According to the United States' Department of Veterans Affairs, there are currently 1.6 million people in the United States with limb loss; 1.3 million of those individuals have lower limb amputations, and 28% of the lower limb amputees have transtibial amputations.[1] Current amputation rehabilitation includes an interdisciplinary approach, with an emphasis on early pre-amputation facilitation to ensure short hospitalization stays and earlier return to productivity.[2] Once the individual is medically stable, postoperative rehabilitation should begin and should focus on maximizing functional independence.[3] Goals of rehabilitation include promoting a healthy lifestyle, preventing contractures, increasing lower extremity strength through exercises and early ambulation, and adjusting to the loss of a limb both psychologically and through improved coordination and endurance.[3] Prosthetic fitting typically occurs around three weeks after surgery, once sutures are removed and the wound is healing.[3] Longer healing periods cause limb weakness, body deconditioning, risk of falling, and joint stiffness or contractures.[4] Early prosthetic training and incorporating daily functional activities into patient rehabilitation helps to facilitate weight shifting while using the prosthesis, which makes gait more energy efficient and increases the likelihood that the individual will use the prosthesis long-term and stay mobile.[3]

This paper will focus on post-prosthetic musculoskeletal complications that are common in patients who have undergone a transtibial amputation. The objectives of this paper are to describe the causes of residual limb pain and complications that can occur with a poor fitting prosthesis, explore interventions that can provide pain relief, and explain how utilizing a physical examination can be used to distinguish causes of pain and determine prosthesis trouble areas.

*Causes of Residual Limb Pain*

Pain in the residual limb can be contributed to many things, though many healthcare professionals who are unfamiliar with amputees typically consider pain in the residual limb to be phantom pain; however the presence of chronic phantom pain is rare.[5] Another assumption often made, is that pain in the residual limb is caused by a poor fitting prosthesis, which leads to unnecessary alterations in the prosthesis.[5] There are many causes for residual limb pain, for example, prior to the amputation, disruption of the proximal tibiofibular joint interosseous membrane results in hypermobility of the fibula and can lead to pain.[5] Treatment for hypermobility of the fibula consists of a fusion of the new proximal tibiofibular joint, which is a relatively simple procedure, does not require any further shortening of the residual limb, and has been found to stop the pain that occurs due to this injury.[5]

Another cause of residual limb pain in skin breakdown that occurs through improper socket contact. The socket is the part of the prosthesis that provides structure, control, and directs the proper transfer of forces to the residual limb during ambulation.[6] The socket fits around the residual limb and it transfers force loads in static and dynamic conditions; therefore a stable and snug connection is required between the residual limb and the socket.[7] A good fitting prosthesis socket requires total contact on the residual limb, which affects the ventilation at the socket-skin interface.[6] The socket has low moisture permeability which contributes to higher skin temperatures and high rates of perspiration accumulation inside the socket.[6] The accumulation of moisture in the socket can negatively affect the prosthesis suspension, prosthesis use, amputee activity level, and therefore the overall quality of life of these individuals with transtibial amputations.[6] In addition, it causes skin irritation, friction, blisters, unpleasant odor, and an environment for bacteria to invade into the residual limb and cause an infection.[6] Skin care of the residual limb is important because skin irritation can limit the residual limbs' load bearing abilities and prosthesis use. Poor fitting sockets create focal pressures and additional shearing forces on the skin in non-traditional areas such as the tibial tubercle or the wound site, which will initiate irritation and inflammation of the superficial layers of the skin.[8] With further weight bearing the irritation and inflammation will erode deeper into the epidermis and dermis, then into the subcutaneous layer or the fascia and potentially into the muscle or bone.[8] A common site for skin breakdown in transtibial amputees is on the distal anterior part of the tibia due to inadequate beveling of the tibia during the amputation.[5] Socket adjustments can be made to provide a reduction in pain, however, if that does not work then local bursa injections and surgical revision may be required.[5] Areas with slight moisture and high tissue stress are prone to friction blisters.[6] Despite 60% to 70% of individuals with lower extremity amputations reporting that high perspiration inside of the socket is a major problem, there is still currently no accepted solution to resolve the heat and perspiration discomfort with prosthesis use.[9] Patient education is especially important for skin care; patients should be educated on signs of infection and how to perform a thorough observation of their residual limb after each prosthetic use to check for erythema, ecchymosis, skin abrasions, or tenderness of the residual limb. In addition, therapists can suggest the use of breathable material for prosthetic sockets and liners, as well as anti-perspiration medications, powders, and sprays to attempt to reduce thermal discomfort, however, these have not been found to provide relief for all individuals.[9]

It is common for transtibial amputees to experience pain due to adherence of skin to bone due to the application of split-thickness skin grafts directly over the tibia during surgery.[5] The adherence of skin to bone will cause pain and ulceration with prosthesis use because the skin has no underlying soft tissue to provide resistance to the shear forces that are caused by the prosthesis.[5] Amputees can be taught how to mobilize tissue through a daily cross-frictional massage for several weeks, which may help relieve some of the adhesions.[5] In addition, gel socket liners and nylon sheaths have been found to provide pain relief by reducing shear forces.[5] Additional socket adjustments such as an addition of a long thigh corset or the addition of ischial weight-bearing may be useful in reducing pain by allowing for additional distribution of weight.[5] Surgery revision should be utilized as a last resort.[5]

If the fibula is left longer than the tibia after surgery, then weight bearing with the prosthesis will occur at the distal fibula and will cause tenderness with weight bearing.[5] This can typically be assessed with palpation, and socket modifications can be made to relieve pain, however, surgical revision is often needed.[5] In addition, torn knee ligaments may cause pain and instability if the individual is wearing a standard patellar tendon-bearing prosthesis.[5] In this case the pain can typically be controlled by a supracondylar prosthesis or with a thigh corset added to the original patellar tendon-bearing prosthesis.[5]

It is common for an amputee to have several neuromas in their residual limb as a result of nerve section that occurs during amputation surgery.[5] Neuromas can be nonsymptomatic if the transected nerves are in an area that avoids the scar from the surgery, weight bearing areas, or high pressure areas from the prosthesis.[5] If there is a painful mass that is suspected to be a neuroma, then direct manipulation will produce a tingling discomfort that follows a peripheral nerve pattern in the missing portion of the limb, also knowns as a Tinel's sign.[5] If a physical therapists finds a neuroma during palpation, in an otherwise asymptomatic limb, then the patient should be reassured that neuroma masses are normal and does not need corrective surgery.[5] Firm nodules that are found during palpation that are only sensitive in a local area are most likely not neuromas.[5] Treatment of neuromas should start with socket changes to relieve pressure on the painful areas, however if the neuroma is over a bony prominence or cannot be relieved with socket changes then surgery may be necessary to move the neuroma to a deeper location. [5]

*Physical Complications*

The Department of Veterans Affairs reports that the majority of individuals with an amputation have an active and satisfying quality of life.[10] Musculoskeletal imbalances, pathologies, or altered biomechanical movement can develop secondary to poor prosthesis fit in lower extremity amputees and can affect mobility and quality of life.[10] About 68% to 88% of amputees wear their prosthesis for at least seven hours a day.[11] The majority of individuals who walk with a prosthesis have at least one gait deviation or a limb problem as a result of improper prosthetic alignment or fit.[11] As a result, there is inadequate weight-shifting onto the residual limb, which alters the gait pattern and can cause pain in the joints of either the residual or the sound limb, which can result in degenerative joint disease and/or disability.[11] The three most common secondary complications in individuals with lower limb amputations due to compensatory stresses from poor prosthesis fit are osteoarthritis, osteoporosis, and back pain.[11] Gait deviations such as asymmetrical limb stance time and increased vertical ground force on the intact limb can exacerbate these musculoskeletal processed,[12] so early detection and correction of these compensations are necessary to reduce the risk of developing a secondary musculoskeletal condition.

Volume fluctuation within the socket is the most common problematic issue that occurs with amputees; it causes other issues such as decreased comfort, decrease prosthesis use, increased shear forces, increased pressure on bony prominences, skin breakdown, pistoning, and poor gait patterns.[13] Many issues with socket fit can be adjusted with sock ply adjustments.[5] The pressure of the socket on the soft tissues of the limb causes volume change, which can be adjusted by adding socks on throughout the day.[13] There are also “bladders” that can be added to the socket that are filled with air and can be pumped up or deflated as the volume of the limb changes.[13] It is common to have volume fluctuation throughout the day which can increase pressure in certain areas and cause further problems, so amputees should be prepared to add or remove socks throughout the day to maintain proper fit.[14]

Socket looseness, typically caused by atrophy or weight loss of the residual limb, means that the limb will sit in the socket deeper than intended and will cause excessive direct shear forces over the tibia and fibula, fibular head, tibial tubercle, and at the distal end of the patella.[5] Pistoning, is when the limb moves excessively in the socket and creates an increase in shear forces and higher peak pressures during the loading response of gait and can be caused by poor suspension or decreased residual limb volume.[13] Socket tightness, typically caused by wearing excessive sock plies or weight gain, means that there is a loss of distal contact which causes direct tibial tubercle pressure on the patellar tendon and can result in inflamed and/or ulcerated areas of skin.[5]

Sometimes the prosthesis cannot be effectively adjusted with socket padding or stump socks. An excessive number of sock plies (about 10 to 15), disturbs the socket and residual limb interface and can result in reduced rotational control and increased pistoning with ambulation.[5] If at home adjustments are no longer functional then a new socket is needed to avoid skin breakdown or other complications.[5] It is important that when working with amputees that knowledge of loose and tight fitting prosthesis is adequate. Observation of ambulation with the prosthesis, and of the residual limb after prosthesis use will help to locate areas of discomfort and poor fit, such as erythemas, callus or bursa formation, and local tenderness.[5]

*Physical Therapy in Amputee Care*

Osteoarthritis is the breakdown of cartilage in the joints that results in pain, swelling, and reduced mobility in the joints.[11] Research indicates that 40% of individuals with a transtibial amputation will have arthritis of the sound knee, and 45% will have osteoarthritis of the sound hip.[11] Osteoporosis is when bone density decreases, which increases the risk of fractures.[11] In individuals with poor fitting prosthesis, decreased weight-bearing on the residual limb can contribute to the development of osteoporosis; approximately, 80% to 90% of all long-term lower extremity prosthetic users have a 30% decrease in bone density of the hip on the residual side.[11] Individuals with lower extremity limb loss have been found to have significantly more low back pain than the general population, with the majority of these individuals experiencing low back pain within two years after their amputation.[11] Prevention of these complications should be utilized to keep these individuals active and maintain their quality of life. Physical therapists are in the position to aid these individuals in preventative care and reduce their risk of injury by performing physical examinations to check for proper prosthesis fit, stance and gait training for adequate weight-shift on the residual limb, education on avoiding hopping, maintaining good posture, and proper diet and exercise to maintain body weight and improve strength.

Individuals with transtibial amputations can have a wide range of outcomes, with the best outcomes being having the ability to run and jump.[15] Coping mechanisms are individually based, and emotional and environmental support are an important part of processing limb loss and remaining motivated to stay active.[15] Physical therapy plays an important role in getting transtibial amputees back on the feet and gaining the strength and coordination to remain high functioning after an amputation.

Patient education is important during the rehabilitation process, because it allows patients to develop self-management skills. A study on therapeutic patient education on self-care of lower limb amputees found that patient education that was adapted to the patient’s cognitive and functional capacity led to fewer complications with prosthesis care, an increase in prosthesis use, an increase in patient independence with donning/doffing the prosthesis and an increase in quality of life.[16] In addition to patient education, it is important that physical therapists identify patient issues such as pain, depression, and acceptance of change, and address these issues by discussing them with the patient and referring them as deemed appropriate. Ideal outcomes for amputees are achieved through a multidisciplinary approach, and providing patients with optimal resources will help the patient reach their optimal level of independence and highest level of function.[17]

Physical therapy prosthetic training starts with donning and doffing the prosthesis, education on sock management, education on skin checks, and forming a prosthesis wearing schedule that is gradual over several weeks and begins with 15 to 20 minutes of wear time.[17] Gait training with a new prosthesis begins on flat ground and consists of establishing knee stability, acquiring equal step lengths, and avoiding trunk bending.[18] An important part of physical therapy is teaching individuals how to fall and how to get back up after falling, because falling will happen, especially during early phases of gait training.[17] After level ground is mastered then the individual should practice their skills on uneven terrain, and getting in and out of the car to replicate their community and everyday life.[17] Once the patient demonstrates safe ambulation and the ability to perform adequate skin checks then they are able to take the prosthesis home; 97% of post-traumatic amputees will be independent with ambulation at three months.[17]

Three dimensional gait analysis is currently used as the “gold standard” to quantify prosthetic gait deviations.[19] A study done by Kark et al[19] looked to develop outcome measures to quantify prosthetic gait deviations without the use of three-dimensional gait analysis. This study took twelve unilateral transtibial amputees, eight unilateral transfemoral amputees, and twenty-eight control participants who underwent a three-dimensional gait analysis, with the prosthetic users wearing their everyday prosthesis and any walking aids that they typically used.[19] The three dimensional gait analysis was done with six walking trials using an eight camera motion capture system, on a 15 meter walkway with embedded force plates used to detect initial contact, and a reflective marker set on the anterior pelvis.[19] Following the three-dimensional gait analysis participants performed two performance-based tests which were the Timed-Up and Go Test and the Six-Meter Walk Test, which have both been validated for use with individuals with lower limb amputations.[19] In addition, the amputee participants completed the Prosthesis Evaluation Questionnaire which is a self-report measure.[19] Spearman's rank correlation coefficient, ρ, was calculated to determine the relationship between the gait deviation index, which was calculated from the three-dimensional gait analysis, and the participant characteristics, performance-based measures and self-reported measures.[19] The gait deviation index was found to have a significant relationship with self-selected walking speed, and the Six-Meter Walk Test.[19] The strongest relationship was between the normalized self-selected walking speed and the Six-Meter Walk Test (ρ=.96), however, the correlation coefficients for the performance-based measures used in this study were all found to be significant and is presented in Table 1 in the Appendix. This study concluded that it is possible to predict the gait deviations of transtibial and transfemoral amputees through the combination of simple performance-based and self-reported outcome measures, with temporospatial data having the strongest relationship to the gait deviation index.[19] Step length of the intact limb provides great insight to the gait symmetry of the individual because it is correlated with the weight-shift occurring onto the residual limb during ambulation.[19] Another study found that there was a positive correlation between self-perceived balance confidence, measured by the Activities-specific Balance Confidence Scale, and community-based physical activity in patients with transtibial amputations.[20] This is encouraging because it demonstrates that low cost and readily available options are very informative. Physical therapists should use visual gait analysis and performance tests such as the Six-Meter Walk Test and the Timed-Up and Go, and self-report measures such as the Activities-specific Balance Confidence Scale to assess functional status in individuals with amputations.

A study done by Wong et al[21] looked to develop a prognostic clinical prediction rule to identify individuals who will not achieve community ambulation after one year with prosthesis use. They did a prospective longitudinal cohort study with community-dwelling adults with lower limb amputations, and had the participants complete the Activities-specific Balance Confidence Scale, the Houghton prosthetic use for mobility self-report scale, as well as the Berg Balance Scale.[21] The authors developed a clinical prediction rule by using the multivariate logistic regression, receiver operating curves, and probability to identify individuals who will not be at community ambulation level one year after prosthetic use.[21] The clinical prediction rule that the authors formed along with the area under the curve, which was determined by clinical thresholds that were to be met by each criterion is presented in Table 2 in the Appendix. The sensitivity, specificity and likelihood ratios for each part of the clinical prediction rule is presented in Table 3 of the Appendix. The posttest probability of a participant not being at a community ambulation level of prosthetic use was greater than 92% when the individual met two or more criteria.[21] Table 4 in the Appendix illustrates the comparisons and significant differences of the amputees who did and did not achieve community ambulation.[21] The clinical prediction rule may help guide clinicians in patient outcomes and establish a functional prognosis for individuals with transtibial amputations.

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Appendix

**Table 1: Correlations between performance-based measures, Spearman's rank correlation coefficient displayed [19]**

| | $nSL_{pro}$ | $nSL_{int}$ | $nSL_{ave}$ | nSSWS | TUGT |
|---|---|---|---|---|---|
| $nSL_{int}$ | 0.87 | | | | |
| $nSL_{ave}$ | 0.98 | 0.95 | | | |
| nSSWS | 0.84 | 0.91 | 0.88 | | |
| TUGT | -0.70 | -0.71 | -0.71 | -0.82 | |
| 6MWD | 0.86 | 0.89 | 0.89 | 0.96 | -0.83 |

All correlations significant, $P \leq 0.001$. nSL: Leg-length normalised average step length; nSSWS: Leg-length normalised self selected walking speed; TUGT: Timed-up-and-go test; 6MWD: Six-minute walk distance.

**Table 2: Clinical prediction rule criteria to predict people who do not reach the community walking level of prosthetic use [21]**

| Criteria | Cutoff Score | AUC |
|---|---|---|
| Initial Houghton score | ≤7 | 0.885 |
| ABC score, % | ≤65 | 0.927 |
| BBS item 9: retrieve object from floor | ≤3 | 0.771 |
| BBS item 10: look behind over shoulders | ≤3 | 0.875 |

**Table 3: Prosthetic Use for Mobility Prognosis for various levels of the screening tool [21]**

| Criteria Met | Sn | Sp | +LR | −LR | Not Community Walking Level, % (*n*) | Posttest Probability[a] |
|---|---|---|---|---|---|---|
| 0 | 100 | 0 | 1 | — | 0 (0/16) | 59.3 |
| 1 | 100 | 66.7 | 3.0 | — | 0 (0/21) | 81.4 |
| 2 | 100 | 87.5 | 8.0 | — | 8.3 (2/24) | 92.1 |
| 3 | 87.5 | 91.7 | 10.5 | 0.14 | 20.1 (6/29) | 93.9 |
| 4 | 62.5 | 95.8 | 14.9 | 0.39 | 40.0 (16/40) | 95.6 |

[a]Based on pretest probability from initial sample.

**Table 4: Differences between participants with different prognoses [21]**

| Variable | Community Walking Level | Not Community Walking Level | *P* |
|---|---|---|---|
| Age | 53.5 ± 10.6 | 62.3 ± 12.1 | 0.025 |
| ABC | 82.8 ± 16.6 | 37.7 ± 25.1 | <0.001 |
| BBS | 50.8 ± 7.0 | 26.8 ± 14.5 | <0.001 |
| Houghton | 9.6 ± 2.7 | 3.31 ± 3.1 | <0.001 |
| Years since amputation | 9.0 ± 13.3 | 3.1 ± 4.9 | 0.054 |
| Body mass index | 26.3 ± 5.8 | 27.3 ± 7.6 | 0.650 |
| Number of comorbidities | 1.3 ± 1.4 | 1.6 ± 1.8 | 0.534 |