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Examination Of The Rehabilitation Protocol Of Traumatic Transfemoral Amputees And How To Prevent Bone Mineral Density Loss

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EXAMINATION OF THE REHABILITATION PROTOCOL OF TRAUMATIC TRANSFEMORAL AMPUTEES AND HOW TO PREVENT BONE MINERAL DENSITY LOSS

by

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ABSTRACT

The purpose of this literature review was to identify any adaptations that could be made to the rehabilitation process for Traumatic Transfemoral Amputees. Traumatic Transfemoral Amputation is particularly debilitating with the amputees encountering many obstacles throughout the rehabilitation process. These obstacles can prevent the return to pre-morbid functioning. With an ever-increasing number of amputees within the United States, it is imperative the rehabilitation process be addressed. This literature review addresses possible adjustments in the initial stages of rehabilitation examining the post-operative, pre-prosthetic, and prosthetic rehabilitation stage to enhance the physical functioning for the amputee. This comprehensive literature review encompassing 63 academic and medical journals analyzes the research literature regarding each of the three stages of the post-operative procedure. The literature review synthesizes the research findings to see how procedures may be adapted to reduce the risk of further co-morbidities such as loss of bone mineral density and disuse atrophy. Loss of bone mineral density and disuse atrophy are the major contributing factors to the amputees decreased mobility. Reducing this loss can be addressed within the initial post-operative, pre-prosthetic, and prosthetic rehabilitation stages. Further research is required to examine the efficacy of these alterations in relation to this specific population.

Key Words: Traumatic, Transfemoral Amputation, Bone Mineral Density, IPOP, TMR

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INTRODUCTION

Transfemoral amputation, or Above-Knee Amputation (AKA), is a lower limb amputation often associated with trauma, vascular diseases, diabetes, severe infection, or tumor/cancer (Gottschalk, 1999). Traumatic transfemoral amputation accounts for 45% of all amputations, with vascular causes being the most common (Pasquina, Miller, Carvalho, Corcoran, Vandersea, Johnson, Chen, 2014). Traumatic transfemoral amputations are the most emotionally distressing causes of amputations, as the amputees are often unable to come to terms with their new reality prior to the life altering event.

Estimates by the Amputee Coalition of America (ACA) indicate that 185,000 amputations occur each year within the United States including both military and non-military amputations (Ziegler-Graham, Mackenzie, Ephraim, Travison, & Brookmeyer, 2008). Although several statistics on amputation vary, it is estimated of the 185,000 amputations, 113,000 of these are lower-limb amputations (Statistics Brain, 2016). Due to this high prevalence of lower-limb amputations, it is imperative to research further into how life following amputation may be improved. Although this review will focus on traumatic transfemoral amputation, many of the practices discussed could also be used to aid with recovery from other causes of amputation. However, some of the procedures may have to be slightly altered. The age of these patients tends to be much higher and, therefore, may not be applicable depending on the overall health of the patient.

Traumatic AKA could be caused by several mechanisms. These include impact injuries, such as a car accident, penetration wounds, as well as injuries sustained while on military duties. Due to the sudden causes of these amputations, the average age of these individuals is generally lower than amputations associated with other causes. One study found the average age of traumatic amputation to be 37.2 years (Pasquina, et al., 2014). This means they must adapt to this new reality for the remainder of their lives. Due to their young age. the average of this remainder is much longer than those who have had an amputation because of something other than trauma. Therefore, it is even more essential to return to pre-morbid functioning as soon as possible. Many of these individuals, especially those injured while on military duties, are active, healthy, young men and women. Thus, it is a necessity for these individuals' mental health and well-being that they return to pre-morbid functioning as soon as possible and be able to maintain their independence. The aim of the rehabilitation program should be to ensure that amputees are able to function effectively within society following their amputation. The effective social functioning should extend evident at their previous job, with new employment opportunities, or simply in day-to-day activities.

Many of the traumatic amputees come from the military population because of Improvised Explosive Device (IED) explosions or other military related traumas. The Department of Defense (2014) stated that, since April 4th, 2011, the start of the conflicts in Iraq and Afghanistan, 1,186 service personnel suffered major amputations, with most these caused by improvised explosive devices (Goldberg, 2014). At the time of injury, these individuals are at peak health and were suddenly faced with a life-changing injury. The prospect of this new life has been particularly daunting, and everything must be done to ease their transition into life with a loss of a limb. Several issues face these amputees transitioning to their new reality. However, it is more than possible for those who suffer an amputation to return to pre-morbid functioning with just a few minor adjustments to cater for their new reality.

One of the issues facing individuals who have undergone transfemoral amputation is a loss of bone mineral density. Low bone mineral density is concerning because it places the amputee at a greater fracture risk. Low bone mineral density (BMD) is more common in individuals with transfemoral amputation than transtibial amputation (Below the knee) (Gailey, Allen, Castles, Kucharik, & Roeder, 2008). Low BMD is defined using Z-score values as opposed to the usual T-score values used to assess osteoporosis and osteopenia in postmenopausal women and men over the age of 50. A Z-score of 1 Standard deviation below the mean is considered a low BMD and a Z-score of 2 standard deviations below the mean is considered severe BMD loss which results in a significantly increased fracture risk (Flint, Wade, Stocker, Pasquina, Howard, & Potter, 2014). This is a problem area for this particular population. The average age of the traumatic transfemoral amputations is 37.2 years of age. For those who have had combat-related amputations, this age could be even lower. Consequently, these individuals may want to return to high-impact activities such as running or even a return to military service. However, many amputees also experience femoral neck and acetabular stress fractures (hip stress fractures) or low-energy fragility fractures which can prevent them from returning to these activities. (Flint, et al., 2014).

Transfemoral amputees are at an increased risk of developing femoral neck and acetabular stress fractures due to the large compressive and sheer forces placed through the femoral neck during ambulation (Wildstein & Schutte, 2015). This form of stress fracture is commonly seen in athletes and military personnel due to the repetitive submaximal stresses placed on the bone (Boden & Osbahr, 2000). Therefore, military personnel prior to amputation are already at an increased risk of femoral neck stress fractures due to the nature of their lifestyle.

Then, following amputation, one study found individuals to have between 10-28% lower BMD than the control group at the neck of the femur. This puts them at a significantly increased risk of fracture (Smith, Comiskey, Carroll, & Ryall, 2011). There has been much evidence to suggest a link between the loss of BMD, specifically at the femoral neck, and hip fractures. One study discovered individuals of both sexes who suffered a hip fracture had lower BMD than the baseline level. This caused thinning of the cortical bone (the outer surface of the bone), increased bone width, decreased strength and increased instability (Rivadeneira, et al., 2007). Due to the high prevalence of BMD loss following transfemoral amputation, hip fractures are a significant problem facing amputees and must be addressed to ensure quality of life following amputation.

It has also been found that following transfemoral amputation, individuals expend approximately 65% more energy to ambulate at half of the normal speed those without amputation (Ertl, Brackett, Ertl, & Pritchett, 2016)**.** Because of this increase in required energy, and time taken to perform simple day-to-day activities, individuals may adapt their daily activities to perform less demanding activities to avoid fatigue. This can result in a significant decrease in physical activity, resulting in a more sedentary lifestyle. Significant reductions in activity level for military personnel who, prior to injury, were extremely active, can be detrimental to their overall health (Hisam, et al., 2016). Further, it also increases their risk of BMD loss associated with disuse atrophy and, consequently, their risk of fragility fractures is also increased (Flint, et al., 2014).

BMD is a measure of how strong and dense bones are. The lower the bone density, the thinner and weaker the bones, often resulting in an increased fracture risk. As individuals age, the bones naturally become thinner as the existing bone cells are absorbed by the body much faster than the rate at which new bone is made (Romito & Herman, 2015). Due to the gradual loss of minerals, mass, and structure, the bones slowly become weaker, thereby increasing the risk of fracture. For most individuals, this process starts to occur in middle age, and it is more predominant in women (Romito & Herman, 2015). Surprisingly, many fit and healthy young individuals who have undergone transfemoral amputation are now experiencing loss of bone mineral density leading to fragility fractures. This is an alarming discovery, especially due to the age and health status of these individuals suffering from low BMD following amputation. They would not typically be placed "at risk" for BMD loss at this stage in their lives. However, low BMD is a very serious issue for individuals who have had transfemoral amputation. It can prevent them from regaining pre-morbid functioning.

BMD can be measured in several ways. The most common is a Dual-energy x-ray absorptiometry (DXA) scan. The DXA passes x-rays through the body and records the number of x-rays able to pass all the way through without being absorbed by tissues such as fat or bone (NHS, 2016). The measurements acquired through the DXA are then compared to the averages of individuals of the same age and gender. The results are used to determine whether the individual is at risk of fractures due to a low BMD reading. In the case of combat-related amputation, it may also be useful to compare the readings from their amputated side to their non-amputated side (Robbins, Vreeman, Sothmann, Wilson, & Oldridge, 2009). Due to the nature of their high intensity training/lifestyle prior to injury, they may have a much higher BMD compared to average individuals. Although the results may be normal on the amputated side when compared to the average population, the amputees could have significantly reduced BMD compared to their own non-amputated limb. As a result, this could place them at risk of fractures and other difficulties associated with loss of BMD.

BMD loss is generally present in the residual limb (the remaining part of the limb following amputation) on the amputated side. This research study proposed that the loss of BMD is associated with disuse atrophy because of decreased limb loading through the amputated side (Flint, et al., 2014). This may be due to the prolonged time before ambulation following surgery, adjustments in gait pattern, or reductions in physical activity. Following amputation, patients experience varied durations of bed rest and reduced ambulation. This is all dependent on their previous health status, the surgical procedure, any complications experienced, along with the patients' motivation to return to pre-morbid functioning (Sherk, Bemben, & Bemben, 2008). These factors could contribute to the loss of BMD and increase the individuals risk of fractures. This could further hamper their quality of life as well as their ability to perform day-to-day activities. Because the individuals experiencing traumatic amputations are generally younger, and fitter than those from different causes of amputation, returning to pre-morbid functioning could occur much sooner. If these individuals were to return to weight-bearing activities or strength training at an earlier stage than the current rehabilitation guidelines suggest, it may be possible to reduce the negative physiological effects. This could result in reducing the risk of fractures associated with loss of bone mass and disuse atrophy (Beck, Daly, Fiatarone singh, & Taaffe, 2016).

The purpose of the following review is to suggest a possible protocol for returning to ambulation or exercise at an earlier date following transfemoral amputation. This could help reduce the damaging physiological and psychological effects experienced by the traumatic amputees. Discovering a way to reduce the physiological, psychological and biomechanical effects of traumatic transfemoral amputation is a priority, as currently the long-term, functional outcomes are poor. Therefore, more focus should be placed on the post-acute care of the amputees to improve their functional outcome and to reduce the risk of secondary conditions which hamper their recovery (MacKenzie, Bosse, Pollak, Webb, Swiontkowski, Kellam, Smith, Sanders, Jones, Starr, McAndrew, Patterson, Burgess, & Castillo, 2005).

METHODOLOGY

In order to address the issue of loss of BMD in traumatic transfemoral amputees, this thesis will examine the published literature pertaining to this issue. This comprehensive literature review focuses solely on Traumatic Transfemoral amputation and the loss of BMD Therefore, any research studies focusing on amputation outside these parameters were discounted and not included. However, research articles addressing the effects of exercise on BMD for transfemoral amputees were read, summarized, and analyzed for the purpose fo this thesis.

With the guidance of my thesis chair and a reference librarian, initial searches on this topic revealed few articles solely focused on early ambulation for traumatic transfemoral amputees. Therefore, the parameters for research were expanded to include more general studies that considered the effects of exercise on increasing BMD in sedentary populations and to include all studies from 1975 to present. With the assistance of a professional reference librarian, the criteria used to find these scholarly studies included the use of a longitudinal timeline to assess the effect of exercise on BMD over a longer period. This helped to predict what the long-term outcome of this protocol could be for the amputees.

To be included in this comprehensive literature review, the participants in the research studies will have, preferably, been sedentary prior to undertaking the exercise protocol to mimic the 'new lifestyle' following the loss of the limb. All the research articled included in this thesis were summarized, synthesized into physiological impacts, psychological impacts, followed by the three significant stages of amputee rehabilitation including the post-operative, pre-prosthetic and prosthetic rehabilitation stage. Therefore the following chapter headings and subheadings are

used to share the results of this comprehensive literature review and further break down the results.

Key Words: Traumatic, Transfemoral Amputation, Bone Mineral Density, IPOP, TMR

IMPLICATIONS OF TRAUMATIC TRANSFEMORAL AMPUTATION

There are many concerns when treating a traumatic transfemoral amputee. For the sake of this literature review, only the physiological effects of traumatic transfemoral amputation will be considered. Despite this, the psychological implications of amputation are just as important to consider in the rehabilitation process of the amputee. However, this is outside the scope of this literature review. Amputation is generally very debilitating for the individual. However, when the amputation is the result of a trauma, there are even more consequences to consider, when deciding how best to approach the rehabilitation process. Friends, family, and all the professionals helping the amputee through this process should be aware of the consequences of the traumatic amputation. Having everyone informed will help to ensure the highest quality of care and rehabilitation for the amputee as they progress toward pre-morbid functioning.

Physiological implications

Physiological implications of traumatic transfemoral amputation addresses the changes that occur within the body following amputation. While there are numerous adaptations the body will undergo because of traumatic transfemoral amputation, a few of the more troublesome changes are outlined below.

Loss of BMD in traumatic transfemoral amputation patients is particularly troubling because the individuals exhibiting the symptoms are significantly younger than the average patient suffering from loss of BMD. For example, in one study considering BMD loss after combat-related lower extremity amputation, the median age was 24. This is significantly lower than the expected onset-age of osteopenia and osteoporosis (Flint, et al., 2014). Flint et al (2014) considered 156 amputees who were being treated at a tertiary military care facility. All the participants underwent a DXA scan to determine their BMD and to detect if they were at risk of fractures. They discovered 42% of the patients had a Z score <-1.0, which placed them into the 'low bone mineral density' category. A further 15% of the participants were two or more standard deviations below the mean, placing them in the 'severe BMD loss' category. Adachi (1996) suggested that each standard deviation decrease below the mean BMD, represented an increased risk of hip fracture of 2.8 persists. The young average age of these participants highlights the importance of this problem and how it must be addressed. The purpose was to reduce the risk of femoral neck and acetabular stress fractures along with low-energy fragility fractures. This will assist the amputees' return to high intensity activities, which is, ultimately, the goal for many of these patients.

Loss of BMD is more significant in individuals who experience transfemoral amputation as opposed to transtibial amputation according to Gailey, Allen, Castles, Kucharik, & Roeder (2008). Flint et al (2014) found that 68% of transfemoral amputees in their study suffered from low or severe BMD compared to just 28% of transtibial amputees. This finding is further supported in a study by Leclercq, Bonidan, Haaby, Pierrejean, & Sengler, (2004). They found evidence to support a significant decrease in BMD in those with transfemoral amputation compared to transtibial amputation. Leclerq et al (2004) also found a further increased risk of BMD loss if the cause of amputation was due to trauma compared to non-traumatic causes. There was further support from Rush, Wong, Kirsh, & Delvin, (1994) who discovered that there was an average 28 percent loss of BMD in 81 percent of their subjects with transfemoral amputation. This significant loss of BMD following transfemoral amputation suggests the development of osteopenia leading to osteoporosis is a high probability for these individuals

(Gailey, Allen, Castles, Kucharik, & Roeder, 2008). Because of these findings, it is suggested that individuals who undergo a transfemoral amputation because of trauma are at a higher risk of losing BMD. This puts them at an increased risk of fractures compared to other amputees, and significantly higher risk than non-amputees of similar age. (Al-Ani, Cederholm, Sååf, Neander, Blomfeldt, Exström, Hedström, 2015)

It has been suggested that the cause of the significant reduction in BMD following transfemoral amputation is a result of disuse atrophy due to the immobilization and reduced limb loading through the amputated side (Flint, et al., 2014). The decreased stress being transmitted through the amputated limb following amputation, along with the altered gait mechanics during ambulation reduces the stress placed on the bones. Consequently, this prevents the bone remodeling process from being stimulated and will eventually result in loss of BMD leading to increased susceptibility to fractures (U.S. Department of Health and Human Services, 2004).

Individuals who wear a prosthesis for more than six hours a day have been found to have significantly greater hip BMD than individuals who wear the prosthesis for less than six hours a day (Sherk, Bemben, & Bemben, 2008). There is a need for a more standardized measures of an individual's increased risk of low BMD to determine whether the individual is able to walk outside or only walks inside on smoother, less undulating surfaces. One study found that amputees who were comfortable walking with the prosthetic outside on rougher ground had a significantly greater BMD than those who only felt comfortable walking inside on their prosthetic (Smith, Comiskey, Carroll, & Ryall, 2011). Individuals who feel more comfortable walking around on their prosthetics outside are more likely to be more physically active. Consequently, they are more likely to place greater stress through the bone to promote bone remodeling, thus reducing the effects of bone resorption (U.S. Department of Health and Human Services, 2004). These findings suggest a relationship between the physical activity status of individuals following transfemoral amputation and the loss of BMD. With increased physical activity, the individuals can offset the loss of BMD (Kemmler, Lauber, Weineck, Hensen, Kalender, Engelke, 2004). This decreased physical activity in individuals following amputation can also have other detrimental effects to their health.

Many individuals following amputation tend to lose muscle mass. This is due to atrophy because of the decrease in physical activity and the associated gain of fat mass. A gain in fat mass tends to occur during the first two years following amputation (Robbins, Vreeman, Sothmann, Wilson, & Oldridge, 2009). This puts these individuals at risk of developing cardiovascular diseases, diabetes and other associated disorders. Besides the obvious health risks of increased fat mass, it has also been found that the simultaneous decrease in fat free mass places these individuals at an increased risk of fracture (Al-Ani, et al., 2015). Because of these findings, it is imperative that post-amputation patients are able to limit the loss of muscle mass and gain of fat mass through exercise and alterations in diet. This will help lower the risk of femoral neck fractures and hip fractures. Fractures will undoubtedly result in a more pronounced loss of BMD following the injury due to the need to be more sedentary to allow the fracture to heal.

Altered gait mechanics also contributes to loss of BMD, with higher rates of joint disorders being found in the amputee population compared to the general population (Pruziner, Werner, Copple, Hendershot, & Wolf, 2014). To feel more comfortable while walking, amputees tend to favor their non-amputated limb. This places more force through the limb consequently reducing the stress placed on the amputated side. Because of the altered gait mechanics while ambulating, individuals typically favor their non-amputated limb. Therefore, amputees spend significantly longer on the unaffected limb compared to the amputated limb (Burke, Roman, & Wright, 1978). These findings may explain why the remaining muscles atrophy so dramatically following amputation as individuals compensate for the loss of confidence in their prosthesis. This, in turn, reduces the stresses transmitted through the muscles and bone resulting in atrophy and loss of BMD. It has also been suggested that a lack of muscular action at the extremity may be associated with increased bone resorption (Rush, Wong, Kirsh, & Delvin, 1994). Therefore, lack of stress being transmitted through the amputated limb could result in increased loss of BMD due to an increased rate of bone resorption compared to bone remodeling (U.S. Department of Health and Human Services, 2004).

Given that loss of BMD is a particularly serious problem for transfemoral amputees, the rehabilitation protocols must be addressed to limit the effects of BMD loss (MacKenzie, et al., 2005). By adjusting the rehabilitation protocol, individuals may be able to regain pre-morbid functioning much sooner and limit the risk of fragility-fractures. Numerous studies have considered the effects of physical activity and BMD and found a strong correlation between increased activity levels and increased BMD (Nilsson, Ohlsson, Odén, Mellström, & Lorentzon, 2012). This principle could be applied and adapted to fit the rehabilitation needs of many transfemoral amputees. Hopefully, this protocol will limit the loss of BMD and aid in the return to pre-morbid functioning at an earlier date. In addition, prolonged aerobic exercise (swimming) will be beneficial to maintain the individual's fitness and limit the increase of fat mass. However, because non-impact exercise does not provide any notable stimulus to bone, it is not useful in preventing the loss of BMD (Beck, Daly, Fiatarone singh, & Taaffe, 2016). Therefore, focus should be placed on activities that cause pressure to be transmitted through the amputated limb to stimulate the bone remodeling phase and maintain the strength and integrity of the bones (U.S. Department of Health and Human Services, 2004).

Psychological implications

While the psychological effects of traumatic transfemoral amputation are outside the scope of this literature review, they must not be completely ignored. The psychological effects address the amputees' mental and emotional state following amputation. These factors have a significant impact on the rehabilitation of the amputee. For those who do not see the amputee daily, some of the signs may not be obvious. Therefore, it is important to understand what to look for so that the appropriate help can be provided as it is required. Traumatic amputation does not allow the individual to come to terms with the future loss of their limb prior to the event occurring. Therefore, it presents a completely new host of issues to be addressed compared with those whose cause of amputation was not trauma.

The main concerns with traumatic transfemoral amputation are anxiety, major depression and PTSD. It is suggested that approximately 54% of trauma related amputees suffer from one of these issues (Haldaman & Glassman, 2011). Any of these factors could impact the effectiveness of the rehabilitation and must be addressed concurrently with the physical aspects of rehabilitation following amputation. It has been suggested that at the six-month period (the typical discharge point from rehabilitation) amputees begin to display many of these symptoms due to the daunting prospect of having to adapt to their new reality. (Haldaman & Glassman, 2011). Therefore, it could be beneficial to have a sport or training group arranged for these individuals to encourage them to continue their rehabilitation. It could also provide them with a viable social group to interact with outside of their family, friends and rehabilitation team. It has been reported that individuals who feel socially integrated into their community and society feel more ‘normal’ post amputation. This often helps the amputee adapt better to their new reality compared to those who may feel socially isolated. (Ferguson, Sperber, & Gomez, 2004)

BENEFITS OF EXERCISE FOLLOWING TRAUMATIC TRANSFEMORAL AMPUTATION

As discussed previously, there are numerous implications to traumatic transfemoral amputation that must be considered when designing and implementing the rehabilitation protocol for each individual amputee. For the purposes of this review, the focus was predominately placed on the physiological effects of traumatic transfemoral amputation. The most troublesome physiological effects the amputee may experience, and that rehabilitation should address, are described below:

1) The loss of BMD and the increased risk of fractures
2) Disuse atrophy caused by the increased tendency towards a sedentary lifestyle
3) A gain in fat-mass and the associated secondary conditions
4) Gait alterations and the associated increase in joint disorders

The introduction of exercise at an earlier stage in the rehabilitation protocol for traumatic transfemoral amputees could address all the issues listed above and provide the amputee with an enhanced quality of life. Because the average age of traumatic amputees is significantly lower than other causes of amputation, the rehabilitation protocol should be significantly different. Traumatic amputees, specifically those coming from the military, possess characteristics that may make the adjustment following amputation even more challenging. Service members are faced with life or death situations on a regular basis and must believe that they will make the correct decision. As a result, military personnel have a strong sense of independence and self-confidence. Military personnel also exhibit high levels of determination and possess a "never-give-up" attitude. These characteristics, together with the energetic nature of their lifestyle and young age, make facing their new reality as an amputee a very daunting prospect.

However, if the rehabilitation protocol could be adjusted to include physical activity at an earlier stage of rehabilitation, it could allow the individual to find new goals to strive towards. Additionally, it could help them feel less 'useless and lost' post-amputation if they were able to participate in adapted exercises, instead of being bed-bound or confined to their wheelchair. This could make the adaptation to their new reality less daunting. They could see that they could still to do things they could before amputation, with slight adaptations. Opportunities for amputees to compete in sporting activities are ever increasing, with the Paralympics becoming a more prominent and eagerly anticipated event in many countries. This means there are more sporting opportunities and facilities accessible to this population. These facilities could open new windows of opportunities for the amputees. If, during rehabilitation, the amputees were introduced to these new opportunities, it could enhance their rehabilitation, and decrease the physiological and psychological effects of amputation. Enabling amputees to participate in physical activity could suggest opportunities they still have despite their condition. Many amputees are unaware of their capabilities and focus solely upon what they can no longer do. One study discovered that 93% of the amputees were unaware of existing sports facilities available to them (Bragaru, Dekker, Geertzen, & Djikstra, 2011). Therefore, opportunities must be more widely publicized to enable the amputees access.

Exercise could open the door to more successful re-integration into society for the amputees. Providing the amputees with a new goal of competitive sport, or simply the confidence to become independent again, could allow them to take control of their lives instead of being defined by their injury.

Physiological benefits of exercise following amputation

The benefits of exercise on BMD has been extensively researched especially in post-menopausal women. These individuals, along with men over the age of 50, are at the highest risk of BMD loss (Romito & Herman, 2015). The principles applied to these studies can also be applied to the traumatic transfemoral amputees. They are going through similar losses of BMD, although for the amputees at a much younger age. At time of amputation, the traumatic amputees generally have higher levels of activity which places them at an advantage for gaining BMD. It has been found that increases in BMD are more significant for those who have a high level of activity prior to injury compared to those with a low level of pre-morbid physical activity (Nilsson, Ohlsson, Odén, Mellström, & Lorentzon, 2012). If individuals can combat the trend of decreasing their physical activity levels post amputation, remaining at a high level of physical activity has been associated with smaller losses of BMD (2012). This suggests that, if the amputees and their rehabilitation team (family, therapists, etc.) can maintain high levels of activity, they would able to reduce the losses of BMD. Therefore, the amputees would reduce the risk of fragility fractures and enhance their overall well-being.

Most forms of exercise will provide some benefit to the traumatic transfemoral amputee by increasing stress on the bone, maintaining fitness levels, and decreasing the gain in fat mass. It has been suggested, for the most beneficial response from the bone, that exercises performed should be dynamic, induce relatively high bone strains, and be applied rapidly. Short bouts of exercises followed by periods of rest are more beneficial than continuous exercises, as the bone becomes desensitized to repetitive patterns of bone loading (Beck, Daly, Fiatarone Singh, & Taaffe, 2016). Because of these findings, rehabilitation programs for the transfemoral amputee should include a diverse range of exercises. Avoiding excessive use of repetitive movements, such as jogging and walking, places different strains on the bone. This could involve various resistance training exercises that may be altered to fit the needs of the amputee in the early stages of rehabilitation.

As the rehabilitation program progresses, multidirectional exercises should be incorporated into the individuals' daily exercise regimen. This would serve to place unusual strain on the amputated limb which will aid in developing high levels of mobility (Gaunaurd, Roach, Raya, Hooper, Linberg, Laferrier, Campbell, Scoville, & Gailey, 2013). Further, the incorporation of multidirectional exercises will also build the individuals' confidence for using the prosthesis which will help in increasing their physical activity levels (Miller, Deathe, Speechley, & Koval, 2001). It has been shown that amputees who feel comfortable wearing their prosthesis for more than six hours a day have a significantly higher BMD than those who wore the prosthesis for less than six hours a day (Sherk, Bemben, & Bemben, 2008). Therefore, it is essential that these individuals gain confidence and become comfortable using their prosthesis. The increased time wearing the prosthesis would generally be associated with increased physical activity levels which, in turn, increases BMD.

Further research found that an increase in physical activity of 2.5 hours a week, compared to a reduction in physical activity of 2.5 hours a week, was associated with a difference of 14% loss of BMD in the hip (Nilsson, Ohlsson, Odén, Mellström, & Lorentzon, 2012). Therefore, decreases in physical activity often associated with amputation is detrimental to BMD. This should become a factor in the rehabilitation process if the individuals' desire is to get back to high levels of activity and mobility post-surgery. This is the goal for most service personnel.

Once this goal has been established, the correct protocols should be put in place to enable the goals to be reached. This should be a progressive program focusing on the individual becoming more independent and more able to ambulate as the program progresses (Meier III & Melton, 2014). The program should start as soon as possible following amputation. This would limit the loss of BMD and decrease the amount of time the limb is completely unloaded. Once the individual has been fitted with a prosthesis, generally 3-6 weeks following surgery, they should begin to ambulate starting with support from parallel bars, and progressing through to the use of non-ambulatory aids (Meier III & Melton, 2014). If the individual can ambulate without the use of aids it will increase the stress placed through the amputated limb thereby reducing the risk of BMD loss.

Once the individual has undergone the surgery and is able to handle the limb discomfort, the amputee can start muscle strengthening exercises to prevent the atrophy of muscle. It is recommended that range of motion exercises should begin immediately, resulting in fewer restrictions once the individual is able to ambulate. This could help prevent significant asymmetries in gait from occurring (Turkyilmaz Ozel & Kottke, 1975). These exercises should focus on the amputees' primary gait muscles to ensure as close to 'normal' gait following the prosthesis fitting. Exercises should address the amputees' gluteus muscles, hip flexors, hamstrings, quadriceps, abductors and adductors. Exercises could include bridging, leg raises, side-lying hip abduction, prone hip extension, and prone adductor squeezes (Center of Advanced Prosthesis, 2007). By incorporating several muscle strengthening exercises prior to being able to start ambulation could decrease the asymmetries seen in gait. This should also help maintain muscle strength. Muscle strength can be further enhanced through isometric contractions lasting six seconds about 20 times a day. This will increase the tensile strength and endurance of the muscle above the level achieved by only exercising once daily. (Turkyilmaz Ozel & Kottke, 1975) If the individual can perform the range of motion exercises alongside the muscle strengthening and isometric exercises, the amputee may be able to return to independent ambulation at an earlier date. It could also prevent the loss of BMD and other negative effects associated with the amputation.

While the loss of BMD and muscle atrophy can be very limiting for the individuals, it is possible for the amputees to regain most of the BMD lost post amputation. This should be done through a focused and intensive rehabilitation protocol. One study discovered the use of resistance exercise in post-heart transplant patients could restore BMD levels back close to their previous baseline (Braith, Mills, Welsch, Keller, & Pollock, 1996). This study showed that resistance exercise is osteogenic (stimulates bone production) and, therefore, should play a pivotal role in the rehabilitation process of traumatic transfemoral amputees. Strength training will have to be adapted to ensure sufficient strain is being transmitted through the bone to induce the bone remodeling process. Further support for the use of strength training was found after participant's femoral neck and spine BMD increased significantly following a rigorous resistance training program. This included 2-3 days a week for two years of specific strength training for patients with Rheumatoid Arthritis. Along with increases in BMD, there was an outstanding increase in muscle strength ranging between 19-59%. In addition, the participants experienced improvements in walking speed and physical function (Häkkinen, Sokka, Kotaniemi, & Hannonen, 2001). The significant improvements in strength and BMD, coupled with enhanced functional performance, emphasizes the importance of incorporating a structured and targeted strength training program into the rehabilitation protocol. If this were to be established early in the rehabilitation process, amputees' may not suffer as significant loss of BMD. Therefore, the amputee will hopefully be able to regain pre-morbid functioning much quicker while regaining their independence sooner.

Further research has suggested that, to ensure higher levels of mobility following amputation, therapy must be focused on lower-limb strength, and dynamic balance (Gaunaurd, et al., 2013). By incorporating balance and strength training into the rehabilitation protocol, individuals would be more stable on the prosthesis and more confident. These findings correlated to higher levels of mobility. The higher levels of mobility reduces significant loses of BMD. It has also been found that a combination of smaller waist circumference (less central adiposity), increased lower-limb strength, and dynamic balance are associated with significantly higher levels of mobility (Gaunaurd, et al., 2013). One of the best tests to determine levels of mobility is the individuals' ability to perform the "stand-to-sit" activity without the use of upper-limb support (Gaunaurd, et al., 2013). If individuals can perform this without the support of the upper limbs, they have sufficient strength in the lower limbs to control movements. They are more likely to have higher levels of mobility than those who are unable to perform this exercise (Gaunaurd, et al., 2013). Therefore, focus should also be placed on neuro-motor control exercises. These place a focus on enhancing gait, coordination, balance, agility and proprioceptive training. These are all pivotal areas of assessment for amputees hoping to regain high levels of mobility (Khadir, n.d.).

The goal of every rehabilitation program should be ensuring mobility for the amputees, allowing them to continue with as much independence as possible post amputation. Functional performance of amputees has been measured using numerous tests. These include the timed "up and go" test, 2-minute walk test, physiological cost index, and measures of the weight bearing on both legs. One study compared these test results to a control group of amputees. It showed significant improvements in functional performance for those who underwent the intensive physiotherapy rehabilitation program. The intervention protocol consisted of one-hour sessions requiring the amputees to focus on lower limb strengthening, weight bearing, coordination tasks, corrected walking, obstacle management and functional training (carrying water) (Rau, Bonvin, & Bie, 2007). This study showed that, after intensive physiotherapy focusing on functional skills, there was a 20.15m improvement in distance covered for the 2-minute walk test compared to only 8.93m for the control group (Rau, Bonvin, & Bie, 2007) . This showed significant benefits to a more focused rehabilitation protocol addressing the amputee's ability to complete day-to-day tasks and increasing their strength through activity.

A focus on the amputees' ability to complete day-to-day tasks should become a part of the early stages of the rehabilitation process. It has been suggested that a reduction in the number of Activities of Daily Living (ADL's) completed is one of the main causes of detraining and atrophy which further limits their ability to complete such tasks (Pauley , Devlin, & Madan-Sharma, 2014). It has been suggested that lower limb amputation can cause up to 40-60% muscle atrophy on the amputated side (Pauley , Devlin, & Madan-Sharma, 2014). This significant loss of muscle mass makes even simple tasks significantly harder to perform and control. A significant loss of muscle mass through disuse atrophy can result in functional impairments due to the loss of strength and control. The functional impairment of disuse atrophy has been shown to be three times greater in older women, and two times greater in older men, when compared with individuals who have not experienced disuse atrophy (Jansen, Heymsfield, & Ross, 2002).

However, it has been shown that the loss of muscle mass typically experienced by traumatic transfemoral amputees can be combatted. One study demonstrated that, after a period of bed rest, a seven-week intensive recovery period returned the individuals peak torque, angle-specific torque and muscle cross-sectional area back to normal (Berg, Dudley , Haggmark, Ohlsen, & Tesch, 1991). This research implies that specific rehabilitation protocols of amputees can limit the reduction of muscle atrophy. This would, in turn, increase the amputee's functional performance making ADL's easier, resulting in increased independence.

Ensuring the amputees remain active will help prevent the loss of muscle mass associated with disuse atrophy. This will enable them to retain much of their pre-morbid strength and diminish the asymmetries in gait pattern often seen in transfemoral amputees. Compared to inactive transfemoral amputees, physically active amputees retain a higher percentage of pre-morbid maximal torque at their hip flexors and extensors on the amputated limb. The physically active amputees recorded 65.3% of their premorbid maximal torque, while their inactive counterparts scored 55.9% (Kowal & Rutkowska-Kucharska, 2014). By remaining active, this study found that the ability to generate torque was significantly faster for those who remained active compared to their inactive counterparts (Kowal & Rutkowska-Kucharska, 2014). These findings further emphasized the importance of remaining physically active post-amputation as it limits the loss of strength at the hip flexors and extensors. This will result in a more efficient gait pattern which, in turn, will limit further complications caused by gait asymmetries because of amputation.

Amputees have reported the main barriers to physical activity to be pain, embarrassment, insufficient training, and the lack of organized sports programs (Pepper & Willick, 2009). Therefore, these concerns should be addressed during rehabilitation to ensure the amputee is fully prepared to participate in physical activity. The rehabilitation team should ensure the amputee is fully prepared and confident before advising them to participate in physical activity outside of the rehabilitation facility. If the amputee is pushed into activity before they are ready, injury is more likely to occur, further setting them back in their recovery. This approach could require a graduated return to activity. The activity should start with lower impact activities outside the facility such as walking, swimming. Even cycling could be pursued, if this were an activity the amputee hopes to pursue. After the amputees have adapted to this initial protocol, higher intensity exercise should be introduced as they regain the ability to perform pre-morbid activities.

The physiological benefits gained from participating in physical activity earlier on in the rehabilitation process far outweighs the concerns of participating. Therefore, exercise should play a major role of the rehabilitation protocol from an early stage. This will limit the loss of BMD and muscle atrophy while helping to enhance their functional performance. This will also allow the amputees to participate in sports earlier in rehabilitation, as they are not having to overcome such severe muscle atrophy and bone weaknesses. If rehabilitation can limit this loss it could help combat some of the frustrations experienced by amputees. As one amputee, undergoing rehabilitation at Headley Court in the UK stated, “One of the most frustrating things is that I can't play sport – tennis, football, rugby, golf.” (Gentleman, 2010). Although the amputees may not be able to return to these sports, the possibility of returning to high intensity activities is not out of the question. Therefore, it should be a goal of the rehabilitation process. This requires a focus on increasing BMD, and reducing atrophy to allow this goal to be achieved and not be exacerbated by further injury.

Research has also suggested that supplementation with calcium and Vitamin D, together with physical activity, can reduce the loss of BMD and reduce the risk of fractures. It has been shown that low levels of calcium and Vitamin D in the diet are highly correlated with the development of osteoporosis and fracture risk (Lips, Bouillon, Schoor, Vanderscheuren, Verschueren, Kuchuk, Milisen, Boonen, 2010). Having adequate amounts of Vitamin D and calcium in the diet has been shown to prevent osteoporosis and provide a modest increase in skeletal mass without undesirable effects on the skeleton. (Turkyilmaz Ozel & Kottke, 1975). Vitamin D is required for the body to ensure the absorption of calcium into the bones. Without sufficient amounts of Vitamin D, the bones and teeth would be unable to absorb enough calcium to maintain bone strength, thereby leading to loss of BMD and increased fracture risk (Reginster, 2007). Individuals should consume 1000mg of calcium daily and 50-75 nmol/l range (Lips, et al., 2010). Maintaining these levels, together with the increased physical activity, should reduce the risk of fragility fractures and loss of BMD. Consequently, transfemoral amputees should be able to return to a high intensity lifestyle and independence at a sooner date.

In conclusion, research has shown that transfemoral amputees are at an increased risk of loss of BMD, fragility fractures, and significant muscle atrophy making a return to pre-morbid functioning much more difficult. Attention to increased physical activity from a much earlier stage in the rehabilitation program will help to limit the loss of BMD, disuse atrophy, and reduce the trend for significant gains in fat mass. This will help the amputees return to pre-morbid functioning with fewer limitations. This is the goal for most trauma-related amputees due to their young age.

Enhancements to Current protocol

Traumatic transfemoral amputee rehabilitation is a very delicate and specific process, especially when addressing the needs of service personnel. The rehabilitation process is constantly evolving to cater for new research advancements to ensure the most effective treatment for the amputees. New research should address the benefits of early ambulation and physical activity as part of the rehabilitation protocol. It should explore how to enhance the reduction of BMD and atrophy experienced post-amputation. By reducing these problems, the amputee lowers their risks of suffering from further complications which can lead to prolonged recovery time and future difficulties. This is a necessity, specifically for traumatic transfemoral amputees. Because they are generally younger and have lived a very different lifestyle (very active, high-intensity work) than other amputees, their rehabilitation goals tend to be very different compared to those who have undergone non-traumatic amputations.

Following examination of current protocols and current research it would be advisable to encourage amputees to return to ambulation at an earlier date. If ambulation is not possible, load bearing exercises should be introduced. This would allow stresses to be transmitted through the bone, encouraging the bone remodeling process to occur. This will help to reduce the significant loss of BMD often experienced by transfemoral amputees. Currently, there are three main post amputation stages each amputee goes through before they can successfully re-integrate into society with full independence. The three stages are: the post-operative rehabilitation stage, pre-prosthetic rehabilitation stage, and the prosthetic rehabilitation stage (Kovač, et al., 2015).

Post-operative rehabilitation stage

The post-operative rehabilitation stage focusses primarily on pain management. This stage begins immediately after surgery when the individual has awakened from anesthesia and is transferred back on the ward. Once the amputee has become medically stable, the attention of the support team should address rehabilitation intervention emphasizing optimization of function, mobility and quality of life for the amputee. (Department of veterans Affairs & Department of Defense, 2008). The main concerns during this stage are the prevention of post-operative complications such as deep vein thrombosis, pulmonary embolism, wound infection, hematoma or hemorrhage at surgical site, and soft tissue debridement (The Brigham and Womens Hospital, 2016). Due to the high levels of care required, few alterations can be made at this stage. It is essential to ensure the wound heals correctly so the amputee does not experience too much discomfort when wearing the prosthesis and undergoing rehabilitation. As a result, this portion of recovery cannot be rushed or shortened. The amputee must be fit to start rehabilitation to prevent further injury and pain if the wound is not correctly healed. However, it is difficult to place a specific time frame, as individuals may progress at different rates and be able to tolerate different volumes of exercises.

Despite the need for caution during this stage, the amputee does not have to be completely rested. During this stage of recovery, the amputee can perform in-bed exercises (during the first few days post operation) focusing on strengthening the intact limb and trunk. It is also vital that the amputee, if tolerable, begin Range Of Motion (ROM) exercises addressing hip flexion, extension, as well as adduction and abduction on the amputated limb. This is essential as range of motion at the hip joint must be maintained during the recovery process to reduce the risk of significant gait asymmetries during ambulation (Benyaich, Lowe, Hafeez, & Khadir).

Once the range of motion exercises are well tolerated, the amputee should progress to strengthening exercises to start transmitting stress through the amputated limb and limit the disuse atrophy. Isometric strengthening exercises may be used involving contractions of the hip extensors, and flexors. For example, simply laying in either a prone or supine position (whichever is most comfortable) and squeezing the gluteal muscles together represents and effective isometric exercise. Further exercises could include hip squeezes, by placing a pillow between the thighs and having the amputee try to squeeze their thighs together (The Brigham and Womens Hospital, 2016) .

Following the introduction of the strengthening exercises, individuals should progress to balance, mobility and functional activities (Department of veterans Affairs & Department of Defense, 2008). Attention should be placed on the amputee's ability to maneuverer themselves into and out of their wheelchair safely and independently. This will also prepare the amputees for discharge from hospital, as they will no longer have the constant care available to them. Therefore, this stage of recovery addresses the functional activities allowing the amputee to live relatively independently outside of the hospital.

Initially, after surgery, the amputee will use the wheelchair to maneuver around until their ability to balance on one leg has improved and they can begin to ambulate. Therefore, after approximately 5-10 days post operation, the amputee should begin to increase the difficulty of their strengthening exercises. If possible, they should begin to ambulate with walking aids such as a preparatory or training prosthesis (Kovač, et al., 2015). This should be encouraged as early as possible to get the amputee comfortable in a prosthesis and to limit the time the limb is completely unloaded. However, it should not be rushed. If this stage is rushed, it could make the amputee uncomfortable in the prosthesis, resulting in a slower recovery time. Therefore, the amputee should try to regain their sense of balance. Following surgery, the amputees center of gravity will typically shift toward the remaining limb (Fitzsimmons, 2011). This shift in center of gravity makes ambulation slightly more difficult post amputation. Because of this, restoring the amputee's locus of control is of vital importance. This may initially require assistance from ambulatory aids such as crutches and walking frames. However, it should slowly progress to where the amputee feels comfortable standing without any aids (Khadir, Angama, Aird, & Lowe).

Rehabilitation at this stage should be conservative. The amputee should not be pushed beyond their pain tolerance as it could push them further back in the recovery phase. However, slight progressions should be made each day. The sooner the amputee is able to stand up and balance, the quicker they can advance towards the next stage of rehabilitation. The earlier the amputee can stand and start placing pressure through the amputated limb, the risk of significant loss of BMD and disuse atrophy is reduced. As a result, the purpose of this stage of the protocol is to minimize the post-operative complications and maximize the progression of rehabilitation. Amputees who begin rehabilitation sooner after surgery reduce the risk of phantom limb pain and increase the ability to master prosthetic ambulation (Kovač, et al., 2015). Also, if the amputee can master prosthetic ambulation at an earlier date, it will significantly reduce the risk of excessive BMD loss and disuse atrophy. This will reduce the risk of further complications and increase the post-surgery independence of the amputees.

Pre-Prosthetic Rehabilitation Stage

The Pre-Prosthetic Rehabilitation stage begins as soon as the post-operative stage of recovery is completed. This is the stage of rehabilitation where the amputees are most vulnerable to losses in strength, range of motion and BMD (The Brigham and Womens Hospital, 2016). As a result, this stage of recovery should be addressed to limit these effects. This stage of rehabilitation is concerned with the preparation of the residual limb to ensure it is prepared for the prosthesis. This stage also focusses on the physical conditioning of the amputee to ensure they are prepared for the stresses placed through the body throughout the prosthetic rehabilitation. However, the overall purpose of this stage is to return the amputees' sense of control (Esquenazi & DiGiacomo, 2001). This is essential for traumatic amputees, as the events preceding the amputation were completely out of their control. However, now the amputees can take control of the rehabilitation and their life. This must be provided to them in this stage.

This Pre-prosthetic rehabilitation stage of recovery involves limb shaping, stump shrinking, skin care, increases in range of motion and muscle strength, cardiovascular training, progressive functional mobility training and patient education (The Brigham and Womens Hospital, 2016). This stage of recovery could possibly be manipulated the more than the others. The manipulation of this stage of recovery revolves around the type of dressing applied to the residual limb following surgery. There are multiple options which can be used, and all are effective in protecting the wound. However, the type of dressing used may prolong the time until ambulation. Therefore, the type of dressing may increase the risk of BMD loss and disuse atrophy, something they want to avoid if they wish to return to high-intensity exercise following surgery. The options available to the amputees include soft dressings, immediate postoperative prosthesis (IPOP's), and Removable Rigid Dressings (RRDs) (Kinor, Gaussa, & Sutton, 2013). These options are all suitable in ensuring effective healing of the wounds. However, some of the options allow the amputees to return to weight-bearing at an earlier date. This is an attractive option, especially when dealing with young traumatic amputees.

The most common post-operative dressing used for amputees is the soft dressing (Lusardi, Jorge, & Nielson, 2012). Soft dressings are typically used because they are more cost effective and provide easy access to the wound. This allows the amputee and medical professional to keep up with wound healing and to spot possible complications (Smith , McFarland, Sangeorzan, Reiber, & Czerniecki, 2003). However, this dressing is not necessarily the best dressing to be used for the traumatic transfemoral amputees' rehabilitation. It often prolongs the time until ambulation and the time required on bed rest (The Brigham and Womens Hospital, 2016). Increased time on bedrest following surgery will decrease the mobility of the hip joints further. This causes difficulty with ambulation once they are able to be fitted with a prosthesis. Beyond the decreased mobilization, the amputees will experience a more significant loss of BMD and disuse atrophy because the bed rest time can be more than doubled compared to other dressings (The Brigham and Womens Hospital, 2016). This is something amputees hope to avoid if they wish to decrease the time to return to pre-morbid functioning. Therefore, the amputees should avoid any complications associated with loss of BMD and disuse atrophy which could further increase the recovery time. Soft dressings may not be the best option to use for this population. They tend to have more ambitious goals following amputation than those of other amputation causes who are generally significantly older.

Removable rigid dressings offer many of the same benefits as soft dressings. The ability to remove the dressing allows physicians and patients to view the wound, and to be aware of any possible infections (Kinor, Gaussa, & Sutton, 2013). However, it does require a trained individual to remove the dressing and replace it. Additionally, the dressing is unable to be removed for long periods of time. If it is removed for more 15 minutes, the limb will swell and prevent the reapplication of the dressing. (Deutsch, English, Vermeer, Murray, & Condous, 2005) . Despite these restrictions, many studies have found the RRD to be a superior dressing to the soft dressing in decreasing the wound healing time. This will allow the amputee to ambulate at an earlier date, thereby decreasing the potential loss of BMD and disuse atrophy. One study found that the residual limbs of a group of patients with an RRD dressing cut their wound healing time in half compared to a group of patients with a soft dressing (Wu & Krick, 1987). Further support for this finding came from Deutsch et al who discovered the incision site of those with an RRD healed two weeks quicker than those with a soft dressing (2005).   Many studies have discovered decreased wound healing times associated with the use of RRD compared to the soft dressing. Therefore, it is preferable to the soft dressing for the traumatic transfemoral amputees. By decreasing the wound healing time, the amputees can be fitted for a prosthesis and begin ambulating at a sooner date. This results in the decreased likelihood of increased bed rest and decreased activity, conditions which contribute to a longer recovery time.

Immediate Post-Operative Prosthesis (IPOP) can be applied immediately following the completion of the amputation (Bowker, 2004). The IPOP is generally only used on individuals who were previously active prior to the amputation and, therefore, is a suitable device for the typical traumatic transfemoral amputee. This device consists of significant padding and compression socks surrounding the residual limb and is protected by a rigid fiberglass or plastic wrap. An attachment plate is secured within the wrap and allows a pylon and a foot to be connected (Hutson, Dillingham, & Esquenazi, 1998). The IPOP is now used as a semi-rigid protective device to avoid the complications exhibited in the previously used plaster cast IPOP (Pongratz) . This allows the physician to remove the device to observe the wound, thereby decreasing the likelihood of missing any infections or pressure sores which can result in a delayed recovery process. There have been significant advantages associated with the use of the IPOP. These include both physiological and psychological advantages, because it has been suggested that with the IPOP there is a decreased perception of loss of function (Tintle , Keeling, Shawen, Forsberg, & Potter, 2010). This will aid in the rehabilitation process because the individual will feel less restricted by the amputation and progress quicker and easier through rehabilitation. This will enable their return to pre-morbid functioning sooner while reducing the loss of BMD and disuse atrophy which can hamper many traumatic transfemoral amputees progress.

Further studies have found support for the use of the IPOP following amputation. One study found transfemoral amputees fitted with the IPOP returned to ambulation far sooner with only 9.3 days post amputation (Folsom, King, & Rubin, 1992). This is a significant improvement compared to ambulation for the use of soft dressing generally being between 6-8 weeks post-operatively (The Brigham and Womens Hospital, 2016). This suggests that there are significant physiological benefits to advocating for the use of IPOP following traumatic transfemoral amputation for those who aspire to a high-intensity post-amputation lifestyle. Because the IPOP allows weight bearing at a significantly earlier stage of recovery, gait training can begin much earlier. This reduces the risk of significant gait asymmetries in the future which can result in further complications (Smith , McFarland, Sangeorzan, Reiber, & Czerniecki, 2003).

The current research suggests that the IPOP should be the preferred protocol following traumatic transfemoral amputation as it allows the amputees to reduce their recovery time significantly and decrease the time taken to the initial prosthetic fitting (Tintle , Keeling, Shawen, Forsberg, & Potter, 2010). However, the current protocol for traumatic transfemoral amputees does not involve the use of the IPOP. This is due, primarily, to the costs involved with the IPOP as well as the possible risks associated with early mobilization (Tintle , Keeling, Shawen, Forsberg, & Potter, 2010). However, due to the overwhelming advantages the amputees could possibly gain from the IPOP, more research should be conducted to ensure the effectiveness of this course of treatment. This could significantly enhance the recovery process if all traumatic transfemoral amputees were fitted with an IPOP, decreasing their risk of many of the co-morbidities associated with delay to ambulation. This could further enhance the amputees' quality of life post amputation and enable them to return to pre-morbid functioning at a much sooner date.

Prosthetic Rehabilitation Stage

The prosthetic rehabilitation stage begins as soon as the amputee has completed the pre-prosthetic stage. To start this stage, the rehabilitation team must be satisfied that the amputee is mentally and physically prepared to begin. Throughout this stage, the amputee and rehabilitation team may encounter numerous obstacles as the amputee learns how to efficiently ambulate with their new prosthesis. The number and severity of obstacles may be reduced by decreasing the time between the amputation and starting this stage of recovery. As mentioned in the pre-prosthetic stage this can be accomplished by fitting the amputee with an IPOP device immediately after surgery. By doing this, the amputee will try to limit the risk of low BMD and disuse atrophy by slowing down the progress during this stage.

The goal throughout this stage of recovery is to achieve maximum functional independence for the amputee and ensure maximal mobility with the artificial limb (Department of veterans Affairs & Department of Defense, 2008). This stage of rehabilitation will identify the ability to ambulate by assessing their goals, overall health, fitness, and other medical conditions. Most of the traumatic transfemoral amputees will want to achieve the highest level of physical functioning possible post-amputation. Therefore, barring any further physical complications, they would be categorized in the “K4” category. “K4” is the highest level of functioning. This suggests the patient has the ability that can exceed the basic skill levels of prosthetic ambulation, allowing for high impact and high stress activities (Department of veterans Affairs & Department of Defense, 2008). The return to a high impact lifestyle is, typically, the goal for traumatic transfemoral amputees. Therefore, they should be designated the K4 category which will provide a prosthesis that is able to fit these needs.

One of the major issues facing the transfemoral amputee post-surgery is the significant increase in energy expenditure when completing activities of daily living. It has been suggested that transfemoral amputees expend 65% more energy when ambulating at half of their pre-morbid walking pace (Ertl, Brackett, Ertl, & Pritchett, 2016). Gait training from an early stage in the rehabilitation, as well as the use of more technologically advanced prostheses, such as the Targeted Muscle Re-innervation (TMR), could minimize this increase in energy expenditure. This could, allow activities of daily living to be completed with more ease, thereby encouraging a more active post-amputation lifestyle. This could combat the common trend towards decreased physical activity post-amputation and allow them to live more independently and less inhibited by their amputation.

TMR is a very recent advancement in prosthetic science. It attempts to provide amputees with significantly more control over their prosthetic limbs. This is regarded as incredibly important for high intensity, high performance activities (Jiang , Newman, & Hannaford, 2017). This could decrease some of the significant asymmetries observed in the prosthetic gait of amputees. TMR would increase the limb loading through the residual limb while reducing the strain transmitted through the non-amputated limb. If these benefits were to be observed, the combination of the IPOP in the pre-prosthetic stage, and the use of TMR in the prosthetic stage, could reduce the risk of significant loss of BMD and disuse atrophy. These effects would be due to the enhanced ability to perform weight bearing activity from a much earlier stage, and to the increased efficiency with which the amputee can ambulate.

TMR enhances prosthetic control by harnessing remaining nerves and transferring them to the residual muscles that are no longer biomechanically functioning due to the loss of limb. Once these muscles have been re-innervated, they serve as biological amplifiers of motor commands. These re-innervated muscles provide physiologically appropriate Electro-MyoGraphic (EMG) signals allowing enhanced functional use of the prosthetic (Kuiken, et al., 2009). Most of TMRs historic successes have come from use with upper limb amputations.

Recent research has turned towards the advancement of lower limb prostheses, with some early success in transfemoral amputees. For transfemoral amputees, the re-innervated nerves will be placed in the quadriceps and hamstrings where the EMG signals will be generated and lead to control of the prosthetic knee and ankle. One study found that the accuracy of detection of attempted movement was 96% in ankle plantarflexion and dorsiflexion along with knee flexion and extension (Hargrove, et al., 2013). This technology would allow amputees more control over their prosthetic knee and ankle movements. This would allow for a more efficient gait pattern and an increased functional independence which is the purpose of this part of the rehabilitation.

In addition to these findings, it has been suggested that the EMG recordings coordinated with mechanical sensors within the prosthesis, could allow for detection between different ambulatory modes (stair climbing, walking, jogging). The sensors can detect differences in the ground surface to allow more control while ambulating on difficult footing (Souza, et al., 2014). If this new technology can provide all these benefits, it would increase the amputee's confidence, thereby encouraging more time spent ambulating. This technology could return the amputees to pre-morbid functioning with fewer limitations, a goal of this rehabilitation. By providing the traumatic transfemoral amputees the ability to utilize this technology, it is possible many could return to their previous lifestyle with fewer limitations.

If the amputee is unable to utilize this prosthesis, there may still be reasons the amputee cannot return to pre-morbid functioning just as quickly. This stage of rehabilitation, with or without the TMR prosthesis, is similar to the period following fitting of the prosthesis during which the amputee must begin to ambulate. The fitting of a prosthesis device can begin as early as 4-5 weeks post-surgery (Kovač, et al., 2015). Early prosthetic fitting at this stage is generally because of the early provisions of rehabilitation following surgery. Early rehabilitation following surgery enhances the amputees' joint mobilization and decreases the risk of loss of BMD and disuse atrophy, often resulting in delayed recovery time (Department of veterans Affairs & Department of Defense, 2008).

Following the fitting of the prosthesis, gait training should begin as soon as possible. The amputees will have an altered sense of balance and, therefore, will have to relearn how to ambulate and mobilize their joints (Department of veterans Affairs & Department of Defense, 2008). The sooner this able to begin, the lower the likelihood of significant gait asymmetries. Thus, by allowing the amputee to develop a more efficient gait, they may reduce the amount of energy expended while ambulating (Department of veterans Affairs & Department of Defense, 2008). This training consists of a multi-component approach. It addresses rebuilding muscle strength and endurance, increasing flexibility/mobility at all joints, and cardiovascular training (Kovač, et al., 2015). Throughout the gait training, the amputee will slowly progress through each stage ensuring they have mastered each stage before progressing to the next.

The first stage of gait training simply trains the amputee to sit and stand, to ensure they have regained their sense of balance and neuromuscular control (Gailey & Clark, 1992). Following the mastering of this stage, the amputee may begin ambulation. Initially, they should ambulate with the aid of parallel bars for support. While performing these exercises, the amputees should focus on proper walking mechanics by focusing on heel strike and heel rise (Gailey & Clark, 1992). Focusing on the heel strike and raise will help to ensure the most efficient prosthetic gait mechanics possible. This will limit the uncoordinated movement of the prosthesis when ambulating. As the amputee progresses, the parallel bars can be removed so the amputee may ambulate on a flat surface without any aids. After mastering flat surfaces, the physiotherapist could introduce more challenging footing and obstacles to mimic the environment the amputee will experience outside of the physiotherapy room (Kovač, et al., 2015).

While the length of the typical transfemoral amputee rehabilitation is 6-8 weeks, it can vary depending on individual differences (Kovač, et al., 2015). Although the rehabilitation lasts 6-8 weeks, rehabilitation should continue. This will ensure the maintenance of an efficient gait pattern and allow the amputee to maintain a higher level of functioning for the rest of their lives. By continuing this routine, the amputee can lower the risk of disuse atrophy, loss of BMD, and fragility fractures because of their increased ability to ambulate and bear weight.

While most of this stage is governed by the amputees' ability to adjust to their new prosthesis, new technology could enhance this process and increase the amount of control they have over their prosthesis. Because this research is still relatively new, more research must be completed before it is fully implemented. However, TMR could dramatically enhance the Transfemoral amputees' ability to function independently and provide them with a much-improved quality of life. This stage of rehabilitation must also address training the amputee to develop the most efficient gait possible. This will reduce the energy expended while reducing the strain placed on the joints. This will help minimize fragility fractures, which can be very damaging to the amputees' recovery.

Enabling the amputee to regain pre-morbid functioning is the strategic goal of the entire rehabilitation protocol. If the amputee could start rehabilitation exercises immediately post operatively, while being fitted with an IPOP, the overall outcomes of rehabilitation would be more positive. The combination of the two protocols would help reduce the loss of BMD, increase joint mobility, and decrease muscle atrophy. These are some of the primary concerns when treating a traumatic transfemoral amputee with the goal of returning to high intensity exercise. These issues could be combatted by introducing these protocols. Finally, the advancement of the TMR technology for the use in lower limb amputees could provide full function of the prosthesis by allowing the artificial knee and ankle to act more naturally. This could reduce the asymmetries and difficulties normally observed in the prosthetic gait of the transfemoral amputee.

DISCUSSION

The purpose of this literature review has been to identify areas in which the rehabilitation of the traumatic transfemoral amputees could be enhanced. With the constant evolution of medical practices, individuals whose injuries would have proven fatal not so long ago, are now living with the loss of a limb. It is expected by 2050, the number of individuals living with an amputation within the United States will more than double, reaching approximately 3.6 million (Ziegler-Graham K. , Mackenzie, Ephraim, Travison, & Brookmeyer, 2008). Due to the ever-increasing number, and the relative young age of the typical traumatic transfemoral amputee, protocols must be developed to ensure the best functional outcome for these individuals.

This review identified several issues traumatic transfemoral amputees face on their road to recovery and, possibly, how to overcome them. The main issues identified address the loss of BMD and disuse atrophy due to the significant increase in sedentary behavior post amputation. For many of the traumatic amputees, a sedentary lifestyle post amputation if far from ideal. These protocols should be developed to allow them to return to pre-morbid functioning. It has been found that 68% of transfemoral amputees suffer from significant losses in BMD which can lead to an increased risk of fragility fractures (Flint, et al., 2014). This loss of BMD is primarily due to the decrease in weight-bearing activity. Therefore, the bone remodeling process is less efficient and the bone becomes more prone to fractures at the hip joint (Sherk, Bemben, & Bemben, 2008). This would significantly delay the amputees in their recovery processes. Protocols must be put in place to lower the risk of this occurring and increase the probability of the amputee of successfully returning to high intensity exercise.

The best solution to increasing BMD and decreasing disuse atrophy is exercise. However, amputees face many barriers to exercising. Therefore, accommodations must be made allowing amputees to start physical activity at an earlier date to minimize the effects they often experience. If bearable, amputees should start joint mobility exercises immediately post-operatively to increase the range of motion at the hip joint. This will help limit any significant gait asymmetries from occurring (Benyaich, Lowe, Hafeez, & Khadir). These range of motion exercises, coupled with isometric exercises (towel squeezes and glute squeezes) help mobilize and strengthen the hip joint and strengthen the surrounding muscles (The Brigham and Womens Hospital, 2016). These exercises should occur immediately in the post-operative stage of recovery.   The exercises would aid the amputee in the following stages of recovery by limiting the problems they will experience.

The use of the IPOP could decrease the time taken for the amputee to ambulate by almost half, compared to other commonly used dressings (The Brigham and Womens Hospital, 2016). Currently, the IPOP is rarely used for traumatic transfemoral amputations because of the cost compared to the soft and rigid dressings (Tintle , Keeling, Shawen, Forsberg, & Potter, 2010). However, with the benefit of decreasing the recovery time, the IPOP may work out cheaper in the long run. The IPOP could also decrease the likelihood of future complications due to gait asymmetries, loss of BMD and disuse atrophy (Smith , McFarland, Sangeorzan, Reiber, & Czerniecki, 2003).

The prosthetic stage of rehabilitation is the stage in which much more research needs to be directed. Targeted Muscle Re-innervation (TMR) is a relatively new technique that has had great success with upper limb amputees. However, very little research has been directed towards its ability to enhance the transfemoral amputee's prosthetic gait. Certain movements may become more difficult, such as walking on uneven ground and climbing stairs, due to the difficulty experienced with control of the prosthetic ankle and knee joint. Further research should be undertaken to enhance the TMR protocol so it can also be used for lower limb amputees. TMR could provide the amputee with an enhanced functional control of the prosthesis, making ambulation significantly easier (Kuiken, et al., 2009).

In summary, this literature review identified some of the main physiological obstacles facing the amputees. Areas that could be enhanced to decrease problems often encountered were highlighted. However, this is not an all-encompassing review. Tt solely focused on a small portion of the rehabilitation of the amputee. Comprehensive rehabilitation of the amputee is not limited to the physiological recovery. Therefore, further research should address the psychological effects of amputation if these advancements are to be effective.

LIMITATIONS

There are several limitations to this literature review. Initial searches on this topic were limited and, therefore, the search parameters had to be expanded. As a result, many of the articles used reflect somewhat dated research results. This indicates a lack of recent research and suggests the need for further investigation to update current beliefs about rehabilitation of the amputees. Also, the scope of this review was relatively broad identifying several possible enhancements to current protocols. Therefore, it is possible that certain areas of research were overlooked. Finally, subjective inclusion and exclusion criteria could also have limited this review.

IMPLICATIONS AND RECOMMENDATION FOR FUTURE REHABILITATION

Research

Further research is required for the rehabilitation of the traumatic transfemoral amputee. There are several areas future research could pursue, revealed by the limited availability of current research. While this literature review was able to identify some of the physiological issues surrounding the traumatic transfemoral amputee rehabilitation, very limited research was found on preventative measures. As a result, attention should be placed on current protocols and how to advance them to ensure the highest functional mobility outcomes.

A significant focus should be placed on Targeted Muscle Re-innervation, in light of the successes with upper-limb amputees. These successes could also be seen in lower limb amputees, making it an avenue that should be explored. Although it was beyond the scope of this literature review, the psychological aspects of amputee rehabilitation should be addressed to ensure more successful reintegration into society. This research is recommended because of the complex interaction between the psychological and physical well-being. Therefore, it should not be ignored when addressing the rehabilitation protocols.

Practice

This review identified several areas in which enhancements could be made to improve the quality of life for the amputee post-amputation. This review focused on the three main stages of recovery and how they can be improved to decrease the risk of BMD loss and disuse atrophy. Within the post-operative rehabilitation stage, amputees should be encouraged to begin range of motion exercises and isometric exercises as early as possible to counter the effects of prolonged bed rest. Although this may be uncomfortable, it could significantly decrease the likelihood of further co-morbidities as the amputees progresses further through their recovery.

The IPOP should be utilized more regularly because of the significant physiological benefits associated with its use when compared to other dressing types. The ability of the IPOP to reduce the time to ambulation by half should not be ignored. As a result, further education on the benefits of the IPOP should be made available, especially for the traumatic transfemoral amputee population.

Finally, the advancement of the TMR technology should be a priority for prosthetic researchers and orthopedic surgeons to enhance the traumatic transfemoral amputees' recovery. This technology could revolutionize lower limb prostheses, thereby validating the necessity for further research on this technology.

Conclusion

With the ever-increasing number of amputees, specifically young amputees, further research should be directed towards enhancing the quality of post amputation life. The loss of BMD and disuse atrophy prevent many amputees' ability to return to high-impact and high-intensity exercises due to the risk of fragility fractures and associated co-morbidities. This is a significant issue for amputees and needs to be addressed. Although these issues have been identified, little research has been directed towards preventative measures for these amputees. This literature review identified several areas in which further research should be directed to prevent the loss of BMD and disuse atrophy and enhance the functional mobility post-amputation. Utilization of these findings to direct future research into the rehabilitation protocols and educate individuals on the benefits of IPOP over other dressing types could enhance the health outcome of the traumatic transfemoral amputees.

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