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Recent Advances in Foot Amputation Techniques and Clinical Outcomes: An Overview

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Abstract
Amputations have long been considered the treatment of choice in a large variety of situations, and have been widely documented over the ages. These days, amputations are carried out as treatment options more commonly than emergency procedures. The various indications for amputations include vascular complications, malignancies and neoplasms, congenital causes and of course, trauma. A multitude of procedures has been documented, each with its own advantages and disadvantages, especially with regards to post-op morbidity, limb salvage, functionality, where each method is uniquely suited to a specific scenario. In this review, these techniques are discussed in detail with their respective latest modifications and relevant adjuvant treatment options. The global rise in diabetes has made this topic more relevant than ever, quickly becoming the largest cause of amputations of the foot. No matter the cause of amputation, it is important to decide the technique to be used, timely intervention, and most importantly, addressing the patients' concerns with regards to quality of life and rehabilitation.
Keywords Amputation, dysvascular, trauma, tumor, toe amputation.

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Introduction

Amputation is defined as severing or detachment of limbs by a medical illness, trauma or surgery. The surgical amputation happens to be one of the oldest cited surgical procedures, documented in sources as old as the Rigveda (1200 BC) and inscriptions in the temple of Ramses II (13th century BC) [1]. Some of the major indications for performing amputations include malignancy, infection, gangrene and ischemia. The current rise in the incidence of vascular diseases secondary to diabetes and hypertension has resulted in a drastic increase in amputation procedures world-wide. Of the 623,000 Americans surviving with the loss of lower extremity in 2005, 80% had dysvascular disease [2]. By 2030, the prevalence of diabetes is expected to double, which has led to the likely increase in the number of amputations despite efforts made by groups such as Healthy People 2010 as prevention program [3]. Amputation, along with a cause of physical morbidity, carries with it significant emotional trauma. Patients who require amputations tend are prone to depression and a sense of failure. It is a momentous decision that affects everyone involved, from that family of the patient to the surgeon. It is necessary for the surgeon to keep in mind limb salvage, balance, load bearing and if possible, leaving a way for the patient to interface successfully with the limb, with either reconstruction, or prosthesis. In this review, we discussed the different approaches that can be implemented to carry out foot amputation along with their indications and their respective clinical outcomes.

Indications for amputation

Dysvascular

Dysvascular amputation is a type of lower limb amputation commonly to the chronic effects of diabetes and advanced peripheral vascular disease that covers a wide range of adverse health measures such as impaired mobility, chronic pain and depression [4-7]. Ischemia, infection and, in 71% of cases, diabetes represent several interrelated clinical pathways that lead to Dysvascular amputations [2, 8]. In recent years, the alarming rise in the incidence of diabetes has garnered international interests. Consequently, this leads to reduced quality of life, most significantly in disability due to lower limb amputation [9, 10]. This is further exacerbated in elderly (>60 years old), 6% of whom end up suffering from symptomatic peripheral arterial disease [11]. In diabetic patients, up to 15% are affected with diabetic foot ulcers [12], and 11% of them end up requiring amputation [13]. Diabetes usually ends up contracting diabetic foot ulcers and decubitus ulcers, which ultimately may cause sepsis, osteomyelitis, among other conditions. Chronic claudication causing revascularization can cause critical limb ischemia, which may end with dry gangrene and auto-amputation. Therefore, it's not surprising to note that even going forward with minor or partial foot amputation is a big decision to make for the patients and surgeons. Salvage of limb in more than 80% of cases are due to progress in endovascular and vascular surgery [14]. The patients undergoing major amputation include 30% suffering from critical limb ischemia, also known as ischemic rest pain, with a toe arterial pressure <30- 50 mmHg or ankle pressure <50- 70 mmHg [11]. Patients with dysvascular partial foot amputation have high rates of re-amputations, and other complications, which eventually lead them to face very short life expectancies. Around 20-40% dies within a year of their surgery and average 2 years of life expectancy or less [15-17]. Contrary to widely held beliefs that peripheral arterial disease progresses gradually leading to requiring amputation, half of patients who need major amputation do not have ischemic symptoms up to 6 months before their surgery [11]. Due to poor comorbid conditions and healing capacity in this population, only 60% heal by primary intention, and 15% require secondary procedures. Around 34% of foot and ankle amputations as well as 9% to 15% of below-knee amputations progress to limb loss at higher level [8, 5].

Trauma

A prospective, multicentral observational study known as the Lower Extremity Assessment Project to study high-energy trauma to the lower limb, has discovered that established systems for scoring injury, such as limb salvage index, predictive salvage index, and mangled extremity severity score, have proven insensitive in the identification and classification of patients requiring amputation [18]. To amputate, the difficult decision must be made correctly and in a timely fashion because amputations that are performed after the initial discharge have the highest complication rates [19]. Since January 2009, due to conflicts such as operation Iraqi freedom, the ongoing operation enduring freedom, and global efforts against terrorism have caused more than 1,200 soldiers to have sustained major limb amputations [20]. Since World War I, there is treatment for combat-related amputees by the US armed forces, and this remains at the forefront to provide comprehensive, coordinated care to war veterans [21], whereas in underdeveloped countries, causes of traumatic amputations ranging 40 % to 74% of cases due to environmental hazards like land mines, etc. are more frequent [22, 23]. Rapid evacuation from the combat field, early irrigation and debridement, optimal antibiotic prophylaxis, and advances in limb reconstruction have reduced the rate for conflict amputation up to 2.3% compared to previous wars [24]. Because of the wide-ranging spectrum of severity, initial management decisions should be personalized especially in cases of Gustilo type IIIB, and other open tibial fractures [25]. Indications for amputation for the transaction of the posterior tibial nerve or plantar insensitivity have become challenging for extremity amputations, and limb reconstructions in spite of disability for any above-the-ankle lower extremity amputation following trauma [26-28]. The cost for health care are the same even after 2 years, but the projected cost of life are greater for amputation when compared to the reconstruction [29].

Tumor

Limb salvage has always been controversial in these cases because of the structures such as tendons, bone and neurovascular structures existing in close proximity. Anatomical compartments present in the foot are very difficult for preservation and isolation during oncological excision; it is very difficult to use local flaps for covering, or reconstruction of complex tissues. In recent decades, it has become a challenge for the reconstructive and oncological surgeries to be performed maintaining the preservation of uninvolved extremities and appreciable limb function for the patients with malignant bone and soft tissue sarcomas [30]. In spite of continuous improvements in general living conditions as well as medical progress, we still find an increasing number of patients with multiple illnesses, who have already reached the limits of arterial occlusive disease. These patients include about 90% that are all limb amputations, and around 10-15% of amputations due to malignancy or trauma [31-33]. People living in America suffering from malignancy in 2005 (numbering approximately 13,000) necessitated lower extremity amputation [2]. In 95% of patients, the need for amputation can be negated with the advent of neoadjuvant chemotherapy for non-metastatic osteosarcoma and Ewing sarcoma [34]. High grade osteosarcomas now have a 5-year survival rate of more than 65%, compared to 20% in 1970 [35].

Congenital

Amputations in pediatric cases vary from adult cases due to differences in aspects and fundamentals. These demands separate consideration due to the epiphyseal plate present in them, and a few conditions such as purpura fulminans, fibular hemimelia, amniotic band syndrome, are managed by amputations. In the Western world, the largest numbers of pediatric amputations are due to congenital limb deficiencies [22]. In pediatric soft tissue tumors, half of them are due to rhabdomyosarcoma in the US, with 20% of these cases occurring in the extremity [36, 37]. Survival rates have really appreciated in the past several years, specifically due to multidisciplinary studies by the Soft Tissue Sarcoma (STS) committee of the Children's Oncology Group (COG) in the US, and the Intergroup Rhabdomyosarcoma Study Group (IRSG) and others in Europe [38-44]. Bursa formation, residual limb pain, and skin erosion in stump overgrowth are one of the unique complications in pediatrics [22].

Types of amputation

Toe amputations and ray resection

Recent studies favor the use of full-thickness graft or flaps in dealing with plantar diabetic foot wounds because of their ability to deal with stress especially in weight bearing areas [45]. Lin et al. [46] have successfully used this procedure on 9 patients, out of whom, 8 attained full recoveries. Aerden et al. [47] also reported a series of 4 cases where Hallux toe flap was used for the closure of a plantar medial forefoot wound with complete healing in 44 days. However, there was a re-ulceration in 3 out of 4 patients. Repeated infections and ulceration are sequelae of incomplete or inadequate covering of soft tissue defects [48]. Subsequent amputation and transfer ulceration is frequently performed after ray amputation [49]. Diabetic shoe gear is necessary in order to prevent the recurrence of the ulceration after healing [49]. Recently, studies on the complete resection of the fifth metatarsal with peroneus brevis tendon transfer have been carried out. As far as current medical literature goes, it was the first reported technique-involving complete resection of the fifth ray with beaded-antibiotics followed by delayed peroneus longus tendon transfer [50]. This procedure is mostly suitable for patients who have decreased sensation secondary to peripheral neuropathy and cavus foot structures, usually with the association of lateral bony prominences [51]. These bony prominences have a tendency towards ulceration, usually at the base of the fifth metatarsal. A lot of cited data have stated the development of an adductovarus deformity due to the supinatory strength of the posterior tibial tendon, when pronatory power has not been maintained, especially following fifth metatarsal base resections [52, 53]. Roper and Altman [53] described a complication during the removal of the fifth metatarsal base due to dislocation, followed by the transfer of the peroneus brevis tendon to the cuboid in patients with pervious partial fifth ray amputation. The same surgical repair complication was again documented by Carlson et al. [54]. This type of surgical technique has shown to be effective for infections, wounds and underlying foot deformity [50]. Imbedding of antibiotics such as poly-methyl methacrylate beads need removal after 2 weeks of surgery along with a delayed remodeling of the cuboid, and transfer of the peroneus longus tendon. This is the suitable treatment of choice in recurring fifth ray ulcerations and osteomyelitis [50].

Transmetatarsal amputation

Bernard and Heute were the first to describe transmetatarsal amputation **(**TMA**)** in 1855 to treat trench foot. Higher level TMAs are required for ischemia (90%) more often when compared to infections (4%) [56]. In the 1940s, it gained interest in the treatment of diabetic ulcers due the successful results ranging from 44% to 65% [57, 58]. Patients who usually reject transfemoral or transtibial amputations are more open to accepting TMA procedure as a last option, even though proximal amputations heal more reliably than TMA [56, 59]. Care should be taken while making a decision so as to avoid morbidity from multiple procedures. Anthony et al. [60] reported, in a series of 52 TMAs done for an infection or vascular insufficiency, that only 33% achieved primary wound closure whereas 56% required revision to a more proximal level.

Efforts should be made for second metatarsal base preservation, Lisfranc ligament attachment to the site of medial cuneiform, as well as the insertion into the base of the fifth metatarsal by the peroneus brevis [61]. The documented data states the superiority of level of amputation with TMAs in comparison to proximal amputation due to improved biomechanical function of the foot and favorable long–term mortality and morbidity [62-65]. This ideal TMA level is preferred for the patients suffering from forefoot neuropathic wounds, ischemia, infection, or trauma. By preserving the overall foot length and coverage of the wound defect with viable and durable tissue, one can successfully maintain the function of the partially amputated foot [66]. According to available literature, most authors prefer closing the TMA primarily, but improved healing has been reported with insertion of antibiotic pellets, requiring later definitive closure [67].

Midfoot amputation

When TMAs are not a viable option due to the loss of soft tissue structures, disarticulation procedure at the level of Lisfranc or Chopart joint is considered as a suitable alternative. The level of transmetatarsal amputation, a partial foot amputation was first described by Bernard and Heute and the same procedure was followed by McKittrick et al. [68]

instead of using proximal leg amputation as a limb salvage technique. They reported that the best indicator of the outcome for the patient with borderline circulation was good resolution of the infection [66]. They also maintained special attention towards the timing of the definitive procedure, proper handling of the dorsal and plantar flaps, adequate dissection, and limited weight bearing after the procedure to gain complete healing [68]. Meanwhile, mid-foot amputations work on the same principle for higher rates of success [66]. A tendon-balancing procedure is required to maintain function as well as to prevent continued breakdown in Lisfranc amputations when compared to TMA [66]. In Lisfranc amputation, usually seen is a lengthening of the Achilles, which is then incorporated for concomitant ankle equinus deformity for both procedures, and becomes more serious with a short foot lever arm [62]. Lisfranc amputees have a greater tendency for lateral column breakdown when compared with transmetatarsal amputees owing to excessive weight-bearing on the cuboid due to removal of the metatarsal and loss of peroneus brevis function and have the potential to lose peroneus longus and tibialis anterior tendon function, depending on the extended resection of the medial cuneiform [66]. The preservation of the metatarsal base tendon insertions in short TMAs makes it preferable to a Lisfranc amputation, because of the improved mechanics, foot stability and durability with improved results [65, 69, 70]. Whereas in Chopart amputations, extensor tendons must be secured at the talar neck in order to prevent equinovarus and the tibialis posterior should be released. Lengthening of the Achilles tendon is done in both of the above procedures [61]. The other standard procedure for the treatment for Charcot plantar ulceration is off-loading [71]. From the ulcerated area, the bony prominence can be removed directly or indirectly by surgical excision along with the base of the exostosis. Plantigrade foot is then established and enabled by ostectomy and can be appropriately accommodated [72, 73]. The use of a medial plantar artery flap was first reported by Shanahan and Gingrass [74] in 1979 to cover heel defects, whereas fasciocutaneous island flap based on the cutaneous branch of the medial plantar artery to treat calcaneal defects was used by Harrison and Morgan [75] in 1981.

The removal of the entire talus, while preserving the calcaneus, is a difficult task and is accomplished by Boyd amputation. Due to fusion in calcaneotibial structures post operatively, it has become less popular, though still carried out in pediatric patients primarily, although several recent case series in adults have demonstrated success [76, 77].

Syme amputation

This procedure of amputation for chronic foot infections was originally described by James Syme in 1843, and now ankle disarticulations are performed for a wide range of indications [78, 79]. Syme amputees need the same level of energy to walk around, as was observed in comparison with matched controls, and minimal rehabilitation is required to acquire premorbid levels of function [80]. The original technique has been modified several times, most noticeably by Spittler et al. [81] who was the first one to describe the two-staged procedure, which later got popularized by Wagner [82] in 1977 and had a success-rate as high as 95% in selected patients. The success-rate notwithstanding, the single stage Syme amputation has gained in popularity; being performed more commonly these days, except in cases of aggressive soft tissue infections, because of similar general success between 50% to 88% of patients reporting primary wound healing, [80, 78, 83] and it also helped in avoiding the trauma and morbidity of a second operation [79, 83]. The weight bearing surface in Syme amputations consists of a viable posterior flap and the heel pad, both of which are the essential requirements to proceed with the surgery [84]. Syme amputations helped trauma cases primarily [85] rather than patients with diabetic foot infections, which had shown poor results [86, 87]. But it is still a viable option for a carefully selected group of diabetic foot cases, due to some measure of success [86]. Patients in this group include diabetics with a palpable posterior tibial pulse and an ankle brachial index of more than 0.5 [86-88]. The many reasons this procedure is not preferred include poor adhesion of the calcaneal flap to the tibial surface due to innate instability [89]. Another disadvantage is significant limb length differences post-surgery [90]. The Boyd's and Pirogoff's amputation are postulated to give better results than the Syme's amputation in these cases [90-93]. The relative advantages of Boyd and Pirogoff amputation over Syme amputation in cases of diabetic foot are still being researched.

Pirogoff amputation

This surgical technique for amputation was first described by the Russian surgeon Nikolai Pirogoff in 1854 [94]. For the sake of improved results and reduction in the risk of complications, modifications have since been made to the original Pirogoff amputation [90, 95]. A case where a 74-year old male with necrosis and infection of the right forefoot and peripheral vascular disease was treated with modified Pirogoff 's amputation and achieved good result, was reported by Langeveld et al. [92] in 2010. In another publication, he described his own technique by doing 60-degree oblique cut, a modified Pirogoff amputation [95]. The result of Pirogoff amputation was described by den Bakker et al. [93] in a case, where a 26-year-old man with no significant medical history was run over by a bus. The Pirogoff amputation, despite being around for a long time, is still being researched about in the context of diabetes. A successful modified Pirogoff's amputation leads to various advantages such as minimal limb discrepancy, a weight-bearing stump, and an easy site for the fitting of prosthesis when compared to Syme amputation [96]. The modified Pirogoff's amputation is a viable option for the distal hind-foot or minor amputation for diabetic foot, as classified by Nather and Wong [96] for the prevention of limb loss in diabetic foot patients.

Transtibial amputation

Amputations have regularly yielded relatively better functional outcomes than the preservation by modern reconstruction techniques of severely traumatized lower limbs and those are affected by painful chronic osteomyelitis with their subsequent prosthetic use [97, 98]. Notably, transtibial amputations have resulted in excellent functional outcomes [99]. Transtibial osteomyoplastic amputation developed by Ertl [100] in 1949, is a technique which help to restore intraosseous pressure through obliteration and bony bridge between the fibula and distal tibia creates a terminal support to the extend area. The original technique involves a tibiofibular synostosis at the end of the stump, which is formed by an initial preparation of a periosteum cylinder which is extracted, along with attached bone fragments, from the tibia, via obliteration. This raises a major problem with the technique when it is not possible to form bony bridges [101]. Those who are excluded include patients under the age of 18, and those with insufficient tibial length then the creation of an osteoperiosteal flap is impossible, i.e. the same contraindications as those for the original Ertl's technique [102].

Conclusions

The foot and leg amputation is a difficult task. The presence of various indications such as infection, congenital abnormalities, malignancy, ischemia etc., depending on the severity and seriousness of the pathology, the selection criteria is very important to keep in mind, especially with regards to the level and side of amputation to be performed, and to keep in mind the advantages and disadvantages for the technique to be used for amputation. For this, perfect planning should be made, and efforts should be made, requiring dedication from the multidisciplinary team, and also effort and concern of the patient plays a major role to gain the maximum functional outcome.

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