, and possibly shoe length, will change the dynamics of how the foot component and shoe work together. The resulting interaction may cause a foot slap.

PT Intervention. —

To remedy this deviation, the PT must be certain the patient has an awareness of what he can consciously do during his gait pattern to decrease the occurrence of foot slap. That is, he should not forcibly extend the knee. Also, the patient should not drive the heel into the ground. Driving the heel into the ground magnifies the momentum of the foot and may contribute to the foot slap. It is important to remember that habit pattern can be very difficult to break.
Uneven Step Length

Appearance.—

First, it is important to know what is meant by a step. "The term step refers to the distance between successive positions of the sound foot and the prosthetic foot." This deviation is present when the length of the sound side step length is different than the prosthetic side step length. It may be measured at any point during the gait cycle, but is easiest to note by measuring successive periods of double limb support when viewed from the side.

Amputee Causes.—

The long prosthetic step is more common than the short prosthetic step. A hip flexion contracture may inhibit the patient from extending the hip during stance phase. This, coupled with weak hip and back extensors, will cause a decreased step length on the sound side due to less hip excursion on the stance (prosthetic) leg. Therefore, the prosthetic step will be longer than the sound limb step length.

Lack of confidence may also contribute to the prosthetic step being longer than the sound limb step. The amputee will have more confidence while he is in stance phase on the sound limb. Therefore, he might want to spend more time in sound limb stance. This results in a longer time for prosthetic limb swing phase, which causes a longer prosthetic limb step length.

Pain on the prosthetic side during stance will also warrant a decreased step length on the sound side because the amputee will want to quickly transfer
weight from the prosthesis to the sound limb. The short and rapid step with the non-prosthetic limb.

Again, habit may be a cause of long prosthetic step. The short prosthetic step may be due to either lack of confidence or pain, as stated by Engstrom and Van de Ven. Obviously, the patient’s attitude and concern toward the deviation will greatly influence if or how they will attempt to remedy this habit pattern.

Prosthetic Causes.—

For a prosthetic step that is too long, inadequate initial flexion in the socket may be a cause of the deviation. They will not be able to extend the hip as much due to the poor position of the stump in the socket. Once again, the decreased hip extension range allows a shorter step length on the sound limb.

Inadequate knee friction also contributes to this gait pattern. Edelstein states that “if friction is insufficient, the patient tends to hurl the prosthesis forward a greater distance than is taken with the sound limb.” He also claims that a loose or tight knee extension aid contributes to this deviation, while Berger only attributes a loose extension aid to be a cause of long prosthetic step length.

Faulty socket contour may cause pain that leads to a long prosthetic step. This is an attempt to relieve pain caused by pressure generated by bad design. Faulty socket contour can be a cause of both long and short prosthetic step lengths. Another cause of short prosthetic step length is the prosthesis
being aligned in too much socket flexion.\textsuperscript{11} The hip extensors will be powerful in this situation, but the alignment does not allow for full range of motion. The result of this is a small range of motion of the prosthetic hip. The prosthetic step will be shorter than the sound limb step length.

PT Intervention.—

The PT’s job here is to prevent hip flexion contractures by implementing a prone lying program early in the rehabilitation program.\textsuperscript{22} To determine if the patient has a hip flexion contracture, place the patient in supine, use the Thomas test position, and have the patient hold the sound limb by flexing that hip and knee as much as possible.\textsuperscript{22} Have the patient extend the hip as much as he can; the stump should be able to come in full contact with the supporting surface.\textsuperscript{22} In the standing position, the hip should be able to extend five degrees beyond the vertical.\textsuperscript{20} One of the best ways to correct this contracture is to do active ambulation exercises.\textsuperscript{22} Therefore, get the patient up and moving with the prosthesis as soon as possible.

Edelstein\textsuperscript{21} believes that unequal step length is very common and that no action needs to be taken to correct it unless the differences in length are marked.\textsuperscript{21} However, he does not state what margin of difference is unacceptable.
Lordosis

Appearance.—

Exaggerated lordosis may also be referenced as extensive trunk extension by some authors.\textsuperscript{22} This deviation occurs when the prosthetic limb is in stance phase and is best viewed if the PT observes from the side.\textsuperscript{20,22} The PT will see a marked increase in the lumbar lordosis during its presentation.\textsuperscript{11,20,22} This is done actively by the amputee.\textsuperscript{22}

Amputee Causes.—

The two most common amputee causes for this deviation are hip flexion contractures or weak hip extensors.\textsuperscript{11,20-22} With a hip flexion contracture, the hip flexor muscles pull the pelvis anterior and down. Because of the resulting lordosis, there is often a backward lean of the trunk to keep the body balanced.\textsuperscript{20}

Weak hip extensors can either be the sole cause of this deviation or can occur with the hip flexion contracture. In any event, the weakness allows anterior and downward movement of the pelvis resulting in a lordosis.\textsuperscript{11,20-22} The active lordosis may also be used to supplement the weak hip extensors as an effort to help stabilize the knee joint.

Weak abdominal muscles also can contribute to this gait pattern.\textsuperscript{11,20,22} Part of the normal activity of the abdominals is to help keep the pelvis in proper alignment. If part of this is lost, then there will be an anterior pelvic tilt with resultant increased lumbar lordosis.\textsuperscript{20} Engstrom and Van de Ven\textsuperscript{11} state that the
lordosis moves the center of gravity forward to improve balance, but according to Kumar, the movement of the trunk extension is to help keep good balance. According to Kumar, the movement of the trunk extension is to help keep good balance.

As with many gait deviations, bad habits also contribute to this deviation. Identifying this deviation early and preventing it from becoming a habit is the best way to avoid it.

Prosthetic Causes.

A poorly contoured posterior wall and brim may cause the pelvis to tilt anteriorly to prevent full weight bearing on the ischium. The poorly shaped socket may cause pain on the ischium. According to Berger, insufficient support from the anterior brim will also promote this pattern.

Another major cause may be the lack of adequate initial flexion built into the socket. It is important to remember that a certain amount of flexion in the socket is good because it allows the hip extensors to be placed on a slight amount of stretch. This will allow more power to be generated by the amputated muscles. To get that initial flexion, the amputee will tilt his pelvis anteriorly which decreases the distance between the pelvis and thigh and puts the posterior thigh musculature on stretch.

Engstrom and Van de Ven also blame this deviation on the prosthesis when the heel of the shoe on the prosthetic limb is too high. A high heel causes an anterior pelvic tilt and resultant lordosis.
PT Intervention.—

To correct this problem, it is important to have proper muscle balance between the hip flexors, back extensors, and abdominals. An over-powerment in any one group could facilitate this gait deviation. The prevention of hip flexion contractures is of paramount importance, and a good educational basis for gait training is invaluable.

Vaulting

Appearance.—

This deviation occurs when the patient actively and intentionally plantarflexes the non-amputated foot to allow the prosthetic limb to swing through without dragging on the ground. With this technique, little knee flexion is needed in the prosthetic knee. The time to observe vaulting is during swing phase of the amputated limb and may be viewed from the side or from behind the patient.\textsuperscript{11,20-22}

Amputee Causes.—

This deviation may result if the patient fears catching or stubbing the toe of the prosthetic foot.\textsuperscript{11,22} Also, if the stump is very short or has inadequate muscular control, the patient may resort to this behavior.\textsuperscript{11} A combination amputee/prosthetic cause is when the patient walks too quickly for the design of the knee component. With a friction knee, the patient is able to walk comfortably at one speed. Deviations from that speed will cause the patient to compensate. If the patient walks too quickly for the set friction of the knee, it will take longer
for the knee to resume its extended position, and the person will have to vault to prevent dragging the foot on the ground. Like many other deviations, pain and habit pattern may contribute to this faulty pattern. Prosthetic Causes.—

There are many prosthetic elements that may lead to this deviation. The prosthesis may have too much length during crucial parts of the gait cycle. This may be due to inadequate knee flexion, too much knee friction, an overaggressive knee extension aid, or a manually locking knee.

If the prosthesis pistons on the stump because it has a poor fit or because of an inadequate support system, the PT will also observe this pattern. Poor fit may also cause the ischial tuberosity to rest higher on the brim when the socket is not large enough. This adds overall length to the prosthesis and may cause vaulting. It may be deduced that if the amputee has gained an excessive amount of weight and the stump gains volume, the prosthesis may not fit correctly and the patient may compensate by vaulting.

Another prosthetic cause is incorrect positioning of the foot in too much plantarflexion. In order to clear the prosthetic foot, the amputee learns to compensate by vaulting. Lastly, Kumar cites “excessive stability in alignment of prosthesis” as a prosthetic cause of vaulting. This would make it difficult to flex the knee, and the patient vaults to prevent dragging the prosthetic foot.
The PT can assist the patient in developing adequate muscular control, especially hip flexion that is needed to create flexion of the knee. However, the other surrounding hip musculature should not be neglected. Building confidence and avoiding habit formation are also aspects of rehabilitation that require attention.
CHAPTER IV

PROSTHETIC GAIT ANALYSIS

Assessing the patient's gait pattern is a crucial part of the rehabilitation process. Knowledge and experience combine to create a skilled therapist. Experience comes with longevity in the field of physical therapy and knowledge comes from understanding and appreciating the biomechanics of an amputee gait pattern. The physical therapist (PT) must know what to observe when assessing gait. This chapter will address specific areas of concern and will give an example of a simple evaluation form.

According to Radcliffe,\textsuperscript{26} the essential focus of fitting a patient with a prosthesis is "to restore to the amputee the ability to perform everyday activities in an easy, natural, and comfortable manner."\textsuperscript{(p35)} To accomplish this, the components of comfort, function, and appearance (cosmetically and during use) must be satisfied.\textsuperscript{26} A thorough evaluation covers these dimensions resulting in a plan to remediate gait deviations.

As with any evaluation, subjective information and history collection are crucial to holistic treatment of the patient. The PT must collect information regarding history, past medical history, family history, medications, and past hospitalizations. It is also important to know the patient's occupation, hobbies,
and pre-morbid lifestyle activities. The PT must know the patient’s expectations to help facilitate realistic patient goals.

Objectively, the focus of the evaluation will change depending on the patient’s status. Initially, range of motion, strength, and residual limb statistics (such as shape, length, circumference, and vascularity) will be of primary concern. Sensation, proprioception, and kinesthesia are important for future mobility and gait activities. Likewise, neurologic status will be monitored for pain and neuropathies. Knowing the patient's cognitive and emotional well-being is important for total patient care. Skin integrity is essential for prosthetic fitting. The scar must be well healed, non-adherent, and pliable. The patient’s functional abilities without the prosthesis are important to address during therapy and when the patient is discharged. Vital statistics, bed mobility, and wheelchair skills are major factors in determining functional abilities without the prosthesis.

When the prosthesis is available, the PT will want to know what motions the components of the prosthesis will allow. The prosthetist will be a great resource in explaining the intricacies of each prosthesis. Identifying the socket design, suspension system, knee components, ankle/foot mechanism, and procedure for application are essential to a thorough assessment. Each component can be explained in detail during the evaluation.

Prosthetic training begins with patient education regarding donning and doffing the prosthesis, wearing schedules, and identifying pressure areas. Pre-gait activities involving balance and coordination are absolutes in eventually
developing a good gait pattern. A thorough gait analysis is probably the most challenging part of the evaluation. Each body segment must be analyzed for deviation. A thorough understanding of the normal gait pattern is essential.

During the patient's gait cycle, swing and stance phases must be reviewed and assessment of the uninvolved limb must be included. The patient's history may reveal potential problems in the intact limb. Therefore, precautions must be taken to avoid abuse and to promote good condition of the non-amputated limb.

An organized, methodical approach is best for identifying problematic areas. Once a problem is identified, a more specific assessment can be done. The PT may start by evaluating one side of the body, observing one joint at a time, and progressing either proximal to distal or vice versa. Different planes of observation will reveal different deviations. Changing from a posterior to anterior view to a lateral view is recommended. The PT may also break the gait cycle observations into swing and stance phase elements.

**Posterior View**

When viewing the patient from behind, the proximal areas (trunk motion) will be evaluated first, progressing to the distal areas (foot/ankle). First, the PT may note **lateral trunk bending** during the time from heel-strike to midstance. Then, trunk and pelvis displacement, as with an **abducted gait** may be observed during double limb support. Next, a **circumducted gait** will be evident during swing phase. Continuing to move distally, **medial** and **lateral** whips may
occur with movement of the heel at toe-off. Lastly, rotation of the foot at heel-strike may be seen from behind as the patient walks away or from the front as the patient approaches the observer.²⁰

Side View

Again, observation will be explained by examining the proximal then the distal areas. Vaulting may be noted if the entire body motion lurches forward during swing phase of the prosthesis. It can be seen from the side or from behind the patient. Throughout stance phase, excessive lordosis may be evident. Uneven step length can be observed from the lateral view. Comparing the step lengths of each limb is the easiest way to identify this deviation.

At the knee, terminal swing impact will often give an audible sound during swing phase knee extension just prior to heel strike. The uneven heel rise may be noticed during the beginning portion of swing phase. Comparing from the side is the most efficient way to note differences between the heel rise levels. Finally, foot slap will occur just after heel strike with an audible slap of the foot when the forefoot hits the floor.²⁰

See Fig 1 for an evaluation form that covers the basic entities of an amputee gait evaluation. It lists the gait deviations that are addressed in this literature review. Each deviation is grouped according to its occurrence in the gait cycle.
AKA GAIT ANALYSIS

Name: ______________________ DOB: __________ Date: __________

Dx: ______________________ Date of incident/surgery: __________ Occupation: __________

Physician: ____________________________ Prosthetist: __________

Amputated limb: L R Length of residual limb: __________________________

Type of: socket _______ knee _______ ankle/foot _______

Suspension: _______ Assistive device: _______ Amb. Distance: _______

Stance Phase

Initial contact: foot slap Y N Cause: _______

rotation of the foot at heel-strike Y N Cause: _______

lateral trunk bending L R Cause: _______

excessive lordosis Y N Cause: _______

Midstance: lateral trunk bending L R Cause: _______

excessive lordosis Y N Cause: _______

Push-off: medial whip Y N Cause: _______

lateral whip Y N Cause: _______

excessive lordosis Y N Cause: _______

Swing Phase

uneven heel rise Y N Cause: _______

vaulting Y N Cause: _______

circumduction Y N Cause: _______

terminal swing impact Y N Cause: _______

Other

Abducted gait during double limb support Y N Cause: _______

Uneven step length Y N Cause: _______

Step length: L>R R>L R=L 

Step time: L: __________ R: __________

Stride time: L: __________ R: __________

Cadence (steps per unit time): _______

Speed: slow normal fast Width of walking base: _______

Degree of: L R Toe in _______ L R Toe out _______

Comments: ___________________________________________

_________________________________________________________________

_________________________________________________________________

_________________________________________________________________

_________________________________________________________________

PT signature/date: ___________________________________________________________________
CHAPTER V

CONCLUSION

Gait analysis to identify gait deviations is crucial when the goal is enhancement of the gait pattern of a person who has had an above-knee amputation (AKA). Regardless of the cause of the injury, each patient will face the same prosthetic decisions and each will have to psychologically cope with the changes in lifestyle. Pre-morbid health, age, and motivation may all impact the degree to which a person rehabilitates. However, gait deviations can occur even with the healthiest and most motivated patients. Recognizing, changing, and/or avoiding the development of deviations is the responsibility of all members of the interdisciplinary team.

Prosthetic problems are the primary concern of the prosthetist. Proper fabrication, fitting, and alignment are ultimately decided by the prosthetist. He or she will be the team member most aware of current costs and new advances in the field. The prosthetist will be intimately involved with ordering the correct options on the prosthesis. Socket type, knee component, and ankle/foot design will reflect the lifestyle and expectations of the patient and family. All aspects of the patient’s life will determine the specifications of the prosthesis. Choosing the
appropriate combination of components is determined by the patient, physical therapist (PT), prosthetist, and physician.

Gait deviations caused by prosthetic problems may not be immediately apparent. Gait training is necessary to teach the patient how to control the prosthesis. During that time, the patient will adjust to the feeling of the socket on his or her stump and will learn the intricacies of managing the prosthesis. Time is also crucial for the rehabilitation of weak musculature. Muscle may be weak due to trauma, disuse, or because of general debility of the patient. Confidence in using the prosthesis will also be developed throughout the rehabilitation of the patient.

PTs must be well versed in recognizing prosthetic causes of gait deviations after the patient has had time to adjust. Incorrect analysis may result in unnecessary modifications. These requests, if unwarranted, will most likely be costly, time consuming, and ineffective. The skill of correctly analyzing gait deviations is important at all times. This is especially important in rural communities where the primary health professional may be the PT.

Rural areas are often isolated from access to complete medical care. This means that all health professionals are not readily available. Unavailable access to a prosthetic clinic delineates responsibility to the PT for identifying problematic areas. How effectively the PT distinguishes between amputee or prosthetic causes of deviations has a strong influence on the lives of the patients. Travel time is often inconvenient, costly, and physically taxing. Out-of-
town appointments often significantly impact the patient’s family because the family will drive the patient to the appointment. Effectively managing the care of the patient will help to avoid these inconveniences.

PTs have a direct impact on correcting gait deviations due to anatomic or amputee causes. Maintaining or obtaining adequate hip range of motion (ROM) is a major focus during rehabilitation. Implementing stretching programs and teaching proper positioning early in the patient’s progression will help ensure adequate ROM. Avoiding contracture formation is particularly important. There is a tendency to develop contractures with a very short stump because of the large muscle imbalances that are present. A hip flexion contracture that is present with a longer stump will be accentuated by the length of the stump. Modifying the socket to accommodate for contractures is more difficult with longer stumps. Responsibility of maintaining adequate ROM must be given to the patient.

Strong muscles are also necessary to avoid developing gait deviations. Strengthening may begin with isometric contractions, move to active ROM, then advance to progressive resistive exercises as the patient is able to tolerate. Muscle weaknesses can be identified during manual muscle testing. Appropriate strengthening programs can then be developed to obtain functional strength of hip and trunk musculature.

Proper strength of the musculature is foremost in importance when enhancing the gait pattern. Hip abductor strength is important in preventing hip
drop. Good stump control, especially at heel strike, is promoted by strong hip extensors and medial rotators. Muscular control and strength of the hip flexors is necessary to properly gauge knee flexion and heel rise. Equal step length will be fostered by strong hip and back extensors. Strong hip and back extensors will also help prevent an excessive lumbar lordosis. Conditioned abdominal musculature will also help avoid an excessive lumbar lordosis. Functional activities, such as walking, are very appropriate for developing balanced muscles as well as maintaining normal ROM. Manual cues may be needed to help the patient identify the appropriate muscles movements during the gait cycle.

Pain management education is also an area the physical therapist may need to address. Massage and hot or cold modalities are strategies the patient can use to relieve pain. Monitoring skin integrity is also necessary. If skin breakdown occurs due to poor prosthetic fit or excessive rubbing, it may cause pain which may lead to gait deviations. Pain will delay progress of rehabilitation, frustrate the patient, and may lead to poor rapport between the patient and the team. Pain may debilitate even the most compliant patient and must be addressed seriously if it exists.

Another strong role of the PT is to educate patients regarding management of the prosthesis during ambulation. Teaching the mechanics of the knee and ankle/foot mechanisms is critical for proper operation of the prosthesis. Initially, the PT and prosthetist may do a co-treatment, but it is the
PT who will spend hours working with the patient. Early education may curtail bad habits and prevent deviations from forming.

PTs influence the gait pattern of people with AKAs by accurately identifying the deviation. This is the first step in enhancing the gait pattern. Localizing the area of deviation, whether it is at the hip, back, knee, or ankle, is necessary for identification and communication. Recognizing the cause, whether it is a prosthetic or amputee problem, is the second step. Knowing the location of the deviation is of little importance unless the actual cause of the deviation is known. The third step is taking the right course of action to get the problem fixed. PTs must know not only how to treat the musculoskeletal concerns, but also they must know when to refer to another health care professional. Some causes of amputee gait deviations are beyond the scope of practice of PTs, which makes appropriate referral essential.

An adept therapist will be an asset to the interdisciplinary team. He or she efficiently utilizes rehabilitation time with the patient and serves the amputee population in a cost-effective manner. The PT will spend more time with the patient than most other health care professionals and is the person most likely to recognize gait deviations. PTs are the professionals with the skills and capabilities to work with the patient to enhance gait patterns. Helping the patient attain functional and efficient ambulation is a primary concern of the PT. It is important to remember, however, that complete patient care is best served by the interdisciplinary team approach.
REFERENCES


