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Physiotherapy rehabilitation for adults with unilateral lower limb amputation – Independent study material for students

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Abstract

Rehabilitation for patients encountering the need for lower limb amputation is important, and the physiotherapist's role is essential in this process. Over the years, the need for lower limb amputation has grown primarily due to vascular disease, and more particularly, diabetes, for which the number of people is going to keep growing in the future.

In this matter, physiotherapists must be aware of their role in rehabilitation and how to interact with the healthcare team to ensure the best outcomes of rehabilitation for the patient. This thesis is action research-based, and the aim is to provide independent study material for physiotherapy students in the form of a PowerPoint PDF. This will enable them to use the material in a clinical situation and acquire information and knowledge on the subject.

Keywords

A comma separated list of the main keywords describing the content of your thesis.

Rehabilitation, lower limb amputation, physiotherapist, vascular disease, healthcare team

CONTENTS

1 INTRODUCTION

Amputation is a surgical procedure which implies the removal of a part of the body. The word originates from Latin: amputātus of the verb amputāre am- /amb-“about, around” and putāre “to prune” meaning to prune away, remove by cutting (Amputate Definition & Meaning - Merriam-Webster, n.d.). It is one of the oldest types of surgical medicine and the earliest evidence of amputation is found in tropical Asia: a skeleton which could suggest a lower limb amputation (LLA) procedure occurring 31,000 years ago. Nevertheless, the oldest confirmed case of amputation procedure was found in a skeleton of a farmer in France, which dates back 7,000 years to the neolithic era (Maloney et al., 2022).

The first documented use of amputation is during the 1st century, when the surgical procedure of amputation is described by Aulus Cornelius Celsus. During the 16th century in France, the surgeon A. Paré (1590) improved the procedure by reducing blood loss without cauterizing the arteries. He also collaborated with a lock smith to design an artificial limb. (Robinson, 1991) The 16th century with its wars and the invention of firearms and bigger artilleries increased the need for amputation intervention due to traumatic limb injury, and medical procedures and management developed further (Kinch & Clasper, 2011).

During the 20th century the first and second World War caused millions of injured, and the injuries often led to amputation of a limb. In France, in 1915, a hospital for soldiers was opened at the Grand Palais of Paris where healthcare professionals, doctors and physiotherapists specialized and evolved therapeutic treatments for the veterans and collaborated with engineers for the fabrication of prothesis. The goal of this institution was to reinsert former soldiers to professional activities and participation in the society; thus, it had a considerable impact on the progress of medicine and rehabilitation. (Invalides de Guerre et Centres de Rééducation - Histoire Analysée En Images et Œuvres d’art | Https://Histoire-Image.Org/, n.d.).

In the United States (US) at the end of the World War I the clinician Maj. Gen. Kirk specialized in amputee care and contributed to developing amputee rehabilitation further. He standardized protocols for patient wound care, ambulation, and activities to perform as daily tasks while collaborating in a multidisciplinary team. Physical therapy was at its early days at this time and centers for amputees at hospitals started to be implemented. This also allowed scientists to evolve research in the prosthetic field. (Dougherty & DeMaio, 2014)

These days each year in the US 185,000 individuals are treated with an amputation. 54% of the amputations are caused by diabetes and peripheral arterial diseases, following by 45% because of trauma and less than 2% due to cancer. Up to 55% of Patients who underwent LLA due to diabetes will require amputation of the other leg in the following years. (Limb Loss Statistics - Amputee Coalition, n.d.). In 2020 in the US there were estimated 30.3 million person with diabetes, 1 out of 10 people and 1 out of 3 people with prediabetes (CDC, 2020).

In between 1997 and 2018 in the hospitals of Finland 34,361 individuals have been treated with a LLA and the study finds a 25% increase in this procedure. This could be explained by the rise of patients with diabetes mellitus worldwide and the fact that diabetic ulcer is the biggest risk factor of LLA. The International Diabetes foundation estimated that in between 2019 and 2045, 300 million more people will be affected by diabetes around the globe (Ponkilainen et al., 2022).

All things considered the increase in eventual LLA should address the need for rehabilitation of patients. The author decided to write about the physiotherapy rehabilitation process of LLA and create a material which can be used by physiotherapist students.

2 AIM AND OBJECTIVE OF THIS THESIS

The aim of this thesis is to improve the knowledge of physiotherapy students about rehabilitation for adults with LLA. The objective is to create an independent study material for physiotherapist students, the study material will be provided with a PowerPoint presentation in Moodle.

3 LOWER LIMB AMPUTATION

3.1 Causes of lower limb amputation and complex cases

The main causes of amputations can vary from country to another, amputations in war zone or earthquake areas are mainly the result of trauma while in non-war zone areas the cause of traumatic amputations is mainly due to traffic or work accidents. In the western countries the amputations are done mainly due to peripheral vascular disease, due to diabetes in most of the cases, while the amputations in developing countries are usually caused by trauma (Engstrom & Van de Ven, 1999, p.3).

Amputation is chosen as a treatment option of last resource for patients when other treatment procedures are unsuccessful or weren’t a suitable option. In approximately 75% of amputation cases in older adults, it is the result of vascular disease which can be the cause of a systemic problem usually as diabetes, arteriosclerosis, embolism, venous insufficiency or peripheral vascular disease and cigarette smoking can also be one of the risks factors. When amputations are caused by trauma the most common reasons are from compound fractures, blood vessels rupture, compression injuries, severe burn and cold injuries which can be due to gun shot, stabbing or traffic accidents (David J. Magee, 2021, p.1162).

Sometimes patients with amputation have or may develop – even as a result of the amputation, other health conditions such as sensory disorders, neurological or orthopedic conditions and this can make rehabilitation more challenging. These conditions can happen at different stages before or after the amputation, and it is important as a healthcare professional to identify challenges associated and treat each patient individually (Engstrom & Van de Ven, 1999, p.284).

Some examples, in the case of hemiplegia following a stroke, it can occur in the same side or opposite side of the amputated limb. Depending on the severity, hemiplegia on the opposite side of the amputation can lead to major mobility dysfunction. A person with paraplegia rarely uses prothesis and the focus in their rehabilitation could be to retrain sitting balance, transfer, and the use of a wheelchair independently. With progressive neurological diseases such as multiple sclerosis, Parkinson's disease or motor neuron disease, locomotion and balance can become challenging. The goal of the rehabilitation will be defined individually, but often the use of a prothesis can be difficult and the use of a wheelchair or walking stick may be preferred (Engstrom & Van de Ven, 1999, p.284 – 285).

Sensory disorders such as visual or hearing impairment and vestibular disorder are other disabilities to consider. Diabetes mellitus can sometimes be the cause of visual impairment, this requires proper explanation of the sensation with the use of the prothesis during gait re-education. In the case of vestibular disorder, the balance can be a challenge to prosthetic rehabilitation and proper assessment and training is necessary (Engstrom & Van de Ven, 1999, p.286).

If mental health issues are detected, the healthcare professionals should collaborate with a psychiatrist closely as the patient can possibly be a danger to himself. Self-damaging of the residual limb, also called stump abuse, or other harmful behavior suggesting a mental disorder should require close attention to and the observation of the patient (Engstrom & Van de Ven, 1999, p.291). Other conditions affecting the rehabilitation of a patient with amputation can be due to orthopedic conditions like fracture or joint replacements, burned grafted skin, infections, prosthetic suspension like osseointegration (Engstrom & Van de Ven, 1999, p.286).

3.2 Types of lower limb amputation

LLA can occur at varying level from the toe to the hip. The higher the level of amputation is, the greater it will affect the overall functional ability (David J. Magee, 2021, p.1164). The goal in the surgery is to save the most bone and joints possible and to allow adequate tissue coverage for the residual limb (RL) that will assist the eventual use of a prosthetic. In order to cover the wound with RL, different surgical procedures can be done, for example in some cases other skin flaps of the body can be used (O'Sullivan & Schmitz, 2019, p.953).

Hemipelvectomy also called hindquarter amputation refers to a part of the pelvic removed, and a hip disarticulation is an amputation that is the removal of the femur through the acetabulum. These amputations are rare and usually caused by malignant bone tumors (Engstrom & Van de Ven, 1999, p.149). Trans-femoral amputation refers to an above knee (AK) amputation, which is a frequent type of amputation. It can occur at different levels of the femur and be categorized to short femoral amputation with 35% of femoral length remaining, trans-femoral when 35% to 60%, and long femoral when the length of the femur is above 60% (O'Sullivan & Schmitz, 2019, p.953).

A knee disarticulation refers to an amputation through the knee joint, below the knee (BK) also known as transtibial amputation can occur at different length of the tibia and fibula, from short BK, which is less than 20% of the tibia length, 20% to 50% is medium BK and exceeding 50% its considered as a long BK (O'Sullivan & Schmitz, 2019). LLA includes amputation of the mindfoot or hindfoot, for example Syme's amputation which is a disarticulation of the ankle joint or Chopart amputation which is a partial tarsal amputation thought midtarsal joints. Additionally, there is also Lisfranc amputation (also called tarsometatarsal amputation) which is the complete amputation of the metatarsal, transmetatarsal amputation, when the amputation occurs at the midsection of the metatarsal bones or finally toe amputation concerning the removal of one or more toes. The picture 1 below illustrate those common levels of LLA (David J. Magee, 2021, p.1164).

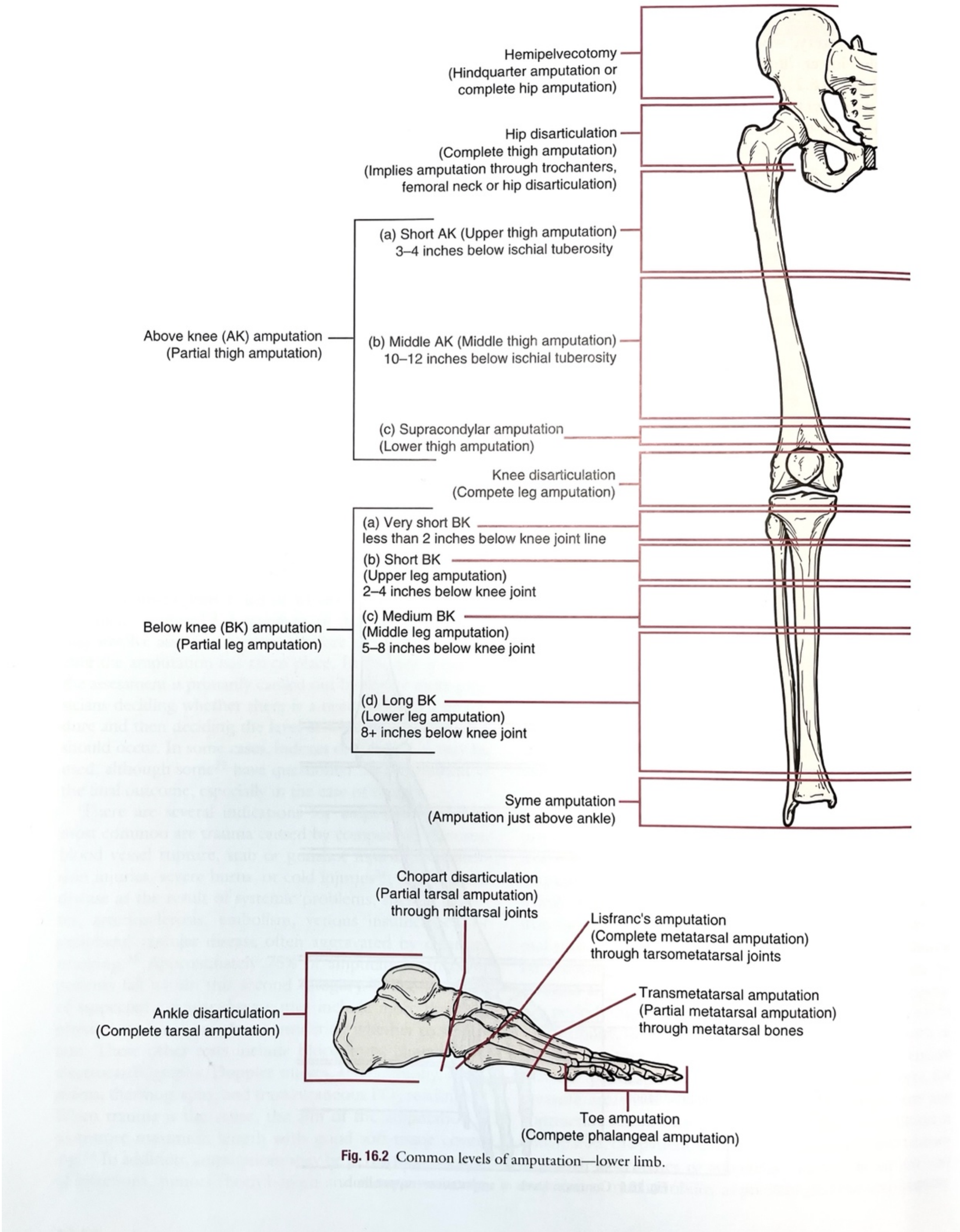


Fig. 16.2 Common levels of amputation—lower limb.

Picture 1. Common levels of amputation of lower limb amputation (David J. Magee, 2021, p.1164)

3.3 Impact of lower limb amputation on biomechanics

LLAs have an impact on movement and locomotion and the understanding of the biomechanics in LLA by physiotherapists is important to optimize rehabilitation of the patient and the use of a prothesis. The center of mass of the patient following LLA is changed, and the patient is developing compensatory strategies, it affects the stability and the walking pattern of the patient using a prothesis. When using a prosthetics a person increases its energy expenditure while walking, understanding the compensatory strategies of gait deviation of a person with LLA will help patient to optimize their daily life and prosthetic use (Friedel, 2020, p.)

Hindquarter and hip disarticulation implicate amputation of the muscles surrounding the pelvis. At this level of amputation, functionality is challenging, and energy consumption is high, as there is no residual limb to act as a lever in controlling the prosthetic (Engstrom & Van de Ven, 1999, p.149). For this type of amputation the control of the pelvic lordosis, its range of motion, and abdominal strength are necessary to potentially achieve movement with a prothesis and balance on a single leg should also be trained to promote autonomy and prevent falls. (Prosthetics for Individuals with Hip Disarticulation and Hemipelvectomy Amputations - Physiopedia, n.d.).

In trans-femoral amputations, the longer the residual limb length is, the better the muscle control and leverage will be and it widens possibilities in prothesis options. The above-knee amputation when using a prothesis also requires high energy consumption due to the use of an artificial knee joint (Engstrom & Van de Ven, 1999, p.161). A study compared the moment arm of the adductor muscles and found the adductor magnus muscle to have a significant impact in maintaining the femur in its anatomical axis. The lack of function in this muscle would cause the residual limb to abduct causing greater disfunction in walking with a prothesis (Gottschalk & Stills, 1994).

Patients with a knee disarticulation have a greater base of support than patients with transfemoral amputation, the remaining femur and muscles surrounding it facilitate sitting balance and transfer due to a longer lever arm (Stark, Gerald BSME, CP, 2004). The patients with trans-tibial amputation have greater success in gait with prothesis use, the knee joint having an important impact on the gait pattern and less energy is consumed due to a long lever arm (Engstrom & Van de Ven, 1999, p.187). In transtibial amputation the lack of plantar flexor muscles, responsible for about 80% of the power during gait generate increases in compensatory strategy of the muscles surrounding the hip, that can be responsible for asymmetries in gait (Soares et al., 2009).

Patients with ankle disarticulation can usually acquire independency faster than patients with amputations mentioned above, particularly in walking. This is explained by the longer arm applying force and the distal structure of the bones that allow direct weight-bearing in the prothesis. Energy consumption during gait is reduced, and a successful prosthetic user can acquire a standard lever arm during ankle push-off allowing better stability (Pinzur, 2010).

Mindfoot amputations has still major impact in the biomechanics, removal of the metatarsal head impacts the gait and patient undergo considerable mechanical adaptation. The plantar flexion of the ankle during gait is minimal, and the primary force of power is generated by the hip joint (McGuire et al., 2021).

Different gait deviation can be observed in patient with LLA, depending on the amputation level and the patient condition in can affect the overall locomotion. This can be caused by the lack of stability, muscle imbalance or weakness, stump discomfort or pain. During the stance phase of gait lateral inclination to the prosthetic side is observed. This can be due to the length of the prosthetic being too short or its incorrect alignment, also socket joint can incorrectly be align and excessive plantar flexion of the prosthetic causing the knee joint not to flex properly or have delayed flexion. In opposite if the prosthetic foot is overly dorsiflexed it could cause too early and excessive knee flexion during drop off in the stance phase. During the heel strike, inward rotation of the foot can occur if the plantar flexion resistance is too hard or is a poor suspension of the socket. Also, when the weight is not properly applied on the prothesis it can cause uneven step length (Friedel, 2020, p.72).

4 PREOPERATIVE STAGE

4.1 Patient assessment

In cases of traumatic amputation, a preoperative phase of rehabilitation may not be possible due to the sudden and unexpected nature of the injury. For patients with peripheral vascular disease and critical limb ischemia, where amputation is considered a potential intervention, the optimal approach is to initiate a preoperative intervention with the patient prior the amputation procedure (O’Sullivan & Schmitz, 2019, p.958).

In the preoperative stage, it is crucial for the physiotherapist to gather important information about the patient. This includes their background, medical and psychological history, employment status, hobbies, family situation, involvement in the community, and how the patient is currently feeling and perceiving their situation. The information of the background of the patient are necessary to elaborate strategies to create a personalized rehabilitation plan (David J. Magee, 2021, p.1165). Factors such as age, previous health condition, mental statue and level of amputation would considerably influence the resources needed for rehabilitation (Kevin Chui, Milagros Jorge, Sheng-Che Yen, 2019, p.441). Studies have shown that quality of life after amputation is influence by socioeconomic statue (David J. Magee, 2021, p.1165).

It is important to determine individual believes, expectations and goals, the assessment should include the physical and psychological aspects of patient life as different factors can potentially influence the engagement of the patient in the rehabilitation process. Information like possible substance abuse and the patient coping strategies will help the team of professionals to understand the potential prognosis of the rehabilitation plan’s success. Also, information regarding the living environment of the patient such as if the home is accessible and considering eventual needs for adjustment. If the patient can drive or would be able to use public transportation and how they can access those. It is important to know how the patient is going to be able to keep going with his life, for follow-up appointments with healthcare professionals these information’s would help to anticipate the discharge planning (Kevin Chui, Milagros Jorge, Sheng-Che Yen, 2019, p.508).

During the interview understanding the current emotional state should also be identified in order to support eventual depression or anxiety regarding the amputation procedure. Often a person undergoing amputation can have a loss of confidence and self-body image. Attention in the eventual need for psychological referral should be addressed. The current involvement of the patient, or readiness to be involved in physical activity is also an important factor to consider for the rehabilitation (Kevin Chui, Milagros Jorge, Sheng-Che Yen, 2019, p.508).

Physiotherapists want to determine the ambulatory status of the patient before the operation, by observing the current gait and the need and use of assistive devices. They determine the required assistance that the patient is going to need while walking, the distance that the patient can walk. Other comorbidities need to be considered as they could affect ambulation. This information is an important predictor in the potential use of a prosthetic. At this point in the rehabilitation the primary focus is the safety and functionality of the walking pattern (Kevin Chui, Milagros Jorge, Sheng-Che Yen, 2019, p.525).

Also, in the pre-operative phase a physiotherapist should assess the range of motion (ROM) and functional level, the muscle strength, and the functional mobility bilaterally to provide comparison in future assessments, and any abnormal tissue should be recorded. The physical fitness should also be measured as patients with LLA experience increased energy demands. (David J. Magee, 2021, p.1162)

4.2 The physiotherapist in a multidisciplinary team approach

The rehabilitation of the LLA requires the collaboration of the physiotherapist with specialists of a multidisciplinary team (MDT) to optimize outcomes in the rehabilitation. A study with 61 individuals following amputation shows the evidence that the model of MDT predicts 85% of successful prosthetic users. For this each member of the team needs to be aware of the role of others and communication should be effective. The physiotherapist can collaborate with nurses, surgeons, general practitioner, prosthetist, dietician, psychologist, social workers, or adapted devices services (BACPAR, 2016).

Members of the MDT can vary in size depending on the patient needs, nevertheless the focus of the team should be in the patient receiving the amputation and their relatives which is particularly important at this preoperative stage. Health care providers should consider the concerns and expectations of the patient as these have an impact on the success of the rehabilitation (Kevin Chui, Milagros Jorge, Sheng-Che Yen, 2019, p.505).

In the clinical guidelines of British association of physiotherapist, they recommend the physiotherapist to motivate and support patients in adopting a self-management approach during their rehabilitation journey. Also, like other member of the MDT they should know how to connect and involve other professionals' who are part of the rehabilitation team and be involved in evaluation of the patient. This way, the patient can receive comprehensive and specialized care from different professionals, each contributing their expertise to improve well-being of patients (BACPAR, 2020).

4.3 Prevention and psychological support

An important role of the physiotherapist in the preoperative stage is to educate patients and their relatives about the importance of physiotherapy rehabilitation by familiarizing them with what to expect after the surgery, and preparing them physically and psychologically (Siraj et al., 2022).

At this stage, patient can already encounter feelings of anxiety and depression. It has been demonstrated to impact both postoperative pain intensity and the presence of chronic pain after amputation. Healthcare providers should take these factors into consideration when creating a care plan (Kevin Chui, Milagros Jorge, Sheng-Che Yen, 2019, p.533).

These emotions of social discomfort or body-image anxiety can lead to depression and limitations in activities, particularly during the two first year after amputation and can impact rehabilitation. For patients to better adapt to limb loss, having more social support, feeling more satisfied with the prosthetic limb, actively using coping strategies can be beneficial (Horgan & Maclachlan, 2004). Early treatment for anxiety should be addressed and physiotherapist guidance enhance these challenges. Psychological screening test can be used as for example the Personality inventory (MMPI) to help detect depression (David J. Magee, 2021, p.1177).

Discussing with patients about prosthetic rehabilitation and interacting with successful prosthesis users can reduce fear and improve readiness for amputation. These discussions can empower patients and lead to better rehabilitation outcomes (O'Sullivan & Schmitz, 2019, p.958).

4.4 Preoperative conditioning and pain management

At this stage physiotherapist can begin physical rehabilitation with the patient as muscle strengthening or enhancing the range of motion. They can also practice transfer skills, wheelchair mobility or ambulation with assistive devices and teach care techniques to the patient for skin protection (Kevin Chui, Milagros Jorge, Sheng-Che Yen, 2019, p.441).

The Gülhane Hospital in Germany with experience in lower limb amputation, employs a physiotherapy protocol in the preoperative stage to enhance joint range of motion, stretch and strengthen lower limb key muscles and trunk, perform gait exercises without loading on the affected limb, conduct posture exercises and engage in respiratory and aerobic exercises (Demir & Aydemir, 2020).

A case study shows the preoperative physiotherapy rehabilitation plan of a 65-year-old man who underwent an above-knee amputation due to gangrene that develop into peripheral vascular disease. This plan included prevention of circulatory obstruction and respiratory complication, stretching and strengthening of the upper and lower limbs, gait training with crutches, as well as patient and relatives' education about the importance of rehabilitation and care technique to prevent friction and infection. The picture 2 below illustrates the preoperative physiotherapy protocol chosen for this patient and can be an example applicable as a preoperative treatment. Nevertheless, treatment should be individualized to each patient (Siraj et al., 2022).

Preoperative	Goals	Intervention	Treatment dose
	To give awareness of the condition to the patient and family.	Educate the patient and caregivers about the importance of physiotherapy. Counseling for control of addiction. Psychological counseling.	
	To prevent circulatory obstruction.	1. Ankle pumps. 2. Dynamic quadriceps.	10 reps × 3 sets
	To prevent respiratory complications.	1. Thoracic expansion 2. Pursed lip breathing.	10 reps × 3 sets
	To stretch, and Strengthen individual muscles of the upper and lower limbs. To prevent extensor lag.	1. Stretching for the right hand. 2. Weight lifting according to 1RM for shoulder, elbow, wrist, and fingers. 3. Vastus medialis strengthening.	10 reps × 3 sets
	To train gait with walker/crutches.	1. Focus on each component of gait cycle. Explain the different gait patterns.	100 feet × 3 sets
	To teach techniques for suture care.	1. Prevent friction. 2. Prevent infection.	

Picture 2. Preoperative physiotherapy protocol for a patient of 65 years old having a above knee amputation following a peripheral arterial disease (Siraj et al., 2022).

When applying stretching around the affected limb in cases of peripheral vascular disease amputation, the duration of stretching should not exceed 6 seconds. This is because prolonged stretching can create tension on fascia and surrounding muscles, potentially having a negative impact blood circulation or arterial flow. It should be gentle and controlled stretches within a comfortable range of motion, without causing any discomfort or pain (Arribart, 2019).

Additionally, patient education and involvement of family member concerning phantom limb pain and RL pain already at this stage is important by setting realistic goals about pain expectation. Despite their actual reported pain levels, patients who have realistic pain expectations for the year following amputation tend to experience a higher level of satisfaction in their rehabilitation (O'Sullivan & Schmitz, 2019, p.958).

Physiotherapists should consider implementing prophylactic pain management strategies to improve outcomes the physical rehabilitation of the patient. Pain, which can arise from multiple factors, may manifest both before and after surgery. Pain assessment is crucial during all stages of rehabilitation. Standardized assessment tools like the Visual Analog Scale (VAS), Short Form McGill Pain Questionnaire (SF-MPQ), or Pain Interference Scale (PIS) can be used by the healthcare professional to evaluate pain. Pain intensity should be measured at specific sites, including phantom limb pain, residual limb or low back pain, ensuring a comprehensive evaluation of pain-related limitations (Blake et al., 2007, p.24).

Physiotherapists have the option to employ non-pharmacological methods for managing patient pain. These techniques include transcutaneous electrical nerve stimulation (TENS), desensitization, scar mobilization, relaxation, and biofeedback. These approaches should be customized to suit each patient's unique needs, enhancing their pain management experience (Blake et al., 2007, p.24).

5 ACUTE POSTOPERATIVE STAGE

5.1 Postoperative assessment test and measure

In cases where preoperative assessment is not possible, post-surgery rehabilitation referral is essential as soon as possible. Delaying these referrals often leads to muscle and joint contractures, worsened cardiovascular and musculoskeletal health, postponed prosthetic fitting, increased dependency risk, and there is a higher chance that amputation reoccur. It also can cause longer care in institutionalization and increase mortality risks. As during the preoperative assessment, patient medical and social history is necessary to determinate the possible complication that could affect rehabilitation (Kevin Chui, Milagros Jorge, Sheng-Che Yen, 2019, p.507).

After the surgery a physiotherapist should assess the patient to determine the functional limitations using different tests and measures. These evaluations serve as a baseline for diagnosing movement-related issues, determining the prognosis of the rehabilitation and ability to evaluate rehabilitation outcomes. Certain adjustments may be necessary and specific to the conditions of the patient. For example, adaptations may be required depending on the level of amputation and eventual residual limb length, such as modifying the point of resistive force application during manual muscle testing for knee extension strength following a transtibial amputation. It's essential to consider that altering measurement techniques can impact their reliability and accuracy. The tests and measures suitable for the postoperative stage are detailed in the table 1 below (Kevin Chui, Milagros Jorge, Sheng-Che Yen, 2019, p.510).

Table 1. Test and measures in the postoperative and preprosthetic period (Modified from Kevin Chui, Milagros Jorge, Sheng-Che Yen, 2019, p.510).

Category	**Example of test and measure strategy**
Pain	- Description of nature or type of the pain - Visual analog scale for intensity of pain - Body chart for location of painful areas - Description of factors increase/ decrease pain
Physiological Measurements	- Residual limb length - Residual limb circumference - Edema type and location
Skin and circulation condition	- Condition of the incision - Condition of the intact limb; skin color, elasticity, temperature - Palpation of peripheral pulse

Cognition and Psychologic	- Mini-Mental State Examination, Mini-Cog - Delirium scales - Depression scales - Montreal Cognitive Assessment (MOCA)
Sensory integrity	- Protective sensation ; Semmes-Weinstein mono filament test (SWM) - Proprioception and kinesthesia - Vestibulo-ocular function during position change - Hearing impairment
Joint mobility	- Manual examination of ligamentous integrity - Documentation of bony deformity
Aerobic capacity and endurance	- Heart rate at rest and maximal attainable in activity - Arm ergometry, single limb bicycle ergometry and - combined upper extremity/lower extremity ergometry. - Respiratory rate at rest and during activity - Ratings of perceived exertion or dyspnea (Borg or visual analog)
Transfer mobility	- Observation of bed mobility - Observation of transitions - Observation of description of level of assistance
Balance	- Static postural control (various functional positions) - Anticipatory postural control in functional activity - Reaction to perturbation - Specific balance tests (Berg, Functional Reach)
Gait and locomotion	- Use of assistive devices - Level of independence, cueing or assistance required. - Time and distance parameters (velocity, cadence, stride) - Pattern and symmetry

	- Perceived exertion and dyspnea
Muscle Strength	- Strength: manual muscle test, handheld dynamometer - Manual resistance through range at various speeds of contraction - Endurance: 10 repetitions maximum, or maximum number contractions, time to fatigue
Neuromotor function	- Observation of quality of motor control in activity - Observation of efficiency of motor planning - Muscle tone - Reflex integrity
Patient self-care / Home management	- Observation of BADLs and IADLs - BADL and IADL rating scales (Basic activity of daily living and instrumental activity of daily living)

A thorough examination of the residual limb is essential to monitor healing and potential issues. To begin the assessment, the examiner evaluates the intact limb, checking for sensation, pulses, temperature, and skin health. The examiner pays close attention to swelling, skin condition, and any joint contractures, particularly if the amputation is near a joint. The patient should be observed standing, sitting, and walking. Special attention is given to the remaining limb, which will now bear more functional and mechanical stress due to the loss of the other limb. For LLA this remaining limb takes on a greater load during walking. The observation ensures proper care and eventual prosthetic fitting for the amputee's optimal mobility and comfort (David J. Magee, 2021, p.1168).

The examiner touches the limb gently to see if it's tender or if there are any lumps or areas of pain that might affect rehabilitation. The movement of the joints in the remaining part of the limb is tested, comparing it to the other leg including the hip, knee, and ankle. This helps find any limits or stiffness that could affect how the person can move. The strength of the muscles that are still there is also checked, as well as the condition of the ligaments and tendons. This part of the assessment is essential to help customize the rehabilitation plan and eventual use of a prosthetic leg (Video 1 - Patient Evaluation - YouTube, n.d.).

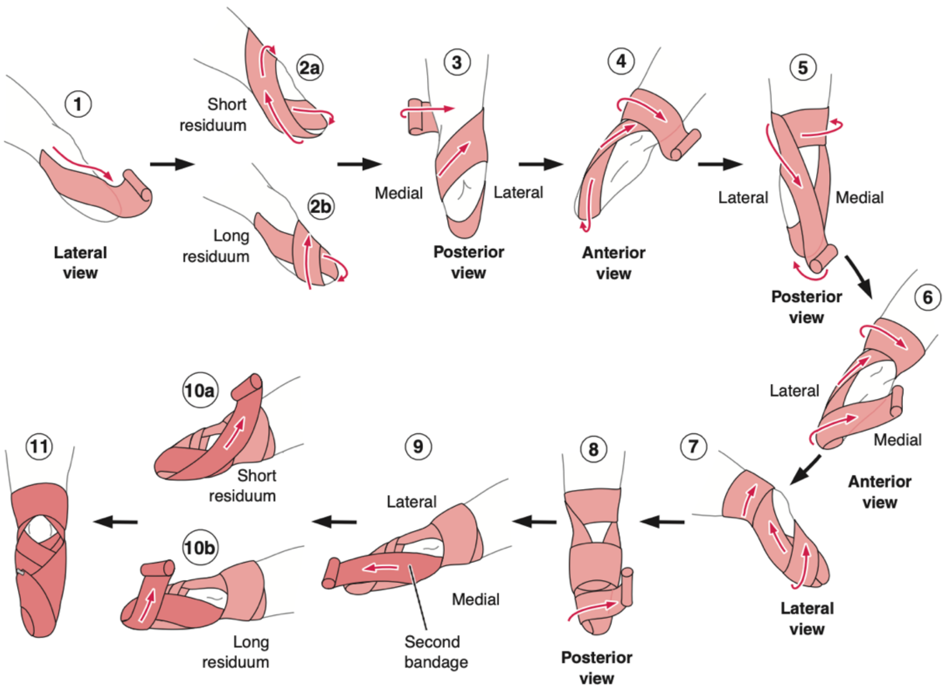
5.2 Residual limb and wound healing

The healing process of the residual limb (RL) is a key component at this stage of the rehabilitation and each patient healing is influenced by a multitude of factors. Among the most significant postoperative concerns is the risk of infection, which can arise from external or internal sources. Individuals with wounds that have been contaminated due to injury or infected foot ulcers are vulnerable to infection. Some conditions that can affect wound healing are vascular issues, diabetes, renal disease, cardiac disease and other physiological complications. Also, research has shown that smokers had a 2.5% higher chance to infection and a new amputation compared to non-smokers. To enhance the wound healing process, physical therapists play an active role by educating patients on proper bed mobility, minimizing pressure on newly amputated limbs, and promoting mobilization. (O'Sullivan & Schmitz, 2019, p.956)

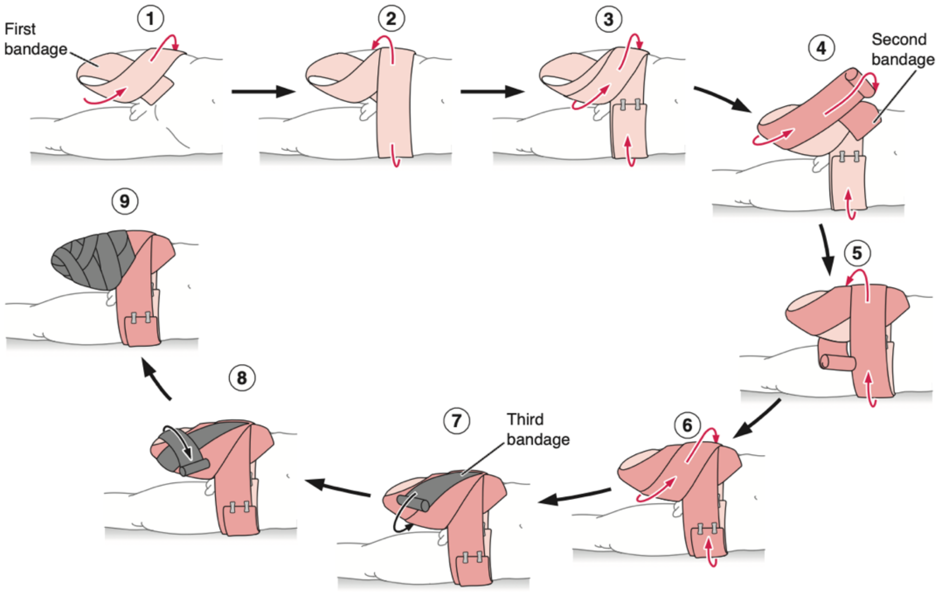
Post-surgical dressing options for individuals with LLA include rigid dressings, semirigid dressings or soft dressings. Rigid dressings include removable rigid dressings (RRDs) and immediate postoperative prostheses (IPOPs). RRDs, is either custom-made or prefabricated, they are applied over the residual limb, while IPOPs are surgically applied by immobilizing the knee. This option is mostly for patient with transtibial amputation. IPOPs is providing good edema control, ensuring optimal RL protection, and effectively managing RL pain, and contributes to decrease in time to fit a prosthetic limb. However, these options require careful patient selection, including the absence of infection and the patient's ability to understand postoperative instruction. Those are expensive options that require a skilled practitioner to fabricate it (O'Sullivan & Schmitz, 2019, p.957).

Semirigid dressings, known as Unna's dressings, consist of a bandage infuse with a mix of zinc, oxide, gelatin, glycerin, and calamine. It offers a better healing and edema control than soft dressing, though they may loosen easily. It needs frequent changing, and it cannot be applied by the patient (O'Sullivan & Schmitz, 2019, p.956-957).

Soft dressing represents the oldest approach to manage the RL after surgery, and it's the one most frequently encountered by physiotherapist in acute care settings. A soft postoperative dressing consists of a nonadherent, wide and elastic dressing placed over the surgical incision. The goal is to ensure proper compression and it must be applied to distribute even pressure across the residual limb. This compression aims to manage edema and facilitate the healing process. Some surgeons may delay the use of elastic wrapping until the incision has fully healed and sutures have been removed. This delay allows for the full development of postoperative edema, potentially reducing pain and the risk of compromising circulation in the skin. The pictures 4 and 5 below illustrate the application of bandage technique for a transtibial amputation and a transfemoral amputation (O'Sullivan & Schmitz, 2019, p.957).

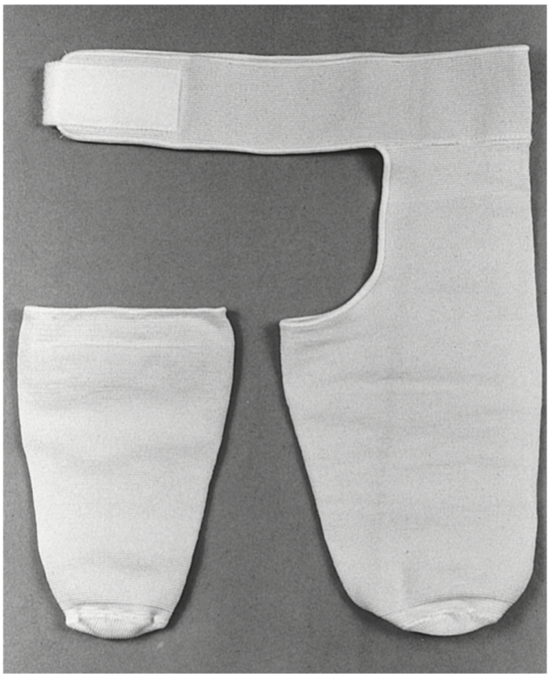


Picture 4. Elastic bandaging technique of transtibial residual limb (O'Sullivan & Schmitz, 2014, p.1013).



Picture 5. Elastic bandaging technique of transfemoral residual limb (O'Sullivan & Schmitz, 2014, p.1014).

Also, as a soft dressing elastic shrinkers can be used. They are conical in shape and are available in various sizes and can be challenging to apply. Pulling the shrinker onto the residual limb during the healing process may also apply pressure on the still-healing incision. An alternative approach involves the use of silicone liners that are applied through a process, which is gentler on the healing incision. Another consideration with shrinkers is that as the RL gradually decreases in size during the healing phase, multiple sets of shrinkers must be needed in smaller sizes until the limb volume of the patient stabilizes. Therefore, shrinkers are most effectively utilized after a considerable period of healing has occurred, picture 6 below show two types of elastics shrinkers. (O'Sullivan & Schmitz, 2019, p.958).



Picture 6. Left side a transtibial elastic shrinker and the right a transfemoral elastic shrinker (O'Sullivan & Schmitz, 2014, p.1005).

The physiotherapist educates patients and their families on effective edema management techniques, while remaining vigilant for excessive bleeding or drainage when using IPOPs or RRDs. The primary focus revolves around teaching patients how to protect their residual limb during movements such as sitting up in bed or transferring, emphasizing the avoidance of pressure (O'Sullivan & Schmitz, 2019, p.957). Also maintaining proper hygiene and skin care for RL is important, involving regular cleaning and drying. Careful attention is needed to prevent abrasions and cuts. Gentle scar massage techniques, applied after wound healing and without infection, can prevent the formation of adherent scar tissue and hypersensitivity. Regular inspections, particularly for those with reduced sensation, is important to identify eventual sores on the RL (O'Sullivan & Schmitz, 2019, p.971).

5.3 Complication and pain management

Pain management can be a challenge following amputation and individuals with a recent amputation often have acute postoperative pain. RL pain can arise from various causes such as palpable neuromas or formation of spurs at the amputated bone end.

Phantom limb sensation, which is a painless perception of the amputated limb sometimes accompanied by tingling, can be encountered. These sensations usually fade away naturally without intervention. Patients, in their subconscious state, might unknowingly attempt to stand with both legs leading to potential falls (Leg Amputation Rehabilitation - Special Subjects - Merck Manuals Professional Edition, n.d.).

About 54% to 99% of patient experience phantom limb syndrome, before the surgery it's important to discuss postoperative phantom limb sensations with the individual and their family. These conversations should continue after the operation. Phantom limb sensations can be intense and disturbing with a recent amputation. Discussions about this phenomenon helps alleviate anxiety and raise awareness about safety risks, reducing the chances of falls and related injuries, which can affect rehabilitation and prosthetic fitting (Kevin Chui, Milagros Jorge, Sheng-Che Yen, 2019,p.512).

Phantom limb pain is another possible complication that can be severe and requires diverse treatments like exercise, massage, mechanical devices, and medications (Leg Amputation Rehabilitation - Special Subjects - Merck Manuals Professional Edition, n.d.). It's caused by the eventual spinal cord injuries following the tearing of a nerve root and about 80% individuals who have undergone amputations experience phantom pain. Phantom pain can be experienced differently in intensity, frequency, duration, and sensation. The pain spasms can be an intense experience for the patient, manifesting as a painful ache, burning or electrical sensations. It can arise in the first post-surgical week and may stabilize over a few months but can unpredictably reappear months or even years later. Usually, it tends to gradually diminish in terms of frequency, duration, and intensity during the first six months. Complications in the healing process can contribute to its persistence, and comprehensive pain management strategies are required for the rehabilitation (David J. Magee, 2021,p.1167).

In a randomized controlled trial, participants were divided into two groups of twelve each. Both groups received mirror therapy and routine physical therapy, while the experimental group was additionally provided with phantom motor exercise (PME). The results showed a significant decrease in pain, as measured by the VAS, in the experimental group. This study concludes that the incorporation of PME enhances pain management control after amputation, highlighting its efficacy in improving the overall patient experience (Zaheer et al., 2021).

Therapists must employ various methods and assessment tools to assess the character, location, and intensity of the individual's pain. It's also important to evaluate the extent to which pain disrupts daily functions, identifying activities or circumstances that exacerbate the pain. Documenting pain management approaches is also important because certain medications like opioids can potentially impact attention, learning ability, and response time during mobility and balance activities (Kevin Chui, Milagros Jorge, Sheng-Che Yen, 2019, p.511).

Treatment options are diverse and cater to different causes of pain. Pharmacological interventions, such as post-operative analgesia, anti-inflammatories, opioids, and nerve blocks, are commonly used. Electrophysical therapies like TENS, laser, ultrasound, and heat can be beneficial, while prosthetic adjustments, physiotherapy, and early mobilization are essential for managing pain related to prosthetic use and gait abnormalities. Stump management techniques, including reducing stump edema through bandages or compression therapy, massage to mobilize scar tissue, and improving stump hygiene, are crucial. Additionally, alternative modalities such as acupuncture, mirror box therapy, hypnosis, and cognitive behavioral therapy, as well as surgical options like stump revision and removal of spurs, provide a comprehensive approach to managing post-amputation pain and improving the patient quality of life (AustPAR - Amputee Pain Management, n.d.).

Physiotherapists should also be attentive to potential complications in the acute stage following amputation, as they can pose significant risks for the patient and affect the rehabilitation process, potentially even leading to a risk of death. These postoperative complications can occur in older patients or in patients requiring blood transfusions, those with wound infections, or individuals with medical conditions such as renal disease, chronic obstructive pulmonary disease, or cardiac issues (Kevin Chui, Milagros Jorge, Sheng-Che Yen, 2019, p.528).

5.4 Postoperative rehabilitation exercises

During hospital recovery, physiotherapists will guide exercises designed to prevent blood clots and enhance blood circulation. These exercises are essential for overall well-being and help maintain a healthy blood supply. These exercises contribute to the recovery process, promoting better healing and reducing the risk of complications (Amputation - NHS, n.d.).

Achieving mobility shortly after surgery is important, commencing when it is clinically safe and in consideration of patient safety and wound protection. Early mobility exercises involve practicing transfers, standing, and walking with the aid of crutches. The utilization of a rigid dressing serves two purposes: safeguarding the stump and reducing potential swelling during mobilization. The primary objectives of early mobility are to sustain muscle strength, preserve cardiovascular fitness, regaining independence to prevent complications like contractures and prepare the patient for the transition to rehabilitation or home discharge (AustPAR - Early Mobility Post-Amputation, n.d.).

Patients are encouraged to engage in gentle, pain-free range-of-motion exercises at the knee and hip, with a particular emphasis on hip extension for transtibial amputations. However, resistive exercises for the residual limb are discouraged at the acute stage, ensuring a comprehensive approach to a smoother recovery process. (O’Sullivan & Schmitz, 2019, p.957). Before engaging in standing and mobility activities, it is imperative to ensure the acquisition of suitable footwear. Furthermore, tailored range of motion (ROM) and strengthening exercises should be introduced based on the specific condition of the remaining limb (O’Sullivan & Schmitz, 2019, p.961).

The role of exercise programs in the rehabilitation of individuals with amputation is important, even though the research of those programs doesn’t confirm their effectiveness, existing evidence displays the benefit of physical fitness in prosthetic success. Preprosthetic rehabilitation includes targeted exercise routines aimed at enhancing muscle function. These exercises focus not only on the RL but also on the intact lower limb and upper extremities. The commencement of resistance exercises for the affected limb depends on various factors, including the type of postsurgical dressing, pain levels, and the progress of incision healing. A critical aspect of these exercise programs is that patients can perform them independently outside therapy sessions. Key muscle groups, such as hip extensors and abductors, core trunk stabilizers, and knee extensors, are specifically targeted for their roles in effective prosthetic ambulation. Exercises such as hip extension against resistance and resistive hip abduction exercises, are designed to imitate muscle activities during walking and replicate pressures experienced within a prosthetic socket. By engaging in these exercises, individuals with amputation are better prepared for successful rehabilitation, ultimately leading to improved mobility and prosthetic functionality (O'Sullivan & Schmitz, 2019, p.970-971).

6 PREPROSTETIC REHABILITATION STAGE

6.1 Assessment and prognosis for a prosthesis

At the preprosthetic phase, the patient can be discharge from the acute care and prepare for the fit of a protheses. Intense program of physiotherapy is recommended at this stage for better outcomes in prosthetic use. The condition of the RL should still be assessed, and the volume and length be measured. Usually, 7 to 12 days after the surgery if the RL is in good condition (O'Sullivan & Schmitz, 2019, p.962).

The assessment of the RL volume and length are important to evaluate the readiness for prosthetic as it would impact the types of socket design used. These measurements should be frequently tracked during rehabilitation to promote success in the prosthetic fitting. RL length is measure in circumference with a tape, the bone length and the total limb length to ensure precision of the measure. Usually, the referral for a prosthetic can be made if the distal limb circumference is equal or no more than ¼ greater than the measurement at the proximal limb circumference. With proper care of the RL the circumference distally should be slightly bigger than the proximal circumference, depending of the type of amputation the distal part of the RL can mature in different type of shapes (Kevin Chui, Milagros Jorge, Sheng-Che Yen, 2019, p.512).

Assessing patient with LLA before prothesis use involves evaluate active and passive movements, tests resisted isometric movements and overall functional capacity. Active movements assess muscle strength, endurance, and joint range of motion in the remaining limb, essential for prosthetic use. Passive movements help prevent contractures and restore range of motion and resisted isometric movements check muscle strength and endurance in both limbs, critical for prosthetic function (David J. Magee, 2021, p.1176).

Assessment tools from the postoperative phase table 1 detail assessment tools which can again be used at this stage, but other tools can be used to measure functional capacity and predict prosthetic used. For example, the amputee mobility predictor or the prosthetic profile of the amputee questionnaire to measure functionality and independence (David J. Magee, 2021, p.1176).

The AMPREDICT assessment tool aims to predict the independence of individual after amputation and the successful use of a prothesis. The test considers the level of amputation, the age of patient, the aerobic capacity and comorbidities as measure to evaluate functional capacity after amputation. Other studies show factors as the cognition, the balance and ability to stand on one leg, the hip extensor strength and even the status of the individual before the amputation as element impacting function and potential use of a prothesis (O'Sullivan & Schmitz, 2019, p.975-976).

Severe dementia, renal disease or advance coronary disease are usually condition affecting the use of prothesis. Underweight or overweight patient may also have difficulty with the use of a prothesis. When different conditions are associated it make it further complicated (Kevin Chui, Milagros Jorge, Sheng-Che Yen, 2019, p.530).

Physiotherapists play an active role in the rehabilitation process as their diagnosis lies on the body structure, function, and limitation of the individuals. The prognosis for potential prosthetic remains challenging and different aspect will help for the decision. All things consider, the factor which predict successful prosthetic use are an overall good physical fitness, and the ability to stand on one leg without assistance. The factors who could affect the use of a prothesis would be delays in wound healing or contractures (Kevin Chui, Milagros Jorge, Sheng-Che Yen, 2019, p.530).

Prosthetic use can cause different problematic like various skin problems, pain of the residual limb or even choke syndrome caused by tight socket obstructing blood flow and creating an ulcer (Selvam et al., 2021). In certain case prothesis may not be a possible option for patient following a LLA. In this case physiotherapist should focus on wheelchair mobility and transfer in the rehabilitation (Kevin Chui, Milagros Jorge, Sheng-Che Yen, 2019, p.556-557).

Nevertheless, rehabilitation should be as intensive as in prosthetic users in upper extremity and healthy lower limb strength. Also, cardiopulmonary exercise to maximize functional potential and balance training is recommended to enhance patient health and functional capacity. It is important to customize these interventions according to the individual potential ensuring a effective approach to their recovery in regaining function and independence (O'Sullivan & Schmitz, 2019, p.976).

6.2 Types of lower limb prothesis

The decision making of the suitability of using a prothesis should me made with the team of health professionals involved and in collaboration with the patient, as the goals and treatment plan of the rehabilitation and expected outcomes should be clearly acknowledged (BACPAR, 2020, p.6).

Prosthetics provide various options tailored to the specific level of amputation. These options include prostheses designed for Symes or ankle disarticulation, below knee prostheses, above knee prostheses, as well as those for hip disarticulation and hemipelvectomy. The objectives of using prosthetics are to replace the missing limbs and restore functional abilities, minimizing energy expenditure during walking. Prosthetics assist individuals with LLA in achieving a stable gait, enhancing their mobility and overall functional capacity. The picture 7 below illustrates the range, spanning from below knee prostheses to hemipelvectomy prostheses (Selvam et al., 2021, Chapter 3).

Picture 7. LLA amputation prothesis: below knee protheses, above knee, hip disarticulation and hemipelvectomy prothesis, (Selvam et al., 2021, Chapter 3).

Prostheses can be endoskeletal or exoskeletal. Endoskeletal prostheses, are commonly used in LLA feature an internal supporting structure with a tube frame, the pylon, crafted from materials such as aluminum, titanium, or stainless steel. This design offers the advantage of comfort during weight-bearing and allows for dynamic alignment, enhancing the user's mobility.In contrast, exoskeletal prostheses have an external supporting structure typically made of wood and covered with plastic lamination. While they are more durable and cost-effective than their endoskeletal counterparts, exoskeletal prostheses tend to be heavier and less comfortable and they are not suitable for all types of amputations (Selvam et al., 2021, Chapter 4.1).

The endoskeletal prosthesis count different components. First, there's the socket, a interface between RL and the prosthesis. The socket serves to protects the stump and offers essential support to generate forces. Additionally, the suspension system securely holds the RL in place. The liner, typically made from flexible fabric, is an integral part that frequently needs replacement, ensuring both comfort and functionality for the prosthesis wearer. The foot and ankle base of the prosthetic allows walking, standing, and provide shock absorption, enhancing mobility and stability for the wearer. In the picture 8 below those different component are illustrate (Selvam et al., 2021, Chapter 4.2).

Picture 8. Components of lower limb prostheses (Selvam et al., 2021, Chapter 5).

Some prostheses are temporary and are used postoperatively for quicker mobility after surgery and can prevent complications. Permanent prostheses are considered once the wound has fully healed and the RL has reached its mature shape. It is essential that the prosthetic device is properly fitted to accommodate changes, especially when the RL shrinks over time, change of the prothesis should be done to ensure that patients can apply appropriate pressure on the prosthesis for them to walk comfortably. In addition, some prothesis are sport-specific and are design to perform special sport activity such as running or skiing. This type of prothesis can be interesting for patient willing to participate in sports activity. (Selvam et al., 2021, Chapter 6).

6.3 Prostheses fitting and osseointegration

The process of fitting a prosthesis involves steps, varying based on the type of prosthesis being used. For the removal of a prosthesis, it requires to remove the suspension system then the socket by sliding the RL out and make sure is no signs of skin damage on the RL. The table 2 below illustrate detailed steps for both above and below knee prostheses fitting (Selvam et al., 2021, Chapter 7-8).

Table 2. Different steps of prosthetic fitting for above knee and below knee prosthesis: modified from (Selvam et al., 2021, Chapter 7-8).

Fitting	**Above knee prosthesis**	**Below knee prosthesis**
Step 1	Check for skin breakdown in RL	Check for skin breakdown in RL
Step 2	Socks to fit the RL into the socket	Remove suspension system and socket
Step 3	Clear wrinkles on sock surface	Turn sock inside out
Step 4	Bend prosthetic in 90 degrees with flat foot	End of the sock against residual limb and roll it on and avoid air or wrinkles
Step 5	Slide RL into socket and loosen suspension system	Place the RL inside socket in ensuring correct foot alignment
Step 6	Stand and hold a stable surface	Push RL in socket
Step 7	Prosthesis under hip joint and straighten the PK	Check alignment of kneecap with socket
Step 8	Adjust RL to fit into the socket and adjust suspension system	Add suspension and check for discomfort

To ensure comfortable use of prosthetic, physiotherapist and patient should be aware of problem caused by improper socket fitting or inadequate prosthetic alignment. It can be cause by improper fabrication or suspension. In case the limb does not fit the socket in can cause pressure in bony end, the change of the socket should occur. When the prosthesis is not well aligned in can cause gait abnormalities and pressure on RL. Realignment of the prosthesis, adjustment and proper suspension should be adjusted to ensure comfort and stability while weight bearing (David J. Magee, 2021, p.1170).

The alignment of the prosthesis must be assessed in static and dynamic. In static the the interaction with the socket, prosthetic knee joint, pylon, ankle/foot, and the floor is examined. This evaluation also considers prosthesis length and the overall fit of the socket on the residual limb. It provides insights into pressure distribution on the residual limb within the socket, impacting both socket pressures and gait biomechanics. Dynamic alignment assessment extends the evaluation to movement, considering suspension and gait symmetry. Both static and dynamic alignment require thorough examination from various perspectives, including anterior, posterior, and lateral views on both the prosthetic and other limb (Kevin Chui, Milagros Jorge, Sheng-Che Yen, 2019, p.682).

It is also possible to directly transplant a metal bar to the residual bone through a method known as osteointegration, bypassing the need for ligament or tendon intervention. This direct fixation facilitates prosthetic fitting, eliminating the requirement for a prosthetic socket. Osteointegration enhances responsiveness and control, improving proprioception and reducing the weight of the prosthesis. Additionally, it eliminates discomfort and the risk of skin breakdown associated with traditional sockets. Sill some risks are associate is the risk of infection, bone fracture, it can be potentially a long recovery as the bone grows around the prosthesis and can cause delays in prosthetic fitting (AustPAR - Osseointegration, n.d.).

Osseointegration, also known as transdermal implantation, might not be suitable for certain patients, especially those prone to infection, poor wound healing, individuals who have undergone amputation due to diabetes, or those dealing with mental health issues. However, a study conducted with a limited number of patients demonstrated positive outcomes for individuals with peripheral arterial disease. It is crucial for a multidisciplinary team to carefully assess the patient's suitability for transdermal implantation. Patients must actively participate and be motivated to adhere to the rehabilitation protocol (Overmann & Forsberg, 2020).

Physiotherapist can be involved in the selection of prosthetic components and must engage with prosthetists in assessing the patient's readiness for prosthetic use or issues related to prosthetic alignment. Clear and effective communication between physical therapists and prosthetists is important for coordination in the rehabilitation process (Kevin Chui, Milagros Jorge, Sheng-Che Yen, 2019, p.441).

7 PROSTHETIC REHABILITATION STAGE

7.1 Biomechanical principles of prosthetic lower limb

Gait cycle consist of two stages, the stance which contribute to 60% of the gait cycle and the swing phase 40%. The stance phase is when the foot is in contact with the ground and start to raise for the next step and the swing phase is when the foot is off the ground. When a person is using a prosthesis, gait pattern is going to be disrupted and cause energy expenditure during gait or lead to overused injury. Physiotherapist should ensure proper alignment of the prosthesis and that patient is having even weight distribution. The foot must be properly in contact with the ground and mobility of the knee in extension and flexion is necessary to ease proper plantar flexion to dorsiflexion (Selvam et al., 2021, Chapter 11.1)

Gait reference line named GRV is referring to the center of gravity line while walking, it is important reference for the adjustment of the prosthetic allowing patient to have correct gait pattern while walking. For transtibial prosthetic users the prosthetic foot must be moved anteriorly for the knee to be behind GRV to insure stability. The concept of heel and toe lever explain stability with transtibial prothesis. When socket move backward, the toe lever is increasing improving the stability and heel lever decreases. Longer heel lever tends to destabilize prosthetic user. The picture 9 below list the effect of prosthetics alignment in transtibial support and show the challenges encounter by individuals in keeping stability while maintaining support with the prosthesis (Chris Kirtley, 2006, p.242).

	Increased stability (reduced heel lever or increased toe lever)	Decreased stability (increased heel lever or reduced toe lever)
GRV with respect to knee	More anterior	More posterior
Knee moment during loading	Less extensor	More extensor
Socket translation with respect to foot	More posterior	More anterior
Ankle angle	Plantarflexed	Dorsiflexed
Socket angulation	More extended	More flexed
Activity level	Sedentary	Active
Potential problem for amputee	May have difficulty unlocking the knee for swing	'Drop off' (knee flexes too early before swing is initiated)

Picture 9. Effect of different prosthetic alignment in transtibial prosthetic users (Chris Kirtley, 2006, p.244).

Too much support of the prosthesis can make the flexion of the knee difficult during swing phase. Stability of prosthetic is also influenced by the angle at which the foot and socket are attached. Slight plantarflexion improves stability, while a flexion of the socket improve control. The socket is usually in 12 to 14 degrees of flexion. This improve motion during walking, compensating for the lack of natural push-off in amputees and prevent knee hyperextension. For patient with transfemoral amputation, control of the prosthetic knee is also required, the knee joint can be attached more backward for stability or forward for control. Different approaches can be used based on individual strength and control abilities. Those with strong hip extensors can lock a single-axis knee by pulling the thigh back. Weaker hip extensors benefit from a weight-activated stance-control knee that locks automatically when bearing weight (Chris Kirtley, 2006, p.243).

A study aimed to compare gait pattern with the use of two type of knee prosthetic system for adult with transfemoral amputation. The knee joint activated braking knee and automatic stance-phase lock knee. The findings of the study reveal that the knee with weight-activated braking resulted in a slightly longer swinging motion during walking and the pelvis tilted forward more with this type of knee, suggesting differences in the stability and movement control. Nevertheless, is many different component of prosthetics, those must be choose and adapt depending of the individual needs allowing better function (Soares et al., 2009).

Most of the time, issues with prosthetic design can impact a person gait and overall mobility. Common problem can occur, for example the foot can swings outward and limit knee flexion due to limited movement in the prosthesis, and limitation can lead to the development of an avoidance mechanism and affecting the person's gait pattern. Also, shoulder depressed towards the affected side is often caused by factors like incorrect prosthesis length, insufficient adduction, or amputee sensitivity. Specific issues with the prosthetic foot, such as excessive heel raise and drop off during late stance, indicate problems like inadequate knee flexion resistance or unproper toe and heel lever placement. Another complication can be caused by abnormal plantar flexion quick after heel strike due to insufficient resistance in the prosthetic foot. Addressing these issues as a physiotherapy are crucial to ensure stable gait for individuals using prosthetics and avoid asymmetric posture (Selvam et al., 2021, Chapter 11.1).

7.2 Gait training exercises

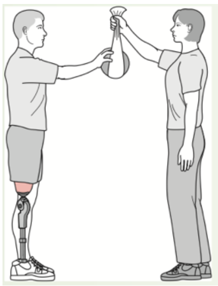
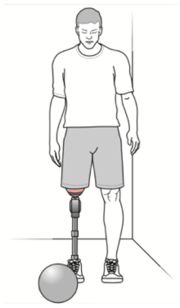
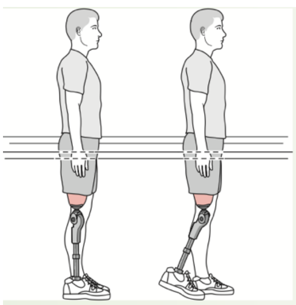
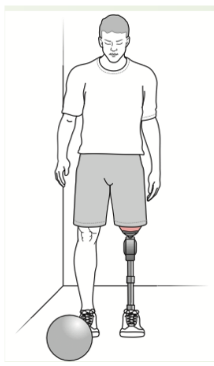
During prosthetic rehabilitation stage physiotherapy still include range of motion, strength exercises and stretches. Balance exercises and gait training should occur more intensively at this stage (Selvam et al., 2021). The aims of the rehabilitation for patient, with or without a prosthesis is to return to daily activities. The physiotherapy rehabilitation focus is gait training, shift safely and adapt to different surface (Kevin Chui, Milagros Jorge, Sheng-Che Yen, 2019, p.441). The physiotherapist's role is essential in identifying abnormal movement patterns. By emphasizing proper posture, weight shifting, proprioception and targeted exercises, physiotherapists and patients aim to enhance prosthesis control (BACPAR, 2020, p.8).

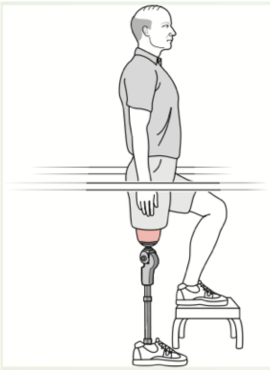
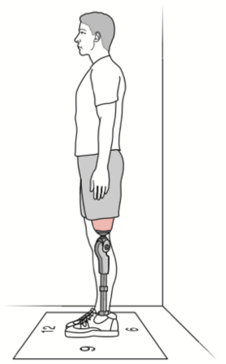
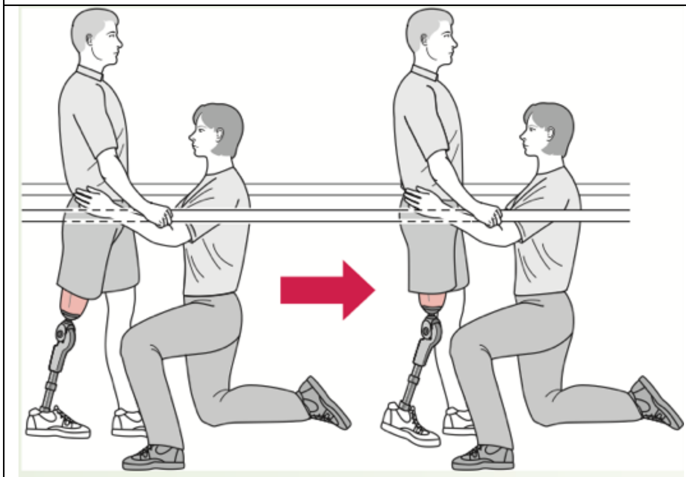
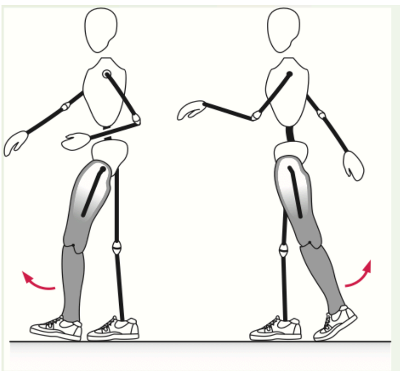
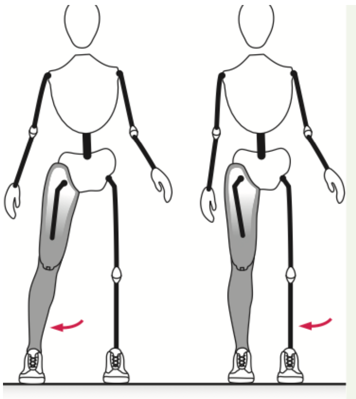
A analyse of ten controlled trials has demonstrated the benefits of strength and functional physical exercises in improving cardiovascular fitness and overall functional capacity among adults with unilateral LLA. Specifically, strength exercises have a pronounced impact on the achievable walking distance (Bouzas et al., 2021).

Concerning gait training, the aim is to assist patient to achieve proper weigh bearing on their new prosthesis with good stability and using the less energy expenditure possible to walk longueur distance and be able to return to their activities. For this physiotherapist work would be to prescribes weight bearing and balance exercises and specific gait training program. Also, functional exercises like sitting and raising from a chair are important type of exercises in the rehabilitation to ensure patient capacity to achieve daily activities (Cross International Committee of the Red, 2018).

Exercises essential for effective gait training involve instructing patients to bear weight on each leg, maintain balance on a single leg, and work through various phases of gait. These types of exercises contribute to improve patient's mobility and ability to walk .For patients with a transfemoral (TF) or transtibial (TT) prosthesis, with adjustment made concerning the knee control step with TF prosthetic user. Specific exercises are showed in the table 3 below (O'Sullivan & Schmitz, 2019, p.1019).

Table 3. Key training type of exercises for lower limb prosthetic rehabilitation table modified from (O'Sullivan & Schmitz, 2014, p.1020-1023).

Key training element – Exercises	Key training element – Exercises
Reaching for object without hand support, change object direction to encourage weight shifting. 	To work on prosthesis control place ball in the front of prosthesis leg and the patient kick the ball. 
Standing without hand support. Trying to bend and flex knee in varying degrees for balance and to test control of the knee. 	To work stability on prosthesis place ball in the front of non amputated leg and the patient kick the ball. 

To work stability with the prosthesis, stand on a stool with unamputated foot and return to the floor with prosthesis. only with TF prosthesis user. 	The patient is having both legs on a paper with a clock. Patient is instruct to place foot in the clock in different order, to train proprioception. 
	Secure standing without hand support with the prosthetic leg behind unamputated leg. Add resistance to forward pelvic mouvement when foot is at initial contact.
Stepping with the prosthesis without support, step forward and back. Focus on knee control with TF prosthesis users. 	Step from side to side and backward with prosthesis leg and with unamputated leg. 

Efficient exercises for patient with amputation of the foot using an energy storing releasing type of prosthesis include, stepping to enhance standing balance on the prosthetic foot, resistive gait training to refine pelvic rotation and movement symmetry during walking, and resistive ambulation exercises to ensure proper balance and toe-loading during specific phases of walking. Ball rolls, performed with the intact foot, focus on strengthening hip muscles essential in maintaining balance on the prosthetic limb. Trunk rotation exercises aid overall balance and movement symmetry. Additionally, patients practice exercises that involve changing direction, turning, and agility, enhancing their ability to move confidently (O'Sullivan & Schmitz, 2019, p.980).

During rehabilitation the use of external support by the patient must be avoided as much possible as individuals can achieve more efficient walking without aids. The use of a walker in prosthetic training should be avoided, except in cases the individuals need it. Also, gait training and detection by physiotherapist of poor posture and abnormal gait pattern are important, specially asymmetry in gait pattern and excessive reliance on unamputated leg can lead to musculoskeletal injuries, arthritis, or knee and back pain (O'Sullivan & Schmitz, 2019, p.981).

Various gait training techniques are employed to enhance the walking ability of patients following LLA. A systematic review study gathered different research studies on this topic, classifying individuals into those undergoing treadmill training and others walking on regular ground. The results suggest significant improvements in gait due to intensive expert guidance. Additionally, advanced techniques such as body weight-supported treadmill training, virtual reality, and gaming have emerged as innovative rehabilitation strategies that have proven to be effective in gait training (O'Sullivan & Schmitz, 2019, p.981).

7.3 Advanced technologies in prosthetic

Prosthetic components have undergone significant technological advancements over the years, revolutionizing the comfort and mobility for patients following amputation. Through the integration of high-quality materials, sophisticated electronics, advanced energy management, and signal processing, and the use of artificial intelligence, prosthesis design and functionality have been significantly improved. The improvement of those prosthetic systems aim to improve natural limbs pattern in responding to patient intentions and their surrounding environment (Domínguez-Ruiz et al., 2023).

A prosthetic bionic limb is a robotic technology which aim to reproduce natural movement and can interact with the body though different ways. It can be through electromyogram signals which record electronic signals send by muscles, it can be iEMG signals detect through wires inserted in muscles or sEMG more commonly use as its less invasive, it used electrodes sensors place around the muscle which measure electric signals of muscles. Those are sending the information through the bionic prosthetic limb using an algorithm to reproduce movement pattern. Another technique is by brain-computer interface which record brain signals and its send to the prosthetic limb using electroencephalography signals (EEG), these are selecting part of the brain associated with the movement to reproduce specific activities. The other option is based by the interaction with environment which would predict movement of prosthetic, this by using camera and force sensors and plates (Domínguez-Ruiz et al., 2023).

Also, prosthetic have been developed for sports activities and athletes. Depending on the type of sports, biomechanical needs can be applied to the prosthetic responding to sports demand. Prosthetics can be adapted to athletes to use the best-fitting socket while changing components for optimal performance and reduced risk of injury. Specialized components like pylons, energy-absorbing ankles, and heels are essential for minimizing forces on the residual limb. Athletes in running or sprinting often use energy-storing feet made of high-performance carbon fiber for enhanced efficiency (Kevin Chui, Milagros Jorge, Sheng-Che Yen, 2019, p.735). In prosthetic foot it is complicated during the push-off as plantar flexors are not possible and can be a problem in running activities or other sports. Technology has developed energy storing foot. It stores energy in the carbon fiber of the prosthesis during the stance phase and reproduce energy when the foot is going the swing phase (Chris Kirtley, 2006, p.262).

The company of prosthetic Össur from Iceland is specialize in prosthetic since 1971 and is one of the leaders in prosthetic innovation they have developed bionic leg, as energy storing foot prosthetics (All About Össur, n.d.). They offer various options and design specific to the sport, as prosthetic foot for distance running, hiking and sports activities or prosthetic for everyday life activities. In the picture 10 below the Flex-Run prosthetic for distance running which can be used for a person following transfemoral or tibial amputation. The Flex-Run prosthetic as a longer toe lever with efficient energy return which make it ideal for high impact activities and running activities (Prosthetic Solutions | Prosthetics | Össur UK, n.d.).

Picture 10. The Flex-Run prosthetic by Össur (Össur. Life Without Limitations., n.d.).

Also, Össur developed the Bionic leg and are offering different type as the Power leg, Rheo leg and Proprio leg which can be choose depending of patient better solution. The Power leg aim to restore motion of walking pattern by replicating musclular motion. It can be featured with a custom socket by Össur, which can be designed perfectly to patient needs, added with a power knee using microprocessor knee technology which adapt to directly to motion. Then different type of prosthetic foot can be choosen depending on the patient daily activities, like Pro-flex XC torsion which able wide range of activities due to is shock absorption and rotation, or like the Proprio foot for patient having more moderate activities and ease walking pattern on different surfaces. The picture below illustrate the Power bionic leg by Össur (Bionic Legs | Bionic Technology by Össur, n.d.).

Picture 11. Power leg the prosthetic bionic lower limb by Össur (Bionic Legs | Bionic Technology by Össur, n.d.).

Studies and improvement on the field of prosthetic have involved over the past year and research are still going. As this research aiming to improve prosthetic control by using magnetic sensor tracking muscle length and velocity, those yet have not been tested with human (Magnetic Sensors Track Muscle Length | MIT News | Massachusetts Institute of Technology, n.d.) Also, research in bioartificial replacement limb by the Harvard Stem Cell Institute have been done. This method use cells regeneration technic done in animals organs and would aim in the future to be apply to more complex tissues like bone or cartilage and connective tissue. The challenges remain regrowing and integrating nerves, the researchers are optimistic based on the success of nerve regeneration observed in clinical limb transplantation. The next steps in the research is to use with human cells and expanding the approach to regenerate other tissue. The ultimate goal is to develop bioartificial replacement limbs suitable for transplantation (Researchers Develop a Transplantable Bioengineered Forelimb | Harvard Stem Cell Institute (HSCI), n.d.).

7.4 Return to activities

After discharge from the hospital around 75% of patient following amputation are able to return to their daily activities and even their have chronic condition associated they are able to use prosthetic (Kevin Chui, Milagros Jorge, Sheng-Che Yen, 2019, p.530). Recommendation from the British association of chartered Physiotherapists in limb absence rehabilitation (BACPAR) suggest encouraging prosthetic user to participate to sports and social activities, including driving and help patient to be able to return to work life. Patient using a prosthetic after discharge must continue physiotherapy during the first 12 months and measure to assess the improvement using the prosthetic must be continuing. Overall physiotherapy should guide and educate patient through options and participation, also explaining patient importance of physiotherapy in case of musculosketal disorder due to prosthetic use over time, for example low back pain (BACPAR, 2020, p.14).

The loss of a limb can be a difficult time for most patient and psychologic support must be continued if needed. Inspiring stories, and communities can encourage patient and create motivation and their many possibilities in social and sports activites as a prosthetic user. For example The Amputation Foundation in the UK aim to help people following amputation to get information and advice and to connect people together through support groups meetings (Welcome to the Amputation Foundation, n.d.).

Depending on the country where the rehabilitation is going procedure and discharged can be done differently. In Finland, discharge from the hospital will be done in cooperation with the MDT and social workers that help patient managed insurance or work-related matters. Patient will be encourage to seek psychologic professional if is still having difficulty dealing with the new situation. Follow up treatment can take place in Health center, Rehabilitation center or at home. Advice services are available after discharge if the patient needs more information or facing complications such as long lasting pain after rehabilitation (Lapha.Fi, n.d.).

8 INDEPENDENT STUDY MATERIAL FOR STUDENTS

The author of the thesis creates a PowerPoint aiming to give a material for the fellow students about physiotherapy rehabilitation for adults with lower limb amputation. The goal was to create a material which could be added in the future in the Moodle platform as independent study material, so students that are interested in lower limb rehabilitation or students that need to get better understanding of physiotherapy lower limb amputation could use it. The material contains 22 slides including references, with the idea of as much essential information as possible using the least pages possible. The material has been sent to the students with a google form questionnaire, created by the author, to get feedback from students on the material. The questionnaire was collecting information about the visuals, how easy it was to understand and if the information provided is useful to their knowledge. The pictures below illustrate graphs 1 and 2 from the answers of the 7 participants concerning the understanding and benefice of the material.

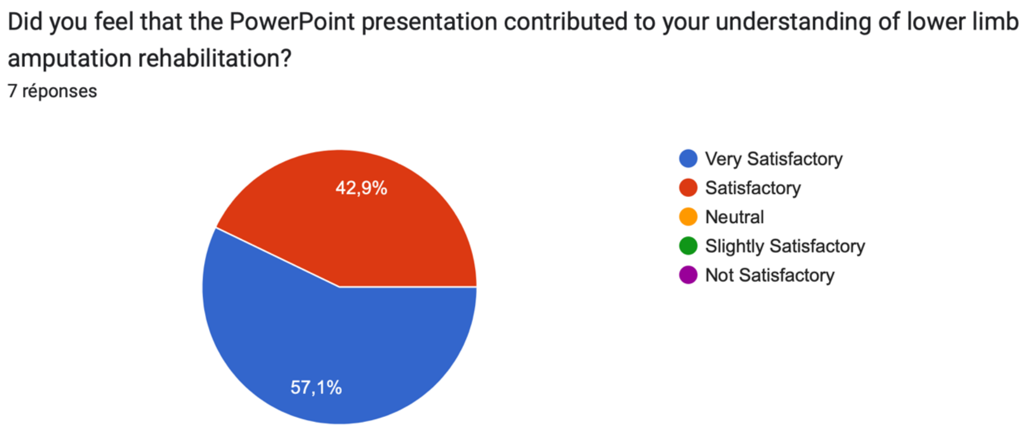


Figure 1. Google form questionnaire question, create by author.

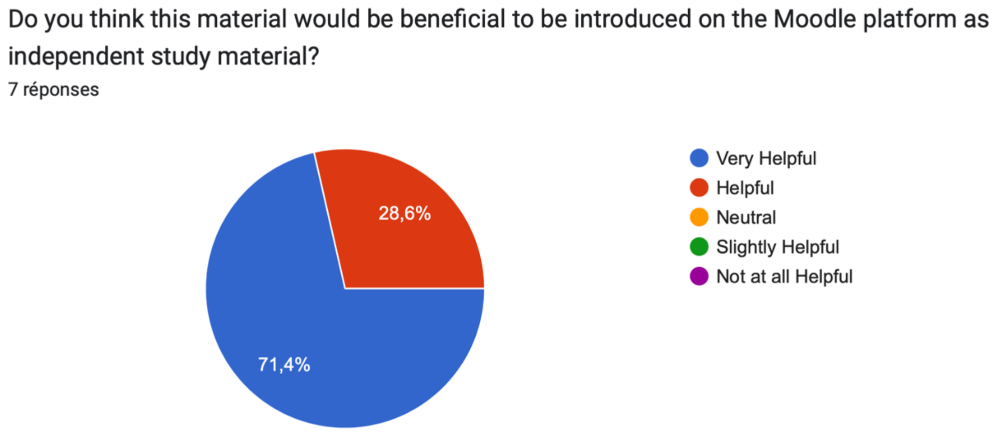


Figure 2. Google form questionnaire question, created by author.

The answers suggest that the material contributes to a better understanding of lower limb rehabilitation for the students and, mostly, that it would be very helpful to be introduced in the Moodle platform. Concerning the clarity of the information and visual appearance of the material 6 answers from very engaging to engaging and 1 neutral answer, which could suggest visual of the material could have been improved but most students thought that the graphics and images were very helpful. The last question of the questionnaire had an open question to share opinions and suggestion to improve the material. Students appreciate the material, some suggestion concerning the clarity of information stated there could have been improvements concerning some pages with too much information. Also, a student would have been interested to get more information about mirror therapy. Overall, the students thought it was interesting and useful to get information and knowledge about physiotherapy rehabilitation for adult with lower limb amputation in their curriculum.

9 THESIS PROCESS AND METHODS

The thesis was commissioned by the Satakunta University of Applied Sciences' Physiotherapy degree program. Employing practice-based research methods, the author opted for this approach to create a comprehensive resource material for students seeking knowledge and information about physiotherapy rehabilitation for patients with lower limb amputation.

Initiated in January 2023, the thesis development progressed through the final selection of a topic. The author chose this topic based on the interest and needs of extra study material on the Moodle platform. Throughout the spring from February to March 2023, the author searched for literature. Resources were primarily from the Finna library and the author also discover relevant books in other libraries. The scientific literature has been chosen thoughtfully based on relevancy and recency on Google scholar and Pubmed. Some of the literature used in the thesis is from the 90's, as the basic information about LLA's hasn't changed. The literature used as reference for, i.e. rehabilitation process and prosthetics is more recent, as the science behind these subjects has developed further. The author also incorporated materials from websites and associations focusing on lower limb amputation. As an example, the British Association of Chartered Physiotherapists in Limb Absence rehabilitation, Red Cross international or Australian physiotherapists in amputee rehabilitation (AustPAR). The selected literature includes many different countries around the globe including United States, England, Australia, Finland, Iceland, France and more. While most of the research has been conducted in English, there is also an incorporation of studies in French and Finnish.

The writing phase commenced in February and ended by November 2023. In the same month, the PowerPoint presentation, summarized from the thesis's research findings, was created and shared with the students alongside a questionnaire for feedback. The thesis has been completed by December 4th, 2023, and the presentation of the thesis occurs on the 12th December.

10 DISCUSSION

A growing number of individuals might find themselves facing the prospect of lower limb amputation in the near future. This escalation over the last years is primarily due to the increased incidence of diabetes. Physiotherapists must understand their role in the rehabilitation of those patients in needs for functional rehabilitation, it allows better chances for a successful adaptation of rehabilitation plans that address the unique needs and challenges faced by a patient.

Through the rehabilitation process, physiotherapists play an important role in empowering patients to regain control over their bodies and lives and facilitate return to daily activities. It is goal is to emphasize in mobility, strength, flexibility, and endurance but also the overall well-being. By employing targeted exercises and therapeutic techniques, physiotherapists guide patients towards achieving milestones that signify progress in their rehabilitation.

The rehabilitation journey involves not only physical aspects but also emotional and psychological considerations. Physiotherapists serve as motivators and educators, helping patients to face the emotional challenges. Establishing a supportive and empathetic relationship with the patient facing those challenges is important to promote resilience throughout the rehabilitation process.

In cases involving the use of a prosthesis, physiotherapists role is to help patient adapting rehabilitation strategies to ensure integration and optimal functionality. They collaborate closely with prosthetists to address biomechanical considerations. Whether it's learning to walk with a new limb or concerning prosthetic fitting, physiotherapists provide the necessary support and expertise. Bionic limbs still have notable issues that require addressing. For example, the open wounds, prone to infection and other problems remains unresolved. The lack of long-term studies on bionic limbs and their use necessitates further studies. Limitations in use, for example due to design for a specific sport and accessibility, for example due to cost are affecting both bionic limbs and prosthetics in general.

In conclusion, the role of physiotherapists in LLA rehabilitation extends beyond mere physical recovery. It encompasses guiding patients through regaining function, adapting to prosthetic devices, and supports the emotional needs of a patient. By understanding the multifaceted nature of their role, and by collaborating closely with the multidisciplinary team, physiotherapists have an important role in restoring patients' independence and enhancing their overall quality of life through the rehabilitation and assist the smooth return to everyday life.

REFERENCES

All About Össur. (n.d.). Retrieved November 18, 2023, from https://www.ossur.com/en-gb/about-ossur.

Amputate Definition & Meaning - Merriam-Webster. (n.d.). Retrieved February 3, 2023, from https://www.merriam-webster.com/dictionary/amputate.

Amputation - NHS. (n.d.). Retrieved October 2, 2023, from https://www.nhs.uk/conditions/amputation/.

Arribart, K. (2019). Principes de kinésithérapie dans le traitement des patients artéritiques amputés de membres inférieurs. Kinésithérapie, La Revue, 19(206), 19–24. https://doi.org/10.1016/J.KINE.2018.11.002

AustPAR - Amputee Pain Management. (n.d.). Retrieved October 8, 2023, from http://www.austpar.com/portals/acute_care/pain_management.php.

AustPAR - Early Mobility Post-Amputation. (n.d.). Retrieved October 8, 2023, from http://www.austpar.com/portals/acute_care/early_mobility.php.

AustPAR - Osseointegration. (n.d.). Retrieved October 24, 2023, from http://www.austpar.com/portals/acute_care/osseointegration.php.

BACPAR. (2016). Clinical guidelines for the pre and post operative physiotherapy management of adults with lower limb amputations British Association of Chartered Physiotherapists in Amputee Rehabilitation Clinical guidelines for the pre and post operative physiotherapy. January, 1–14.

BACPAR. (2020). Recommendations Document Evidence based clinical guidelines for the physiotherapy management of adults with lower limb prostheses British Association of Chartered Physiotherapists in Amputee Rehabilitation. 0–23.

Bionic Legs | Bionic Technology by Össur. (n.d.). Retrieved November 18, 2023, from https://www.ossur.com/en-nz/professionals/bionic-legs#powerleg.

Blake, D. J., Brielmaier, S., Czerniecki, J. M., Hensons, H. K., Kent, M. J., & McDowell, M. L. (2007). Clinical practice guideline for rehabilitation of lower limb amputation. Clinical Practice Guideline for Rehabilitation of Lower Limb Amputation, Module C.

Bouzas, S., Molina, A. J., Fernández-Villa, T., Miller, K., Sanchez-Lastra, M. A., & Ayán, C. (2021). Effects of exercise on the physical fitness and functionality of people with amputations: Systematic review and meta-analysis. Disability and Health Journal, 14(1), 100976. https://doi.org/10.1016/J.DHJO.2020.100976

CDC. (2020). National Diabetes Statistics Report 2020. Estimates of diabetes and its burden in the United States.

Chris Kirtley. (2006). Clinical gait analysis theory and practice (Elsevier Churchill Livingstone (Ed.)).

Cross International Committee of the Red. (2018). Exercises for Lower-Limb Amputees. 76. www.icrc.org

David J. Magee, R. C. M. (2021). ORTHOPEDIC PHYSICAL ASSESSMENT, SEVENTH EDITION (7th ed.). Elsevier Ltd.

Demir, Y., & Aydemir, K. (2020). Gülhane lower extremity amputee rehabilitation protocol: A nationwide, 123-year experience. Turkish Journal of Physical Medicine and Rehabilitation, 66(4), 373. https://doi.org/10.5606/TFTRD.2020.7637

Domínguez-Ruiz, A., López-Caudana, E. O., Lugo-González, E., Espinosa-García, F. J., Ambrocio-Delgado, R., García, U. D., López-Gutiérrez, R., Alfaro-Ponce, M., & Ponce, P. (2023). Low limb prostheses and complex human prosthetic interaction: A systematic literature review. Frontiers in Robotics and AI, 10, 1032748. https://doi.org/10.3389/FROBT.2023.1032748/BIBTEX

Dougherty, P. J., & DeMaio, M. (2014). Major General Norman T. Kirk and Amputee Care During World War II. Clinical Orthopaedics and Related Research, 472(10), 3107. https://doi.org/10.1007/S11999-014-3679-6

Engstrom, B., & Van de Ven, C. (1999). Therapy for Amputees (B. Engstrom & C. Van de Ven (Eds.); Third edit).

Friedel, C. M. V. P. M. R. F. (2020). Prosthetic Gait Analysis for Physiotherapists | International Committee of the Red Cross. https://www.icrc.org/en/publication/prosthetic-gait-analysis-physiotherapists

Gottschalk, F. A., & Stills, M. (1994). The biomechanics of trans-femoral amputation. Prosthetics and Orthotics International, 18(1), 12–17. https://doi.org/10.3109/03093649409164665

Horgan, O., & Maclachlan, M. (2004). Psychosocial adjustment to lower-limb amputation: A review Article in Disability and Rehabilitation · World Health Organization GATE Initiative View project Doctoral Training for Development in Africa View project Psychosocial adjustment to lower-limb amputation: A review. https://doi.org/10.1080/09638280410001708869

Invalides de guerre et centres de rééducation - Histoire analysée en images et œuvres d'art | https://histoire-image.org/. (n.d.). Retrieved February 6, 2023, from https://histoire-image.org/etudes/invalides-guerre-centres-reeducation.

Kevin Chui, Milagros Jorge, Sheng-Che Yen, M. L. (2019). Orthotics and Prosthetics in Rehabilitation (Elsevier (Ed.); 4th Editio).

Kinch, K. J., & Clasper, J. C. (2011). A brief history of war amputation. Journal of the Royal Army Medical Corps, 157(4), 374–380. https://doi.org/10.1136/JRAMC-157-04-05

Lapha.fi. (n.d.). Retrieved November 18, 2023, from https://lapha.fi/alaraajan-amputaatio.

Leg Amputation Rehabilitation - Special Subjects - Merck Manuals Professional Edition. (n.d.). Retrieved September 30, 2023, from https://www.msdmanuals.com/professional/special-subjects/rehabilitation/leg-amputation-rehabilitation.

Limb Loss Statistics - Amputee Coalition. (n.d.). Retrieved February 4, 2023, from https://www.amputee-coalition.org/limb-loss-resource-center/resources-filtered/resources-by-topic/limb-loss-statistics/limb-loss-statistics/.

Magnetic sensors track muscle length | MIT News | Massachusetts Institute of Technology. (n.d.). Retrieved November 18, 2023, from https://news.mit.edu/2022/magnetic-sensors-muscle-prosthetics-1025.

Maloney, T. R., Dilkes-Hall, I. E., Vlok, M., Oktaviana, A. A., Setiawan, P., Priyatno, A. A. D., Ririmasse, M., Geria, I. M., Effendy, M. A. R., Istiawan, B., Atmoko, F. T., Adhityatama, S., Moffat, I., Joannes-Boyau, R., Brumm, A., & Aubert, M. (2022). Surgical amputation of a limb 31,000 years ago in Borneo. Nature 2022 609:7927, 609(7927), 547–551. https://doi.org/10.1038/s41586-022-05160-8

McGuire, J., Thomson, A., & Kennedy, P. G. (2021). The Biomechanics of Diabetic Foot Amputation. Wounds, 33(9), 231–236. https://doi.org/10.25270/WNDS/041421.01

O’Sullivan, S. B., & Schmitz, T. J. (2019). Physical Rehabilitation (O’Sullivan, Physical Rehabilitation). http://www.amazon.com/Physical-Rehabilitation-OSullivan/dp/0803612478

Össur. Life Without Limitations. (n.d.). Retrieved November 18, 2023, from https://www.ossur.com/en-gb/prosthetics/feet/flex-run.

Overmann, A. L., & Forsberg, J. A. (2020). The state of the art of osseointegration for limb prosthesis. Biomedical Engineering Letters, 10(1), 5. https://doi.org/10.1007/S13534-019-00133-9

Pinzur, M. S. (2010). Syme’s ankle disarticulation. Foot and Ankle Clinics, 15(3), 487–494. https://doi.org/10.1016/J.FCL.2010.04.001

Ponkilainen, V. T., Vuorlaakso, M., Kaartinen, I., Kiiski, J., Saarinen, E., Huttunen, T. T., Paloneva, J., & Mattila, V. M. (2022). The Development of Lower Limb Amputations in Finland from 1997 to 2018: A Nationwide Retrospective Registry

Study. European Journal of Vascular and Endovascular Surgery, 63(1), 138–146. https://doi.org/10.1016/j.ejvs.2021.09.030

Prosthetic Solutions | Prosthetics | Össur UK. (n.d.). Retrieved November 18, 2023, from https://www.ossur.com/en-gb/prosthetics

Prosthetics for Individuals with Hip Disarticulation and Hemipelvectomy Amputations - Physiopedia. (n.d.). Retrieved March 13, 2023, from https://www.physio-pedia.com/Prosthetics_for_Individuals_with_Hip_Disarticulation_and_Hemipelvectomy_Amputations?utm_source=physiopedia&utm_medium=related_articles&utm_campaign=ongoing_internal#cite_note-:4-3.

Researchers develop a transplantable bioengineered forelimb | Harvard Stem Cell Institute (HSCI). (n.d.). Retrieved November 18, 2023, from https://hsci.harvard.edu/news/researchers-develop-transplantable-bioengineered-forelimb.

Robinson, K. P. (1991). Historical aspects of amputation. Annals of The Royal College of Surgeons of England, 73(3), 134. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2499312/

Selvam, P. S., Sandhiya, M., Chandrasekaran, K., Rubella, D. H., Karthikeyan, S., Selvam, P. S., Sandhiya, M., Chandrasekaran, K., Rubella, D. H., & Karthikeyan, S. (2021). Prosthetics for Lower Limb Amputation. Prosthetics and Orthotics. https://doi.org/10.5772/INTECHOPEN.95593

Siraj, S. A., Kulkarni, C. A., & Patil, S. (2022). A Comprehensive Physiotherapy Rehabilitation for Lower Limb Amputation as a Consequence of Cannabis and Alcohol Dependency: A Case Report. Cureus, 14(11). https://doi.org/10.7759/CUREUS.31700

Soares, A. S. O. D. C., Yamaguti, E. Y., Mochizuki, L., Amadio, A. C., & Serrão, J. C. (2009). Biomechanical parameters of gait among transtibial amputees: a review. Sao Paulo Medical Journal = Revista Paulista de Medicina, 127(5), 302–309. https://doi.org/10.1590/S1516-31802009000500010

Stark, Gerald BSME, CP, F. (2004). Overview of Knee Disarticulation: JPO: Journal of Prosthetics and Orthotics. https://journals.lww.com/jpojournal/Fulltext/2004/10000/Overview_of_Knee_Disarticulation.7.aspx

Video 1 - Patient evaluation - YouTube. (n.d.). Retrieved September 18, 2023, from https://www.youtube.com/watch?v=MFhftrgfDA4&t=157s.

Welcome to the Amputation Foundation. (n.d.). Retrieved November 18, 2023, from https://amputationfoundation.org/.

Zaheer, A., Malik, A. N., Masood, T., & Fatima, S. (2021). Effects of phantom exercises on pain, mobility, and quality of life among lower limb amputees; a randomized controlled trial. BMC Neurology, 21(1). https://doi.org/10.1186/S12883-021-02441-Z

APPENDIX 1