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PARTICIPATION OF THE LOWER EXTREMITY AMPUTEE IN SPORTS AND RECREATION

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by

Pamela A. Helfrich
Bachelor of Science in Physical Therapy
University of North Dakota, 1996

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
1997

This Independent Study, submitted by Pamela A. Helfrich 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.

(Faculty Preceptor)

(Graduate School Advisor)

(Chairperson, Physical Therapy)

PERMISSION

Title Participation of the Lower Extremity Amputee in Sports and Recreation

Department Physical Therapy

Degree Master of Physical Therapy

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Signature Pamela A. Helfrich

Date 12 / 20 / 96

TABLE OF CONTENTS

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ABSTRACT

Due to the increasing emphasis on fitness in our society, there has appeared a significant population of young and/or active lower extremity amputees who have a desire to participate in sports and recreational activities. The physical benefits of participation in sports and recreational activities may be obvious; however, there are many psychological and psycho-social benefits as well. In order to achieve a successful rehabilitation outcome it is imperative for the health care team to be well informed regarding sports and recreational options available for lower extremity amputees. Along with being knowledgeable in these areas, the health care professional also must possess the ability to assist the amputee in setting realistic goals.

The purpose of this literature review is to demonstrate to both the health care professional and the lower extremity amputee along with society, that lower extremity amputees can lead an active lifestyle comparable to that of the non-disabled population. This paper will also act as a resource guide and reference regarding the rehabilitation management of this particular active group of lower extremity amputees. Topics that will be explored in this review include psychological and physical benefits, biomechanics, prosthetic advances, sport adaptations and a listing of resources for both the health care professional and the amputee.

CHAPTER 1

INTRODUCTION

Full realization of the implications related to loss of physical function and uncertainty regarding the future lifestyle upsets and deeply concerns amputee patients and their families.[1] It has been clinically demonstrated that amputation of an extremity has a significant impact on an individual's level of independence. This dramatic change in status from independence to dependence has a significant affect on life activities. The person's ability to meet personal responsibilities involving work, daily activities, social interaction and personal needs is particularly affected with loss of a lower extremity. Most people with amputations do not resume a completely normal lifestyle. Some degree of initial dependency is viewed as an expected outcome by amputees and health care providers. This state of dependency conflicts with people's drive for self-direction and self-reliance, especially if the amputation occurs after the person has lived independently.[2,3]

Learning how to walk with a prosthesis is only the beginning of the rehabilitation process. Living with a prosthesis requires making some changes in lifestyle and daily habits. The goal of rehabilitation is to return the amputee to a full active lifestyle by achieving the highest possible level of independence physically, socially and emotionally. In order to achieve independence once again, the amputee must physically relearn activities of daily living that were at one time automatic. By relearning they must incorporate the use of their new prosthetic limb.[3,4,5] For some, rehabilitation will include vigorous vocational and recreational activities; learning how to walk is merely the beginning of learning to run.[1,3]

Amputations occur or are performed on patients in all walks of life, at all age levels, and for a variety of reasons. Patients range from the congenital limb deficient child to elective amputation in the aging patient with diabetic gangrene or peripheral vascular disease (PVD).[6] Amputations performed in different age groups show a characteristic pattern of distribution. The incidence in the first year of life is higher, which can be attributed to congenital limb deficiencies. From age 1 to 15, the incidence remains fairly constant with a gradual rise up to age 54 due to increased exposure to work-related trauma and highway traffic accidents. From age 55 and up, there is a sharp increase due to PVD.[1,4] The most common cause of amputation is PVD secondary to diabetes mellitus followed by trauma, congenital deformity, malignancy, chronic infection and cosmesis. Trauma plays an increasingly important role as the cause of amputations in young, vigorous and otherwise healthy individuals.[1,2,6]

In 1971 the committee on Prosthetic Research and Developments of the National Academy of Sciences estimated that 47,300 amputations were performed annually in North America; 85% were amputations of the lower extremity.[2] Due to the large number of lower extremity amputations, the scope of this paper is limited to lower extremity amputees and their ability to actively participate in sports and recreational activities. In the last decade, society has become increasingly active in activities involving fitness, leisure and sports. Most amputees also desire to actively pursue these interests. A full and satisfying lifestyle includes the ability to take part in avocational activities to improve physical fitness, sociability, self-confidence and personal enjoyment. For some healthy and physically fit amputees, rehabilitation has not been successfully completed until they are able to enjoy and possibly compete in activities involving fitness, sports and leisure.[3]

Kegel and associates surveyed 100 unilateral amputees to determine their involvement in sports. Sixty percent of the respondents were active in recreational activities ranging from fishing to jogging. Level of amputation did not play a major role in the amputees decision to be involved in sports or recreational activities. Age was found to be more of an influential factor for amputees when given the choice of whether or not to participate. Only 28% of the unilateral amputees surveyed believed that their prosthetist was aware of the components currently available for sports. Several amputees had even designed their own adaptations. In order to achieve successful rehabilitation outcomes the physical therapist, prosthetist and other health care professionals need to be knowledgeable regarding the latest advancements in prosthetics and adaptive equipment.[3]

It is estimated that 20,000 amputees currently participate actively in various sports activities, with more than 5,000 in organized competition.[7] Avocational issues are often overlooked as being an issue for the amputee. If the amputee is going to successfully complete their rehabilitation, then avocational activities will play a large role in maintaining both mental and physical health. Rehabilitation management of the amputee requires an understanding of the multidimensional effects of the amputation on the individual and their environment. Expertise in each area of rehabilitation also contributes to full functional restoration of the amputee.[1]

The coexistence of expertise in amputation rehabilitation and sports medicine is seldom found in one physical therapist (PT). To function optimally in the hospital or clinic, the PT must keep abreast of the latest prosthetic developments and training procedures. The therapist specializing in amputation rehabilitation will provide the best treatment and advice by working closely with experts in specific fields (e.g. sports PT's, trainers, prosthetists) to gain insight into the individualized physical and prosthetic requirements necessary for the sport in which the amputee chooses to participate. It follows that the PT must also maintain continued interest in the prosthetic literature, attend courses to acquire new information, and work closely with the amputee and the members of the rehabilitation team.[1,2]

The purpose of this literature review is to demonstrate to the health care professional, the amputee, and society, that lower extremity amputees can lead an active lifestyle comparable to that of the non-disabled population. It will also act as a resource and reference guide for the health care professional as well as the lower extremity amputee containing information regarding the rehabilitation goals and management, biomechanics, prosthetic advancements, sport adaptations and a resource listing of organizations and support groups.

CHAPTER 2

PHYSICAL AND PSYCHOLOGICAL BENEFITS

Nearly every amputee feels quite depressed immediately after the surgery. This feeling is usually quickly replaced by the will to resume an active life.[8] From a psychological standpoint it is important to identify types of activities promoting self-preservation, social acceptance, intimacy, self-expression and achievement. Attainment of these enhances self-esteem and self-fulfillment, the basics to developing a positive self-concept. Development of a positive self-concept allows the individual to recognize their capabilities and find the personal motivation necessary to achieve independent functioning.[4]

Introduction of Sports into Rehabilitation

For healthy and physically fit amputees, rehabilitation will not be complete until they can enjoy or even compete in sports and recreational activities. Depending on the type of sport, they may participate with or without their prosthesis. Swimming is an example in which the prosthesis is not worn due to competition regulations. Prosthetic adaptations may be required and occasionally an additional prosthesis will be designed and fabricated to meet specific functional needs of a particular sport.[4]

It should be remembered that the psychological aspects of picking up the pieces of life again will take differing amounts of time for each individual. The physical therapy approach to increasing activity should be very sensitive to each individual's stage of acceptance avoiding "too much, too soon." Actually going out of the house for the first time can be daunting. Participation in other activities or sports is only possible when the individual has gained confidence in their own abilities.[9]

While the value of active recreation in promoting cardiopulmonary health is generally accepted, it should be noted that the psychological and social benefits are at least as important. It has also been stated that including the disabled in sports and recreational activities serves a fundamental role in demonstrating to both a skeptical society and to disabled individuals, their ability to achieve recognition and personal success.[10]

Participation in sports has given many disabled people a new sense of achievement. Taking part in some form of regular leisure activity provides important social contact and the thrill of competition. The challenge of sport may be the only personal challenge experienced by some individuals.[9]

It is important for persons with amputations who are capable and desire to participate in sports, to be provided with every opportunity, including prosthetics and adaptive equipment. Not only for the physical benefits, but for the many psychological benefits as well. Sports participation for the amputee facilitates improvement in attitudes toward physical activity and life by providing opportunities for self-determination and choice. Being given the opportunity to participate in sports and recreational activities gives the amputee a renewed self-concept and builds the confidence and self-esteem once shattered by the amputation.[3,7,11,12]

History of Amputee Sport Participation

Sporting opportunities for individuals with physical disabilities developed after World War II, when a significant population of disabled veterans valuing sports participation appeared. In 1960 the post war sports movement grew into the Paralympics. Currently 400 local programs and teams throughout the country offer opportunities for disabled children and recreational athletes.[7] During the Vietnam War, the United States Army developed a program to teach amputees how to ski. As the program developed, both unilateral and bilateral lower extremity amputees learned to ski using one ski and two outriggers. The sports program expanded to include horseback riding, swimming and even skydiving.[3] With the 80's came the fitness boom which introduced new innovations for skiing and swimming.[10]

Psychological Reactions

Psychological reactions of the amputee may vary in intensity from one individual to the next based on coping mechanisms and support systems. The following are examples of psychological reactions that may be encountered by the health care professional when treating an amputee: grief over loss, loss of self-esteem, apprehension about interpersonal relationships, worry regarding the future, denial of existence of problems, and finally, acceptance of the amputation as a life challenge that must be met.[2,3,4]

To effectively rehabilitate a person who has undergone an amputation, it is important to understand his or her emotional reactions to the amputation. Reactions may vary with age, sex, type of amputation, established coping mechanisms and support groups.[1] Long term adjustment to amputation depends to a great extent on the individual's basic personality structure, degree of emotional maturity, sense of accomplishment and place in the family, community and world. Individual adjustment is also greatly influenced by the reaction of significant others to the amputation, and the amputee's perception of that reaction.[3]

Rehabilitation Goals

The objectives for most amputees should be to enjoy the sport, understanding that the disability may affect their ability to compete with able-bodied persons.[1] In writing functional rehabilitation goals the patient's personal needs should be taken into consideration along with physical and mental status, level of amputation, and premorbid lifestyle. Ideally the amputee is to have the ability to ambulate independently in all types of situations without external support and with as low an energy expenditure as possible.[3]

In starting an advanced rehabilitation program the physical therapist, as well as the amputee, must be realistic with advice and understand the involved limitations. It will take time before advanced functioning necessary for sports will be achieved. Time possibly up to one year may be needed to attain the necessary skills and to acquire the proper prosthesis to complement the activity.[9]

The following must be taken into consideration before beginning any sporting activity: well-healed and toughened stump, good general muscle strength and good stamina. If the amputee was proficient in a particular sport prior to the amputation, it may be easier to return to that sport rather than learn a new activity. However, returning to such an activity can be distressing for some people, as they are unable to achieve the same level of performance. Sometimes finding a new challenge is more effective. [9]

Sports are to be enjoyed. Individuals with amputations should not be pressured into participating, even if they were active in specific or related activities prior to the amputation. It is important that the individual alone possess the motivation and determination to try and to participate. If it is within their capabilities to participate or compete, they will find a way to succeed. In order for this particular group of lower extremity amputees to successfully complete the rehabilitation process, the PT along with members of the rehabilitation team must be aware of the current literature and prosthetic advancements in the areas of sports recreation. The health care team should also know of resources available to which they may direct the amputee patient.[9]

CHAPTER 3

BIOMECHANICS

Amputation of the lower extremity results in loss of a major part of the locomotive system. Compensations must be made for the loss of structure, soft tissue, proprioceptive feedback, and muscle power necessary for locomotion. Gait for the amputee becomes possible through utilization of remaining musculature and successful adaptation to body kinetics as well as prosthetic devices and alignment.[13] Adaptations must be made to compensate for unequal body weight distribution, loss of coordination and proprioception affecting balance, and functional loss of the foot, ankle, knee, hip or all joints in the lower extremity.[14] In order to better understand the amputee gait cycle, chapter 3 will first provide a review of the normal gait cycle followed by an overview of the adaptations made to compensate for loss of structure in the amputee gait cycle.

Normal Gait Cycle

The gait cycle can be defined as a sequence of events in the lower extremity beginning with heel contact of one foot and ending when that same foot reaches heel contact again. Sixty percent of the gait cycle is spent in stance phase, while 40% is spent in swing phase.[1] Stance occurs from the moment the heel of the prosthesis contacts the walking surface until toe off of the same foot. Swing phase takes place from the time the toe leaves the ground until the heel contacts the walking surface once again.[13,15] While one limb is in stance phase, the contralateral limb will be in swing phase.[1]

In the transition between phases there is a period of double support in which both feet simultaneously come into contact with the ambulation surface. As walking speed increases, the amount of time spent in double limb support decreases, and is completely absent in running. The gait cycle begins at 0% with heel strike and progresses into foot flat. Heel rise occurs at 10% of the gait cycle followed by knee flexion in preparation for forward acceleration of the leg at 45% of the gait cycle. Completing the stance phase at 60% is push off which occurs when the toes leave the ambulation surface. Swing phase consists of hip and knee flexion and dorsiflexion at the ankle in order for the foot to achieve clearance of the ground. The gait cycle is 100% complete with heel strike of the opposite foot.[1]

Stance Phase

The stance phase of the gait cycle begins with heel contact or heel strike. During heel strike the hip is flexed approximately 20 degrees, the knee is in full extension and the ankle is in neutral. Following heel strike the knee rapidly flexes allowing the remainder of the foot to come in contact with the ground, known as foot flat. Midstance occurs when the body weight rolls over the foot loading the limb. The hip and knee are in extension and the forefoot begins bearing an increasing amount of body weight. This is followed by heel rise in which hip flexion occurs accelerating the femur forward. Push off or toe off ends the stance phase when the toes leave the ground. During push off the ankle is plantarflexed to provide power for this forward movement.[15]

Swing Phase

During the swing phase of the gait cycle the foot and leg must be brought forward to prepare for the next heel strike. Early in this phase the hip and knee are flexed, initiating acceleration of the extremity forward in swing. The ankle is in a position of dorsiflexion to provide toe clearance of the ground. Eccentric contractions of the hip extensors and knee flexors are primarily responsible for deceleration of the limb late in swing. Adequate muscle strength is necessary to lift and hold the lower extremity up against the force of gravity, allowing the foot to clear the ground and be optimally placed for heel contact.[15,16]

Center of Gravity

Our center of gravity (COG) lies in the midline slightly anterior to the second sacral vertebrae at a distance 55% of the total height from the ground. Within the normal gait cycle the COG is rhythmically displaced up and down approximately two inches in the vertical plane following the smooth path of a sinusoidal curve. Lateral displacement of the COG also occurs in the horizontal plane following a path similar to the sinusoidal curve of the vertical displacement.[1,16]

Amputee Gait Cycle

Stance Phase

Below-knee amputee runners experience a reduction in the total mechanical work performed by the prosthetic limb during stance phase evidenced by both a reduction in energy generation and absorption. This reduction is primarily a result of decreased power output on the prosthetic limb by the concentric and eccentric knee extensors and the prosthetic foot/ankle mechanism. The reduction of prosthetic limb muscle work is the result of two major factors. First, the passive nature of the prosthetic foot or ankle decreases mechanical work by absorbing and generating energy through foam elements in the prosthesis. Secondly, reducing mechanical work at the knee also reduces the total mechanical work done by the prosthetic limb.[17]

Hip musculature of the prosthetic limb is two to three times greater than that of the sound limb. Normally, the knee does four to five times more mechanical work than the hip; however, the hip musculature of the prosthetic limb does approximately one and one half times more work than the knee musculature.[17] The prosthetic limb's hip extensor moment at the beginning of stance is greater in both duration and magnitude than the intact limb. Hip extensors appear to provide compensation for the amputation by assisting the quadriceps to control residual knee function following heel strike and helping with knee extension in the middle half of stance by helping to rotate the thigh backward with respect to the hip.[18] Therefore, the hip extensors become the major source of energy generation and absorption for the lower extremity amputee. This suggests that rehabilitation programs for amputees interested in participating in running sports should focus on the hip musculature of the prosthetic limb.[17]

In addition to providing a relatively normal gait to minimize energy expenditure, the main purpose of the prosthesis in stance is to provide a stable base of support while allowing progressive ambulation. Stability can be provided in three ways: 1.) proper prosthetic alignment, 2.) through a knee device which can provide a flexion resisting moment during axial loading, and 3.) through a polycentric knee mechanism which alters the thigh and shank position center of rotation with extension of the limb, which, in turn, reduces the moment at the hip. Prosthetic knee stability can be provided at the cost of increased effort necessary to initiate knee flexion. A compromise must be reached to permit both stability and sufficient knee flexion without substantially increasing the energy expenditure required by the amputee.[13]

Swing Phase

Mechanical work done by the intact swing phase limb musculature is much greater than normal. Increases in muscle work were found in concentric hip extensors and eccentric knee flexors at the end of the swing phase.[17]

During the swing phase of gait, the prosthetic knee must possess the ability to limit the amount of heel rise in toe off. The prosthetic component must also prevent forceful terminal knee extension of the prosthesis at the end of swing phase before heel contact.[13]

Biomechanics of the Lower Extremity Amputee

Above-Knee Amputee Gait

The trochanteric-knee-ankle (TKA) line is a vertical plumb line referenced in the alignment of above-knee prostheses. Prosthetic knee stability in stance phase is determined by whether the TKA line falls in front of or behind the center of the prosthetic knee. Increased stability is provided by placing the TKA line in front of the prosthetic knee center, also known as negative TKA alignment. When the TKA line is placed in front of the knee's center, an overall extension moment is produced when the extended prosthetic knee is weighted in stance phase, and a greater hip flexion moment is necessary to initiate knee flexion in swing phase.[19]

If the TKA line is placed behind the knee's center, the prosthetic knee becomes less stable with a tendency to buckle under the gravitational weight bearing moment. With the TKA line behind, the knee is assumed to be free flexing, not requiring the production of a hip extension moment by the amputee in order to nullify the gravitational knee flexion moment.[19]

Above-knee amputees control the knee through actions at the hip joint. Knee flexion, which occurs early in normal stance allowing the foot to be flat on the ground, shouldn't be possible in the gait cycle of an above knee amputee. Hip extension is used to maintain the prosthetic knee in full extension throughout stance. The above-knee amputee takes short steps, keeping their weight forward to avoid creating a significant flexion moment. "Pelvic progression" is the way in which an above-knee amputee must thrust their pelvis forward in order to bring the COG forward over the prosthesis. When the hip flexes early during swing phase, the shank lags behind due to inertia. The amputee must acquire the ability to time the stride allowing passive return of the prosthetic knee to extension to coincide with heel contact.[15]

Above-knee amputees present with a stiff unnatural gait, occurring because the natural tibia and fibula axial rotation in relation to the knee and foot is absent. The need for prolonged, active hip extension to maintain prosthetic stability in stance also contributes to the stiff gait pattern of the above-knee amputee.[14]

Biomechanical Adaptations for Running

Criteria for running include the ability to produce alternating periods of single limb support and to complete the non-support or "flight" phase from both feet. The intact leg is responsible for 54% of the amputee running stride length while 46% of the length is associated with the prosthetic limb. Normally, running consists of an increase in both stride length and rate as speed increases from a jog to near maximum speed; however, amputee runners are more dependent on higher stride rates to attain faster running speeds. This may possibly reflect hesitancy by the amputee to lengthen the stride beyond what they consider secure limits.[20]

The biomechanics of amputee running gait have received very limited study. When analyzing the kinematic differences between the intact and prosthetic lower extremities during running, it was found that amputees use different strategies to increase running speed and that the prosthetic limb stance phase knee kinematics are characterized by prolonged and excessive knee extension. It has also been shown that there is a reduction in the stance phase knee extension moment and an increase in the hip extension moment during prosthetic stance phase.[17]

The support pattern involved in running differs from that of walking. More time is spent in the swing phase (70%) of the gait cycle rather than the stance phase (30%) compared to the 40% swing and 60% stance in walking. Also, when running there is no period of double limb support. During running, step length, joint angulation and axial rotation increase to aid in the following functions: 1.) cushioning of ground impact, 2.) helping to facilitate a smooth, rhythmic running pattern, 3.) decreasing the vertical displacement of the COG, resulting in increased energy efficiency, 4.) providing a balance between muscle length-tension and force-velocity, which assists in forward acceleration of the body during push off, and 5.) increasing momentum.[14]

Above-Knee Running Gait

Amputees fitted with standard above knee prostheses are unable to acquire a normal running pattern for the following reason. Forceful prosthetic heel contact occurs without support of the sound leg, and the ground reaction force responds with equal intensity to the impact creating a strong knee flexion moment. Forward momentum of body weight forces the prosthetic knee further into flexion, which the hip is unable to counteract with a sufficient extension moment.[2,14]

Above knee amputees may adapt to this increased flexion moment by using a hop-skip method of running. This method uses a double stance phase by taking an extra hop with the sound limb. The hop provides sufficient time for the prosthesis to complete the swing phase and occurs as a result of forward momentum. Adding the hop also decreases the distance between both legs when heel contact occurs. Combining the short period of double support with the decreased impact of heel contact and the less acute angle of the limb at heel contact, results in controlled weight transfer to the prosthesis, reducing the intensity of the knee flexion moment. This allows the amputee to functionally use hip extension to continue running. Speed for running is mainly produced by the sound limb and facilitated by excessive trunk and arm movements. The hop-skip running pattern is arrhythmic, abrupt and highly energy consuming.[2,14]

Amputee Running Gait Deviations

Continued knee flexion occurring in the first part of stance during running reflects a controlled lowering of the body. Some below knee amputees who do not run regularly may maintain their residual knee in excessive extension during a portion of the stance phase. This "locked-knee" tendency reduces the lower extremity's ability for shock absorption resulting in an abnormal transmission of forces through the knee and hip to the vertebral column. Evidence suggests that through proper training and prosthetic modification, this "locked-knee" tendency can be eliminated.[20]

Another pattern which may be exhibited by amputee runners is caused by restricted knee flexion of the intact limb during the swing phase. This causes the intact foot to be closer to the ground providing a more secure feeling during swing of the intact and prosthetic limb, and during prosthetic stance. In order to run using this particular pattern additional quadriceps contraction is necessary leading to undue fatigue.[20]

Function of the foot is intensified during running, and it's importance in prosthetic foot selection cannot be overemphasized. In midstance the foot must hold the body weight over flexed joints and provide power for push off, not to mention the forceful impact loading it must withstand during heel contact.[14] Large gait asymmetries in running can be contributed to the inability of the prosthetic foot to comply with the kinematic demands and lack of production of a powerful plantarflexion moment.[21]

Ground Reaction Forces

Ground reaction forces (GRF) are placed on the foot by the supporting surface in response to the forces the foot has exerted on the ground. The GRF's are equal in magnitude and opposite in direction to the force the body exerts to the supporting surface through the foot.[22] Despite the fact the GRF's during running are between two and three times the body weight, maximum forces recorded on the prosthetic limb are not found to be significantly different from that of the intact limb or non-amputee runners.[20]

Energy Expenditure

Energy requirements for full activity with lower extremity prostheses range from 25% to 100% more than for normal activity depending on the level of amputation, prosthetic fit and type, and presence of other physical disabilities.[6] Energy efficiency of the amputee is not only related to the presence of physical disabilities, but is also to diseases affecting the heart, lungs and peripheral vessels.[13] Greater metabolic costs are required by the dysvascular amputee over the traumatic amputee. An above-knee amputation in an individual with dysvascularity may have a metabolic cost as high as 120% greater than normal.[23] Walking speed and body weight are also directly related to the amount of energy required by the amputee.[19]

The higher the level of amputation or the greater the number of joints involved, the greater the energy expenditures of the amputee will be in order to compensate for the loss. When a joint such as the knee is involved, a large range of motion must be introduced by the hip joint without the necessary muscles to control the movement.[13] Whether the amputee is young or old, sedentary or athletic, it is critical to lower limb function to retain the knee joint. The longer the lever arm, the greater strength the amputee has to power the prosthesis, not to mention the increased proprioception and greater total area for weight bearing.[1,19]

Generally, major gait abnormalities causing disturbances in kinematics and symmetry will limit the amputee's level of activity as well as increase energy requirements necessary for ambulation.[21] Often symmetry is abandoned by amputees in an effort to compensate for a unilateral sensorimotor deficit.[19] Amputees tend to decrease their walking speed to maintain their normal heart rate, respiration and oxygen consumption, which results in maintenance of energy expenditures closer to normal. Amputees will choose comfortable velocities allowing vital signs to remain stable in comparison to their own levels.[6,15]

A major disadvantage to a slow asymmetric gait is a reduction in efficiency resulting in an increased energy expenditure per meter walked. The body's COG moves smoothly in a near sinusoidal pattern in normal gait. The smoother the path of gravity, the less energy required for ambulation. Each time an unnecessary, increased or abrupt movement of the body occurs, greater energy is required to compensate for that altered movement pattern. The result is an even greater energy expenditure required for each meter traveled, causing the individual to decrease their walking speed. Decreased velocity lowers the energy requirements, however, the time required to get from place to place is increased causing more energy to be used per meter.[19]

CHAPTER 4

PROSTHETICS FOR SPORTS & RECREATIONAL ACTIVITIES

Return of the lower extremity amputee to active participation in sports and recreation is dependent on personal motivation as well three levels of expertise. These levels include the surgeon's ability to create a functional and physiologically optimal residual limb; the amputee rehabilitation team by aiding the amputee in setting sports and recreational goals and by planning a treatment program enabling the amputee to reach those goals; and the prosthetist's skill in designing and fabricating a prosthesis to meet the sports and recreational needs of the amputee.[10] The ultimate goals in prosthetic selection and design is to allow the individual to gain psychological acceptance of their altered body image and to functionally restore the amputee according to their desired level of activity. Prosthetists accomplish this goal by making the prosthesis a well-fitted, functionally capable and cosmetically acceptable device that the patient will accept as part of themselves rather than an assistive device.[6]

Initially, the amputee relies on the knowledge and skill of the rehabilitation team regarding the type of rehabilitation and prosthesis necessary for them to achieve the ability to participate in their chosen sports and recreational activities. Once the lower extremity amputee has become an experienced participant in sports and recreation, they are usually very knowledgeable regarding the training and basic prosthetic components required for their chosen activity. The amputee rehabilitation team holds the task of evaluating whether these components are readily available or may be designed and fabricated realistically. Awareness of the more specific needs of the lower extremity amputee results in the development and design of prosthetic components for sports and recreational activities.[2]

Prosthetic Improvement

The prosthetic goal in the area of sports and recreation is to provide greater comfort in a more responsive prosthesis. Improvements in prosthetic design have resulted from the availability of new designs and materials leading to lighter, more durable prosthetics. Costs for graphite have decreased allowing for cost effective prosthetics that are lighter and more durable. Tools have also been developed that are capable of working with titanium which is more expensive, but also leads to the fabrication of lighter, more durable prosthetics. Plastic leaf springs are being incorporated into prosthetic feet allowing for more normal range of motion (ROM) and added push off. Data is just beginning to emerge suggesting decreased oxygen consumption with the use of these prosthetic feet.[10]

Flexible sockets are being designed with selective flexion to assist impact absorption in competitive sports encouraging a more active lifestyle. There has also been a shift in socket design to total surface bearing or total contact in which every square centimeter of the residual limb can contribute to support of body weight. Variations in suspension range from silicone roll-on suction sockets to rubberized knee sleeves, designed to eliminate axial pistoning and decrease stress on the skin.[10]

Energy-Storing Prosthetic Feet

It is important that the prosthetic foot simulate the natural ankle and foot in both forces produced during gait and ROM. Substitutions provided by the prosthetic foot should include adaptation to uneven surfaces, shock absorption following heel contact, limb length adjustments to smooth out the COG's path, knee stability and prosthetic limb shortening during swing phase. The prosthetic foot should allow cosmetic acceptance and be able to maximize efficiency and stability.[19,25]

Energy-storing prosthetic feet (ESPF) provide a smooth, easy ambulation pattern. The capability of these feet to store and release energy allows some amputees the ability to participate in sports and recreational activities involving running and jumping. A springy component compresses storing energy during heel contact. This energy is used to propel the amputee forward when it is released during push off.[9] There are a large variety of ESPF currently available with choice depending on the amputee's desired activity and performance levels. This paper covers some of the more common prosthetic foot designs most appropriate for participation in sports and recreational activities.

Multiaxial Foot

Most ESPF are considered multiaxial feet. Multiaxial feet allow motion in three planes, plantarflexion/dorsiflexion, inversion/eversion and rotation. A stationary keel composed of carbon fiber reinforced plastic is surrounded by soft rubber and provides moderate flexion in the midsection to help the foot adapt to rough terrain. The multiaxial foot is specially adjusted to accommodate for amputee need, weight and activity level by varying the density of rubber used. Multiaxial feet are ideal for the very active below-knee amputee, reducing the shearing action between the stump and socket.[2,9,19,31]

Solid Ankle-Cushioned Heel (SACH Foot)

This prosthetic foot is lightweight with no mechanically moving parts requiring maintenance. It is jointed at the end of the forefoot. A heel wedge composed of a polyurethane foam compresses to provide simulation of plantarflexion, and the toe section gives some for inversion and eversion. The heel wedge compresses partially absorbing the ground impact and allowing plantarflexion. No dorsiflexion is allowed by this foot. The SACH Foot allows a smooth transition over the full range of step when correctly aligned with the heel wedge, which is selected according to the users weight and activity. A soft heel wedge will be used for a lighter, less active amputee, where a heavier, more active amputee will require a more resistant heel wedge. The SACH Foot provides flexibility for walking over rough terrain for all levels of amputation; however, it is best suited for the above-knee amputee.[1,2,13,19]

Solid Ankle Flexible Endoskeletal (S.A.F.E. Foot)

The S.A.F.E. Foot is made up of five components, three of which compromise the functions of the ankle mortise joint, the subtalar joints, the bones of the longitudinal arch, and the subcutaneous tissues of the foot. These components consist of polyurethane foam sections. The fourth and fifth components are two nylon bands contained in the toe section of the foot extending from the heel to the metatarsal area, which simulate function of the plantar ligaments and tendons of the longitudinal arch of the foot. These bands adapt to uneven ground while controlling the amount of range allowed at the flexible keel. The S.A.F.E. Foot consists of a solid union between the shank and the foot through a bolt attachment. A flexible keel simulates the shape of the arches of the foot. Forces at the socket/stump interface are reduced, but the energy storing capabilities are minimal. This foot is both adaptable and stable; however, it remains stiff in push-off and is heavy and noncosmetic.[2,25,31]

Stored Energy (STEN Foot)

This foot is composed of a system of hardwood and high density rubber blocks and a plantar reinforcement fabric. The STEN Foot is basically a SACH Foot with a double-jointed keel. These components are designed to absorb energy during stance phase as the rubber blocks compress, releasing energy during push off. The main feature of the STEN Foot is it's ability to provide a smoother roll-over in stance. The STEN Foot is similar in appearance to the SACH Foot and, although quite heavy, can be used for running and active sports.[25,31]

Dynamic Foot

A hardwood keel extending into the mid-portion of the foot surrounded by high-density polyurethane foam composes the Dynamic Foot. It is designed to compress the heel during heel strike and provide smooth anterior resistance at toe off through compression of the polyurethane foam. Dynamic Feet are relatively light and are designed with a separation between the toes giving it a more natural look and allowing thong-type sandals to be worn.[25]

Carbon Copy II Foot

Ohio Willow Wood manufactures the Carbon Copy II Foot (CCII) made up of two energy-storing and releasing carbon deflection plates attached to a rigid keel and extending into the toe region. It is designed to deflect during the stance phase and extend during push off. The two carbon plates may produce a "graded" two-stage energy storage system. CCII is similar to the Seattle Foot only 25% lighter. Although the CCII Foot is more expensive than the Seattle Foot, it is considered the lightest and most durable of the ESPF. Carbon Copy II does not provide as much spring as the Flex-Foot, but it is quite responsive and quickly accepted by most patients.[25,31]

Seattle Foot

Similar to the SACH Foot in design, the Seattle Foot is composed of a more elastic cantilevered thermoplastic keel spring which extends from the top of the foot, back around the heel and into the metatarsal area. The Seattle Foot is designed to reinforce the metatarsal area and prevent the keel from pushing through the foam. Energy is stored in the keel section of the foot during weight bearing and released at the end of stance. Simulation of forefoot muscle activity is offered by the Seattle Foot to provide enhanced performance at a modestly increased price. The Seattle Foot performs well during running and walking, but is especially suited to running because of it's ability to provide more spring for push off.[2,19,25,31]

Flex-Foot

Flex-Feet consist of two flat, broad carbon leaves, a larger main leaf and a smaller posterior leaf. The main leaf extends from the base of the socket or knee unit, through the ankle and into the toe region of the foot. A smaller posterior leaf attaches to the main leaf at the mid-foot forming a heel component. The small leaf is designed to attenuate the shock of heel strike and push the prosthesis forward. The main leaf dorsiflexes under stress during the stance phase and extends forcibly during push off.

Flex-Foot offers the highest level of energy storage due to it's long spring design and high modulus carbon construction. High responsiveness and provision of the smoothest running and walking patterns allow the highest jumping performance of all ESPF. This in combination with it's light weight make it a good alternative for hip disarticulation, above-knee and below-knee amputees. The Flex-Foot is specially designed according to amputee weight, stump size and shape, level of amputation and the amputee's expected activity level. Patients may require a longer time to adjust to the Flex-Foot because it forces them to walk more quickly. Although the high cost in comparison with other prosthetic feet may be well worth the additional function for many amputees, for some it may be considered a disadvantage. Despite the Flex-Foot being well recommended for use in sports involving running and jumping, it may be too lively for comfortable use during daily activity.[19,25,27,31]

There are several different models of the Flex-Foot available depending on the activity level in which the amputee chooses to function. The original model consists of a carbon leaf bonded to the prosthetic socket not allowing any adjustments in alignment, meaning it can't be rotated, flexed, extended or lengthened to accommodate growth. In the modular model the carbon leaf is bolted to the socket allowing for adjustments in alignment. Several other Flex-Foot models are available depending on the desired activity and performance levels, three of which will be discussed in the following paragraphs.

Flex-Sprint features a plantarflexed toe specially designed for competitive sprinting. The plantarflexed toe allows the runner to land two inches forward of the toe accommodating a more normal sprinter gait. A constant compression rate is maintained by the plantarflexion angle to maximize energy storage and release potential. A short safety heel is positioned in the Flex-Sprint to act as a check against knee hyperextension common with toe runners.[30]

The Air-Flex prosthetic foot contains an inner air cell formed from radio-frequency welded urethane. By inflating the cell, toe stiffness can be increased for greater energy storage and stability during impact activities. A smoother, more cushioned rollover for less strenuous activities is provided by deflating the cell. Air-Flex eliminates the need for more than one prosthesis through its ability to change it's energy-storing capacity.[30]

Modular III is a durable, lightweight, ESPF made of 100% carbon fiber to provide smooth continuous motion from heel strike to toe off. It is appropriate for active as well as less active amputees, allowing them to utilize less energy. The Modular III is considered the highest energy storage and return prosthetic foot on the market.[30]

Summary

The S.A.F.E., STEN and Dynamic feet provide little energy storage; however, they can be used for running and active sports with less adjustment by the amputee and prosthetist at the cost of higher athletic performance levels offered by Flex-Foot, CCII, and Seattle.

The Seattle Foot, CCII and Flex-Foot are all special ordered in correspondence with the amputee's weight, height, and activity level to ensure obtainment of appropriate energy storage and to decrease wear and tear. These feet are also fabricated using waterproof materials which can be used in swimming. The S.A.F.E. and STEN Feet are manufactured with standardized energy-storing characteristics based on size and are not recommended for use in the water.

Carbon Copy II or the Seattle Foot may be the best prosthetic foot choices for the active lower extremity amputee when considering price and function. The use of a hydraulic knee may require using the heavier Seattle Foot. Despite the CCII being lighter than the Seattle, it is also more expensive. STEN, S.A.F.E. and Dynamic feet are good choices for amputees who have had trouble adapting to heel strike shock, abrupt rollover and lack of pronation/supination of the SACH foot, but who do not wish to experience the liveliness of the other ESPF. The greatest accommodation to shock and uneven terrain is offered by the S.A.F.E. and Dynamic Feet. The STEN Foot, however, is lighter and easier to find a good fitting shoe.[25]

The Flex-Foot is the lightest of all the ESPF and seems to provide the highest level of performance for rapid walking, running and jumping. For some amputees these advantages may not outweigh the increased cost and decreased cosmetic appearance; however, for others the price to pay for maximum performance may be well worth it.[25]

New Prosthetic Foot Designs

TruStep and Cirrus Foot have been introduced into the prosthetic market within the last couple of years. Research studies comparing these new designs to those already available is lacking; subjective information and market studies are available.

TruStep

This is a relatively new design in prosthetic feet developed by College Park Industries in 1994. TruStep incorporates the three basic joints of the foot and ankle, the ankle mortise, subtalar and mid-tarsal joints. Bumpers are customized for shock absorption to meet activity needs of the amputee. TruStep is a dynamic response multiaxial foot allowing motion in three planes to occur in the anatomically correct positions. Motion is allowed for rotation, inversion/eversion and dorsiflexion/plantarflexion. TruStep incorporates a split toe design providing stability for accommodation to uneven ground. An independent study conducted by the Michigan State University Biomechanic Evaluation Laboratory indicated that torque on the sound side of the amputee was reduced with the TruStep. This results in a reduction in contralateral musculoskeletal stress and fatigue. Little research has been done on this prosthetic foot; however, College Park Industries states that it meets the vast majority of amputee's needs regardless of age or activity level.[28]

Cirrus Foot

The Cirrus Foot was launched by Second Nature, a relatively new name in prosthetics, in June of 1996. The Cirrus Foot was designed to meet the needs of the highly unstable amputee to those of the very active amputee. It is composed of three individual toe springs which allow greater ankle motion and aid in conformance to uneven terrain. Two heel springs are also incorporated in the Cirrus Foot to aid in the foot's ability to adapt to uneven terrain and allow a fluid transmission of energy from heel strike to toe off.[29]

Prosthetic Knees

The prosthetic knee must be fabricated to substitute for the normal anatomical functions of the knee. Shock absorption, support during stance and knee flexion in swing are important functions that must be considered when designing the prosthetic knee.[19] Prosthetic knees must provide stability during weight bearing while maintaining the ability to easily flex. Loss of the anatomical knee and ankle function necessitates the above-knee amputee to rely on hip musculature to accelerate and decelerate the prosthetic shank.[35]

Polycentric

Polycentric knees allow movement of the shin in combination with rotation and lateral motion around a moveable center of rotation.[19] Swing control is provided either by mechanical friction or hydraulic resistance. Polycentric knees are especially suited for the above-knee amputee.[9]

Hydraulic and Pneumatic-Variable Friction

Prosthetic knees that provide fluid swing phase control of the lower leg depending on muscle action and forward momentum utilize oil hydraulics, or air pneumatics to control the knee during swing. These hydraulic or pneumatic knees minimize excessive heel rise and provide resistance to knee motion that is appropriate to the amputee walking speed. By minimizing excessive heel rise the time needed for swing phase of the knee is decreased making it much easier to place the prosthetic limb on the ambulation surface in an optimal position to accept weight in the next stance phase. To accommodate a variety of walking speeds, an adjustable knee extension bias is incorporated to assist with knee extension during the swing phase.[9,19]

The hydraulic knee has a broad ROM over which ambulation speed can be varied where pneumatic knees adjust to various speeds in a limited ROM usually consisting of swing phase control only. No mechanisms are built into the hydraulic knee to provide stability in the stance phase. Therefore, all control in the stance phase comes from alignment and muscle control. Due to this fact the amputee who chooses to use this type of knee must have good control of the hip extensors.[9,19,35]

Fluid control in swing and stance can also be offered by the hydraulic knee closely duplicating the forces exerted by natural knee musculature. The hydraulic control mechanism functions independent of walking speed. This allows the amputee to vary the speed in which they ambulate giving them the ability to run one step and walk the next. The fluid controlled stance contains no locking mechanism, yielding the knee from flexion to extension gradually depending on the amount of force applied to the limb in the form of body weight. Gradual flexion of the knee facilitates a more normal step over step gait when walking on ramps and down stairs.

Swing phase control is similar to the previously discussed fluid swing control only it requires a hyperextension moment at heel off and during toe off to initiate knee flexion in swing phase. This may be difficult to adjust to if the amputee has been using another type of prosthetic knee prior to being fitted with a fluid controlled swing and stance phase knee.[19,35]

Otto Bock's Mauch Swing-N-Stance Hydraulic Knee

Stance stability and hydraulic swing control are offered by the Otto Bock Mauch Swing-N-Stance (S-N-S) hydraulic knee. In the stance phase it gives the amputee the ability to bear weight over the flexed knee such is necessary when descending inclines. Automatic breaking occurs whenever the knee buckles or interferes with normal flexion and extension of the knee. Flexion or locking of the knee in extension can be achieved by using a lever setting. The hydraulic swing control of this knee gives the amputee the ability to vary their ambulation speed, and is especially suited for the active amputee.[2,9]

Prosthetic Sockets

One of the most important factors affecting successful prosthetic use is the socket fit to the residual limb. The prosthetic socket is the only interface between the residual limb and the prosthesis acting to transmit forces of weight bearing. Socket shape is critical to comfort and function. If the socket fails to provide an intimate, comfortable fit, the amputee is less likely to use their prosthesis resulting in decreased function.[31] The prosthetic socket must fit securely to provide functional lever control, stability, total contact, avoidance of pistoning, prevention of edema or skin irritation and to permit sensory feedback. All of these factors are important for the development of all phases of the gait cycle.[2]

Flexible Sockets

Above-knee sockets have shifted from the rigid quadrilateral design to more flexible designs allowing total contact and increased medial/lateral support. This type of socket allows flexibility while retaining the integrity of the prosthesis to transfer forces to the residual limb. Flexibility provides the socket with the ability to change shape during ambulation allowing comfort during all phases of the gait cycle. The use of lower density, thinner socket material allows faster heat dissemination during hot weather and during increased activity. Total contact allowed by this type of socket also allows for increased sensation and proprioception, and better suspension allowing for better propulsion.[21,19]

Total Contact

In total contact sockets weight is taken throughout the entire socket. The ischial area and residual limb tissues are in contact with all aspects of the socket allowing for an extremely accurate fit. Total contact sockets contain a valve for one way air flow out which provides distal tissue support by maintaining suspension and preventing any negative pressure. Patients with stable, mature residual limbs possessing good muscle control, full hip joint mobility and no edema or gross scarring are excellent candidates for total contact sockets. Sensory feedback and muscle control providing instant prosthetic movement without time lapse or pistoning are some advantages of total contact sockets.[9]

Contoured Adducted Trochanteric Controlled Alignment Method (CAT-CAM).

CAT-CAM socket designs enclose the thigh and allow the ischial tuberosity to sit in the socket thus relieving weight bearing pressure. This factor leads to an increase in gait velocity, a 50% decrease in oxygen consumption and a decrease in leaning of the trunk toward the prosthetic limb.[32]

Narrow Medial-Lateral

Narrow medial-lateral (ML) sockets, also known as ischial containment sockets, contain the ischial tuberosity within the socket, compressing side to side rather than front to back. The decreased ML diameter brings the lateral wall closer to the femur allowing more precise control of the adduction angle. Femoral adduction enhances the work of the ML musculature during prosthetic stance. An expanded anterior-posterior diameter provides more space for the contraction of the extensor and flexor muscles. Since the ML musculature are no longer compressed they are allowed to function more naturally. Containment of bone and muscle combined with control of the femoral adduction angle and the narrow ML design, biomechanically lock or fix the ischial tuberosity at prosthetic midstance allowing weight bearing to occur over a larger anatomical area. Containment of the tuberosity along with total socket contact allow more controlled prosthetic heel contact resulting in a less tiring gait.[1,9,31]

Sabolich Socket

The Sabolich Socket is similar to the total contact, flexible sockets previously discussed. It is contoured to allow placement for every bone, muscle, nerve and vessel contained in the residual limb. This socket utilizes highly defined shaping and contouring and meshes with distinct anatomical characteristics of the thigh and pelvis. As in the above sockets, the ischial complex of the ischium and ramus are maximally locked to prevent inadvertent motion and rotation. These factors combine allowing the active amputee to run step over step.[33]

Patellar Tendon Bearing Sockets

The patellar tendon bearing (PTB) socket is a total contact socket designed for the below-knee amputee. Weight is taken through the patellar tendon and the medial tibial flare by the use of high, plastic molded and fitted ML socket walls to provide stability. The center of the posterior wall gently compresses the soft tissues below the popliteal fossa to facilitate weight bearing on the patellar tendon. Weight bearing forces can also be absorbed through the following areas: the medial flare of the anterior tibia, the lateral aspect of the residual limb, the pretibial musculature between the tibial crest and the fibula, the lateral surface of the fibula distal to the head and proximal to the anterior end, and the popliteal fossa. The PTB socket is set in slight flexion to permit the amputee to kneel on the prosthesis. Slight flexion also allows for improved proprioceptive feedback since the tissue around the patellar tendon is naturally designed to accommodate weight in kneeling.

The contraction of muscle against the socket walls assists with socket suspension during the swing phase of the gait cycle. Wedge suspension can be utilized through the use of a molded removable wedge inserted between the proximal wall of the residual limb along the medial condyle of the femur. Suspension can also be obtained through suction or an elastic sleeve.[2,19,31] Although the PTB socket has been the socket of choice for below-knee amputees, most recently total contact sockets have been successfully designed and used for the below-knee amputee.

Torque Absorber

Torque absorbers are incorporated into the shank of the prosthesis to limit shear forces transmitted to the residual limb through the socket thereby reducing gait deviations. Rotation is provided by the torque absorber up to 45 degrees from neutral to allow for rotation of the foot necessary for activities such as golf and dancing. Variable torsion resistance is offered by torque absorbers to accommodate for different activities.[34]

CHAPTER 5

ADAPTATIONS FOR SPORTS & RECREATION

Adaptations allowing greater ease of participation in sports and recreational activities for the lower extremity amputee are currently available. Some of the information contained in this chapter is based on resources accounting firsthand experiences of lower extremity amputees active in particular sports and recreational activities. Therefore, not all of these methods of adaptation may be found successful by every individual amputee. These adaptations are only some examples of what is available in the area of sports and recreational adaptations. There are many more available adaptations and equipment for various activities readily accessible through organizations dedicated to promoting amputee participation in sport or recreational activity.

Running

Running is the most difficult skill for lower extremity amputees to acquire due to poor prosthetic fit, inadequate suspension, limited shock absorption, excessive prosthetic weight, alignment instability and fear.[10] In attempts to minimize the pistoning of the residual limb in the socket, below-knee amputees can add an additional fork strap and waistbelt to their prosthesis for running. Rubber latex sleeves have been used for added suspension due to their elasticity and suction effects. Above-knee amputees may choose to use a Silesian bandage for added suspension and a flexible socket for added comfort due to it's ability to change shape with muscular contraction.

Special consideration is necessary in the selection of the appropriate knee and ankle joint for running. Hydraulic knees may not be able to withstand the impact of running. The Mauch S-N-S offers the amputee a higher degree of control during vigorous activity. Careful consideration should be given to selection of the prosthetic foot. An energy-storing, energy-releasing foot that can provide power for push off should be chosen such as the Seattle, Carbon Copy II, or Flex Foot. The prosthetic foot should be set in plantarflexion so the amputee's weight can be centered over the ball of the foot during push off.

Cycling

Cycling can be accomplished by placing the shank directly over the pedal to achieve optimal power output. Some amputees choose to use toe-clips to provide more pedaling power. For above-knee amputees hip range of motion and sitting present further problems. A seat must be selected that is wide enough for the above-knee amputee to balance on, and padded to decrease pinching. Hydraulic knees have been found to be effective for above-knee amputees with the knee set in a free swinging mode. Below-knee amputees should experience little to no difficulty with cycling.[10, 12]

Swimming

Swimming can be done with or without a prosthesis; however, competitive swimmers are not allowed to wear their prostheses during competitions. Otto Bock has developed a hollow-walled plastic prosthesis with a hole drilled into the ankle block which allows water to enter decreasing buoyancy of the prosthetic limb. For the above-knee amputee swimmer the Otto Bock prosthesis utilizes a quick release knee lock mechanism which also has a friction lock for walking or sitting outside of the water.

The Veterans Administration Prosthetic Center developed a "swim-walk" leg which can be set in two ankle positions, 90 degrees to allow walking and 120 degrees for swimming.[10,11,12] The Beach (Utility) Prosthesis can be worn with or without a shoe and can be used for walking, standing in the water, boating, fishing, and water skiing.[12]

Water Skiing

Most unilateral amputee water skiers choose to ski without a prosthesis using only one ski while others choose to wear their prosthesis and utilize two skis. When skiing on one ski the prosthetic leg is usually placed behind the intact limb. For this reason the prosthetic limb needs to be shorter than the intact limb to place weight further back on the ski. It is advisable to externally rotate the prosthetic foot to allow space for clearance of the sound knee.[12]

When skiing on two skis the below-knee amputee should keep the prosthetic ski three to six inches ahead of the other ski to prevent drag from pulling the prosthetic leg backwards. Many above-knee amputees prefer to ski without a prosthesis. Others attach a bucket device to the ski to provide a place for the residual limb to rest. A broad, square-backed ski offers the best stability for the beginning skier. The binding of the ski should be fixed so the ankle joint is about one-third of the length of the ski.[12]

Downhill Skiing

Obtaining substantial dorsiflexion to place the COG more forward over the ski for greater control is the key to downhill skiing for the lower extremity amputee. A heel lift can be place under the foot or binding to allow for this dorsiflexion. Avid below-knee amputees have a separate prosthesis with 15 to 25 degrees of dorsiflexion built into multiaxial ankles. The use of the multiaxial ankle, however, does require greater control by the amputee. The SACH Foot is recommended to provide necessary stability for beginning skiers.

Bilateral below-knee amputees ski with the use of one ski and two outriggers. Outriggers are forearm crutches or ski poles with a 35 cm ski tip placed on a rocker base. Some amputees choose not wear their prosthesis utilizing one ski and two outriggers, while others ski using both limbs. A short ski length aids the skier with control and manueverability.[10,11,12,24]

A prosthetic liner should be chosen that offers as much protection and cushioning as possible. Silicone gel inserts are available that act as a protective layer and help to evenly distribute pressure. Selection of a lightweight ski boot is recommended to make donning of the ski easier. The skiing prosthesis is often fabricated with a thigh lacer and waistbelt pick-up strap. This aids suspension mechanisms to hold the prosthesis on while sitting in a chair lift and to avoid pistoning, which is important in reducing the reaction time between leg movement and movement of the prosthesis. Special skiing prostheses have been designed and aligned for above-knee amputee skiers.[12]

Ice Skating

Prosthetic positions used for skating are quite similar to those used in downhill skiing. The below-knee prosthesis for skiing can also be used for skating. A skate aid or "ice walker" or outriggers can be used in skating to aid balance. Outriggers used for skating replace the small ski with a skate blade.[12]

Golf

Balance and weight shifting during trunk rotation must be mastered for the recreational sport of golf. Rotators or swivel devices along with torque absorbers can be installed into the shank of a prosthesis to allow the necessary internal rotation of the forward leg, or swivels can be placed on the sole of the golf shoe.[10,11,12] The S.A.F.E. foot has been a good choice of prosthetic foot for golfing due to it's ability to simulate the action of the normal foot in three planes, dorsiflexion/plantarflexion, inversion/eversion, and pronation/supination.[12]

Baseball

Below-knee amputees may play any position in the sport of baseball, but may have more success at positions requiring less agility such as pitcher and first base. For the below-knee amputee a thigh corset with side joints may be best suited for participation in this sport. Above-knee amputees face a much greater challenge and are usually better off playing infield. When batting, the intact limb should be positioned behind them to facilitate a good push toward first base.[12]

Hiking

Most amputee hikers choose to wear a prosthesis fitted with a foot that is adaptable to rough terrain such as the S.A.F.E. or Dynamic Foot or newer designs.[25] A rotator similar to the one mentioned for amputee golfers is often recommended for the avid hiker, especially if the amputation is above-knee. For the below-knee amputee a silicone gel liner may prove to be beneficial to prevent trauma to the residual limb.[12]

Mountain Climbing

Mountain climbing can be and is successfully pursued by many lower extremity amputees with the aid of assistive devices. To reduce friction between the residual limb and the prosthesis a Daw Sheath has proven to be quite effective.[12] A prosthetic foot should be chosen that allows motion in all three planes such as the multiaxial Trustep, Cirrus or S.A.F.E. Foot.[25,28,29]

Modifications can be made to forearm crutches in order to help with balance and mastering of terrain. Forearm cuffs as well as handgrips should be padded with one-quarter inch and three-quarter inch Plastazote respectively to absorb forces transmitted through them during climbing. Handgrips should also be covered in neoprene or some type of non-slip material. The use of adjustable crutches is ideal allowing shortening of the uphill crutch and lengthening of the downhill crutch.[12]

If crutches are to be used in snow, a 12 inch waterproof leather basket can be attached near the distal end with approximately a 20 to 25 degree swivel. Synthetic materials resembling seal skin can be used on the bottom of the basket to prevent the crutch from slipping in the snow. Removable ice picks extending approximately five inches below the basket can also be incorporated allowing replacement with regular crutch tips.[12]

Horseback Riding

Horseback riding programs for the disabled have been in existence for over 30 years. The North American Riding for the Handicapped Association (NARHA) established in 1969 has over 140 riding centers in 37 states and Canada. Modifications are few, if any, to allow the lower extremity amputee to participate in a horseback riding program. The NARHA recommends using safety stirrups or the English saddle which is equipped with a safety latch to release to the entire stirrup setup. Western saddles offer more stability but lack the safety options offered by the English saddle.

Horseback riding can be done with or without a prosthesis, however, most amputees choose to ride while wearing their prosthesis. Those choosing not to wear a prosthesis may require a “residual limb stirrup” in order to maintain balance. Prosthetic adjustments may be necessary to allow proper knee flexion and foot alignment. The foot should be canted inward with the toe adjusted up and outward. Above-knee amputees may experience pinching of the gluteal tissue between the saddle and the prosthesis persuading them to ride without a prosthesis. If the above-knee amputee chooses to wear a prosthesis, a pelvic band with a double axis hip joint for flexion, sufficient abduction and comfortable sitting should be chosen.

Above-knee or hip disarticulation amputees would benefit from a knee locking device to hold the knee in a flexed position similar to the natural knee. The Mauch S-N-S knee, capable of locking in a flexed position, is an example of the type of knee beneficial to the equestrian amputee.[12]

Skydiving

A number of amputee sky divers choose not to wear a prosthesis, but instead pad the residual limb for protection when landing. A disadvantage to this is the loss of independence when gathering and returning equipment as well as themselves back to the launching area. The use of a detachable pylon which can be attached upon landing is one alternative allowing the amputee to maintain independence.

During free fall the body must maintain a symmetrical position in the air to avoid spinning. The below-knee amputee can prevent spinning by bending both knees toward the chest or keeping both hips neutral and flexing both knees to 90 degrees. The above-knee amputee may need an assistive device matching the length of the intact thigh allowing them to dive using the same techniques as the below-knee amputee.[12]

Competitive Amputee Sports

In 1996 Atlanta welcomed the 10th annual Paralympic Games involving 120 nations and 3,500 athletes competing in 17 sports, 15 of which are included in the Olympics. The Paralympics are one of the largest organized sports competitions in the nation second only to the Olympics. Amputees were first included in the Paralympics in 1976 when the games were held in Toronto. In 1979 the first World Amputee Competition was held in Mandelville, England and in 1981 the first Annual Amputee

Recreational and Competitive Meet was held in the United States.[36]

Individuals are classified for the Paralymic Games according to their disability and functional abilities. Amputee classification is based on the number of amputations, upper and lower extremity, level of amputation and functional ability.[36] Competitive events in the United States and abroad include sports such as swimming, track and field, weightlifting, air pistol, volleyball and table tennis.[12] The following is the current medical classification for competitive sports according to the United States Amputees Athletic Association:

Class A1: Individuals with bilateral above-knee amputation

Class A2: Individuals with unilateral above-knee amputation

Class A3: Individuals with bilateral below-knee amputation

Class A4: Individuals with unilateral below-knee amputation

The activities previously listed in this chapter are only a small list of the possible sports and recreational options available to lower extremity amputees. For a listing of various organizations dedicated to promoting amputee participation in sports and recreational activities refer to Appendix A.

CHAPTER 6

CONCLUSION

Fitness relative to staying active throughout one's lifetime has been receiving an increasing amount of emphasis in our society. The physical benefits of enhanced cardiopulmonary function and weight control are well known, but there are many psychological benefits as well. Physical activity provides quality of life and the opportunity to socialize with others building confidence and self-esteem. Everyone should be given the option to actively participate in activities involving sport and recreation, including the disabled.

An increasing number of young and/or healthy individual's who have undergone amputation of the lower extremity wish to become or to continue to be active participants in sports and recreational activities. Advances in prosthetic research and materials have made it realistic to design and fabricate prostheses making it possible for individual's with lower extremity amputations to participate in recreational activities involving running and jumping.

Biomechanically, the lower extremity amputee must compensate for the loss of a major part of the locomotive system. Hip musculature has been found to be of great importance in rehabilitation of the lower extremity amputee. The hip extensors help to compensate for the amputation by stabilizing either the anatomic or prosthetic knee. This suggests that rehabilitation programs for the lower extremity amputee interested in running should focus on strength of the prosthetic limb's hip musculature. Adaptations must be made for the loss proprioception and balance as well as loss of the foot, knee, hip or all joints of the lower extremity.[17]

Prosthetic knees providing the best performance for the active lower extremity amputee are those which utilize hydraulics. The hydraulic knee allows the amputee to vary the speed in which they choose to ambulate. The Mauch S-N-S knee offers stability in stance along with swing control and is best suited for the active amputee. Hydraulics can be incorporated into polycentric and single-axis knee joints.

During running, functioning of the foot is intensified, and it's importance in prosthetic foot selection cannot be overlooked. Energy-storing prosthetic feet are the best choice at any level of amputation, possibly providing the amputee with the ability to run or jump. The Seattle Foot, CCII and Flex-Foot are the best choices for those individual's with amputations who wish to actively participate in sports and recreational activities. Overall, the Seattle Foot may be the best choice in regards to cost and function; however, it is not quite as durable as the more expensive CCII. Flex-Foot offers the best performance for activities involving running and jumping, and for some, this advantage may be well worth the cost.

Almost as important as the selection of the prosthetic foot is the choice of prosthetic socket. The socket is the only interface between the residual limb and the prosthesis, and if it fails to provide comfort for a variety of activities, amputee function is going to be decreased. Prosthetic sockets have shifted from the quadrilateral design to more flexible, total contact designs. Socket selection is based on personal preference as well as individual motivation.

Merely acquiring a prosthesis designed for running and jumping doesn't necessarily mean the amputee will also acquire the ability to run and jump. A great deal of hard work and motivation are involved in the amputee rehabilitation program. The amputee must have successfully completed the initial rehabilitation and possess confidence in their own abilities before proceeding into a rehabilitation program designed for sports participation.

Personal motivation plays a large role in returning the lower extremity amputee to sports and recreational activities. The role of the amputee rehabilitation team is to aid the amputee in setting sports and recreational goals and to plan a treatment program enabling the amputee to achieve those goals. Successful participation in sports and recreational activities requires health care professionals to exhibit a team effort and most importantly, the active involvement of the individual amputee in the planning of goals and a treatment program.

Numerous organizations are established promoting sports recreation for individual's who have undergone amputations. Individuals with lower extremity amputations have successfully participated in almost every sport and recreational activity with greater ease due to current adaptations and prosthetic advancements. The only limits to what lower extremity amputees can do are those set forth by personal motivation, determination and attitude.

APPENDIX A

Resources

GENERAL SUPPORT GROUPS:

American Orthotic and Prosthetic Association
1650 King Street, Suite 500
Alexandria, VA 22314
(703) 836-7116

Amputee Coalition of America
1932 Alcoa Highway, Suite 365
Knoxville, TN 37920-1517
1-800-355-8772 or (423) 524-8772
Fax: (423) 525-7917

Institute for the Advancement of Prosthetics
StepAhead Newsletter
4424 South Pennsylvania Avenue
Lansing, MI 48910
1-800-427-3442

Northern Nevada Amputee Support Group
George Maxfield
(702) 358-8449
Fax: (702) 358-5789

Self Help Amputee Group - SHAG
Dorothee Giaimo, SHAG newsletter editor
SHAG Incorporated
13 High Court
Little Falls, NJ 07424-1910

GENERAL SPORTS:

Ability Magazine
PO Box 5311
Mission Hills, CA 91345

Adaptive Sports Program Kinesiotherapy Clinic
University of Toledo
2801 West Bancroft Street
Toledo, OH 43606
(419) 537-2755

Adolescent Amputee Camp
Children's Hospital of Pittsburgh
Physical Therapy Department
125 DeSoto Street
Pittsburgh, PA 15213
(412) 647-5480

Adolescent and Young Adult Amputee Programs
PO Box 99776
Pittsburgh, PA 15233
(419) 537-2755

American Alliance for Health, Physical Education, Recreation, and Dance Programs for the Handicapped - AAHPERDH
1900 Association Drive
Reston, VA 22091
(703) 476-3461

American Amputee Foundation, Inc.
710 West 7th Street
Little Rock, AR 72201
(501) 666-2523

Amputees Are Able
PO Box 250
Angelus Oaks, CA 92305
(909) 794-1179

Amputees in Motion International
PO Box 1736
Fallbrook, CA 92028
(619) 725-6195 or (619) 723-8003

Amputee Sports Association
11705 Mercy Boulevard
Savannah, GA 31419
(912) 927-5406

Breckenridge Outdoor Education Center
PO Box 697
Breckenridge, CO 80425

Courage Center
3915 Golden Valley Road
Golden Valley, MN 55422
(612) 588-0811

Eastern Amputee Athletic Association
2080 Ennabrock Road
North Bellmore, NY 11710
(516) 221-0610

Families of Amputee Children Together - F.A.C.T.
Child Amputee Prosthetics Project
1000 Veterans Avenue, Room 25-26
Los Angeles, CA 90024
(213) 825-5201

Indianapolis Amputee Athletic Association
PO Box 88451
Indianapolis, IN 46208
(317) 926-9755

Mutual Amputee Aid Foundation
5833 Costello Avenue
Van Nuys, CA 91401
(818) 988-1666

National Handicapped Sports
1145 19th Street NW, Suite 717
Washington, DC 20036
(202) 393-7505

National Handicapped Sports and Recreation Association
PO Box 18664
Capitol Hill Station
Denver, CO 80218
(303) 232-4575

Pacific Orthotics/Prosthetics Service - POPS
PO Box D
Phoenix, OR 97535
(503) 535-1569

Shared Outdoor Adventure Recreation - S.O.A.R.
PO Box 14583
Portland, OR 97214
(503) 238-1613

United States Amputee Athletic Association
Route 2, County Line Road
Fairview, TN 37062
(615) 670-5453

Wilderness Inquiry II
2929 4th Avenue South, Suite O
Minneapolis, MN 55408
(612) 827-4001

GOLF:

International Senior Amputee Golf Society, Inc.
14039 Ellesmere Drive
Tampa, FL 33624
(813) 961-3275

National Amputee Golf Association
5711 Yearling Court
Bonita, CA 92002
(619) 479-4578

HORSEBACK RIDING:

North American Riding for the Handicapped Association
PO Box 100
Ashburn, VA 22011
(703) 471-1621

Vinland National Center
3675 Ihduhapi Road
PO Box 308
Loretto, MN 55357
(612) 479-3555

Winslow Therapeutic Riding Unlimited, Inc.
3408 South Route 94
Warwick, NY 10990
(914) 986-6686

RUNNING:

International Running Center
9 East 89th Street
New York, NY 10128
(212) 398-0348

SKYDIVING:

Stump Jumpers Amputee Support Group
4301 Oakdale Place
Pittsburgh, CA 94565
(510) 427-5780

United States Parachute Association
1440 Duke Street
Alexandria, VA 22314
(703) 836-3495

SNOW SKIING:

Alpine Alternatives
1634 West 13th Street
Anchorage, AK 99501
(907) 276-7526

Horizons
PO Box 2143
Steamboat Springs, CO 80477
(303) 879-4466

Ski For Light, Inc.
1455 West Lake Street
Minneapolis, MN 55408
(612) 827-3611

Skiforall Foundation
4160 86th Street SE
Mercer Island, WA 98040
(206) 232-3544

Snowmass Ski School - Handicapped skiing
PO Box 5429
Snowmass Village, CO 81615
(303) 923-3294

United States Ski Association
518 Lake Forest Drive
Bay Village, OH 44140
(216) 871-4494 or (216) 221-4058

Winter Park Handicap Ski Program
Hal O'Leary, Director
PO Box 336
Winter Park, CO 80482
(303) 726-5514 ext. 179

WATER SKIING:

American Water Ski Association
State Road 550 & Carl Floyd Road
PO Box 1911
Winter Haven, FL 33880
(813) 324-4341

Christian Family Ski School
PO Box 7425
Winter Haven, FL 338880
(813) 299-4044

Mission Bay Aquatic Center
1001 Santa Clara Point
San Diego, CA 92109
(619) 488-1036

GENERAL WEB SITES:

Amputee Home Page: http://vanbc.wimsey.com/~igregson/index.html

E-Zine Preview: http://vanbc.wimsey.com/~igregson/ampute.html

I-CAN: http://www.jax-inter.net/users/bbaughn

Orthotics and Prosthetics: http://www.oandp.com

Northwestern University: http://www.repoc.nwu.edu

BioMechanics Gateway: http://www.ifi-mpls.com/biomech

AMP U T CHAT: http://members.aol.com/acdoylefan/main.htm

PROSTHETIC COMPANIES:

NovaCare Sabolich: http://www.novacaresabolich.com

Ohio Willow Wood Company: http://www.owwco.com

United States Manufacturing Company: http://www.usmc.com

Flex-Foot, Incorporated: http://www.flexfoot.com

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