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Limb amputations; etiopathogenesis, diagnosis and the multidisciplinary therapeutic approach

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ABSTRACT

Despite remarkable advances in medicine, limb amputations remain a therapeutic measure that saves the lives of many patients. Given the varied etiopathogenesis, such operations are performed both as an emergency and as an elective procedure. Such interventions address either only the distal segments of a limb, or even the entire limb, having a great psychological, functional and social impact on the patient. Due to these multiple implications, limb amputations must be performed by specialized teams, in order to achieve the best possible functional and aesthetic results to be compatible with the correction of the remaining deficit with a prosthesis. The main causes leading to amputations and the corresponding preventive measures are presented, as well as the general principles of amputations as a therapeutic solution of last resort. In conclusion, reducing the number of traffic/workplace accidents and effective treatment of chronic diseases affecting the vascular system can contribute to decreasing the need for amputations, a life-saving therapeutic solution, but with a devastating impact on the patient and society.

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Introduction

Limb amputation is one of the oldest surgical interventions performed by mankind. There are traces of it from the Neolithic period around 5000 BC [1]. This procedure was most likely performed for frostbite on the fingers or secondary to Hansen's disease [2]. Later, with the development of firearms, the number of amputations increased, being the main surgical intervention performed by military doctors on the battlefield (significant tissue damage and the inability to treat by conservative methods) [3]. French surgeon and anatomist Ambroise Paré described the first vascular ligation as a method of hemostasis in amputations [4]. Until then, hemostasis was obtained by various thermal methods (pouring hot water/pitch on the abutment) or chemical (local application of vitriol), but with high rates of death due to hemorrhage [2].

Despite the fact that modern medicine has evolved, the rate of amputations tends to increase these days, with this intervention being performed on both the upper and lower limbs. It is performed as an emergency (in the case of severe acute or chronic ischemia complicated with gangrene and possible sepsis, post-traumatic partial amputations, where the main goal is to stop bleeding and prevent superinfection) or electively for the correction of various congenital diseases. malformations or in neoplastic pathology [2-4].

From an anatomical point of view, amputations of the lower limb are divided into minor and major amputations. Minor amputations are performed below the level of the ankle and include: finger disarticulation (resection of the finger at the level of the metatarsophalangeal joint), ray amputation (finger amputation with the distal portion of the metatarsal), transmetatarsian amputation, Lisfranc disarticulation (hindfoot disarticulation at the tarsometatarsal articulation), Pirogoff's amputation (amputation of the foot through the talotibial articulation with preservation of part of the calcaneus), and Syme's

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amputation (amputation of the foot through the talotibial articulation with removal of the malleoli of the tibia and fibula) [5,6].

Major amputations are amputations performed above the tibiotarsal joint. This category of amputations includes: transtibial amputation (below the knee level in the proximal ⅓), knee disarticulation, transfemoral amputation (above the knee), hip disarticulation (indicated most often in patients with severe infections, trauma or in the case of neoplastic pathology where oncological safety limits must be respected) and hemipelvectomy (a rare surgical intervention indicated in tumor pathology of the bone pelvis or adjacent muscles and having a high mortality) [7-9].

Amputations of the upper limb have the same indications as those of the lower limb, the limit between major and minor amputations being the radio-carpal joint. Regarding major amputations, these can be: transradial (in which the function of supination and pronation is preserved), transhumeral (with preservation of a stump at humeral level), disarticulation of the shoulder and interscapular-thoracic amputation (reserved for exceptional cases of tumors or severe trauma located at the level of the scapulohumeral joint [10]. Regarding the minor amputations of the upper limb, they are represented by the fingers, the metacarpal amputation and the partial amputation of the hand [11]. A special mention must be made regarding the amputation of the phalanx, which provides 40% of the total motor function of the hand, so every time a reconstructive intervention must be attempted even after the amputation [12].

The general principles of an amputation, whether upper/lower extremity or performed for traumatic pathology or other indications, are: the most physiological reconstruction of the residual limb, with healing as close to normal as possible. This does not always lead to good recovery, but the remaining limb should have thermal, pain or proprioceptive sensitivity as close as possible to the original state, and motor function should be preserved as much as possible especially in the upper limb [10].

The second principle that an amputation must fulfill is the lack of tension in the structures that cover the remaining bone, so that the integument and the muscle layer that covers the bone tissue are not in tension, achieving good mobility and local vascularization. The location of the scar must follow the same principles and also the positioning of the prosthesis must not have an intimate contact between it and the replacement element of the limb [13].

Prevention of complications that may occur (such as local pain, muscle contracture, joint blockage) represents a third principle, which can be achieved by limiting intraoperative time (to be less than 2 hours) and by careful use of electrocautery.

Limitation of postoperative pain can also be achieved by preventing the formation of neurinomas, by careful dissection and release of nerve structures from the adjacent tissue, tying them separately and as proximally as possible [11]. The purpose of this review is to better understand the need for a multidisciplinary approach to the amputee patient. Such patients usually require drug treatment for the correction or mitigation of various associated conditions (degradation of the tumor in malignant pathology and control of pain or other postoperative complications), surgical treatment for amputation, medical recovery and, last but not least, psychological support due to the impact significant effect of such an intervention on the patient.

Discussion

Epidemiology

Although modern medicine has evolved and revascularization and reconstruction interventions have become more accessible and effective, there has been an increase in the number of amputations in the general population [14].

As for the age group, it predominates for the 20-80 years range. In the etiology of lower limb amputations, the most frequently encountered are vascular diseases (peripheral occlusive disease, deep venous thrombosis and chronic venous insufficiency, which is associated in most cases with diabetes) [14,15]. Trauma, neoplastic pathology and congenital diseases follow as frequency [16]. The order presented may be different in developing or underdeveloped countries, where post-traumatic amputations have a higher incidence due to the lack of protective equipment for personnel working in an industrial environment and outdated technology [17]. Another source of traumatic pathology is represented by road accidents, so where the traffic regime is underdeveloped (congested roads, ineffective or absent means of protection for traffic participants) traumatic amputations occur more frequently [18,19].

In developed countries such as the USA, there has been a decrease in the number of post-traumatic amputations, from 11.37 per 100,000 inhabitants in 1988 to 5.86 per 100,000 inhabitants in 1996, the most common cause being traffic accidents [20]. Among them, 41.1% of them had amputations in the upper limbs and the rest in the lower limbs. Considering all offending agents, pedestrians and motorcyclists were observed to suffer lower limb amputations most often; instead, limb injuries with subsequent amputation occur in drivers during airbag system deployment. In the majority of cases where amputations of the thoracic limbs were performed, extensive injuries (associating intracranial, intraabdominal or intrathoracic injuries) were observed on evaluation, and the average blood pressure and the average Glasgow score were lower [21].

Regarding the pediatric population, the main causes of amputations in both upper and lower limbs are congenital malformations and acquired conditions (such as trauma, infections, tumor pathology). Limb development begins in the 4th week after fertilization, most defects are considered to develop between the 4th and 6th week when there is increased tissue proliferation [22]. Among the factors that influence the appearance of limb malformations we can list: administration of drugs (thalidomide, retinoic acid and misoprostol, etc.), vascular damage (amniotic band syndrome), vascular malformations (Poland syndrome) and point mutations at the DNA level. Amniotic constriction can cause various manifestations from joint malformations to defects of the abdomen and chest or even of the craniofacial region. In the limbs, it can cause finger or limb amputations, constriction rings and acrosyndactyly; multiple limb amputations may also occur. The most frequent transverse damage occurs in the proximal third of the arm, with the shortening of the humerus on the same side [23,24].

Longitudinal bone damage is less common, but usually occurs at the level of the radius, varying in severity from hypoplasia of the radius to complete absence of the radius. The cause is most often spontaneous mutation, but it can also be transmitted in an autosomal dominant or recessive manner [25]. In one third of the cases, it occurs in association with malformations of the cardiac or renal systems, such as VACTERL (vertebral defects, anal atresia, cardiac malformation, tracheoesophageal fistula, esophageal atresia, renal and limb anomalies) or Holt-Oram [26].

Affecting the pelvic limb is rarer, with an occurrence rate of 2 per 10,000 newborns, the most frequent segments being represented by longitudinal damage to the femur, hallux or tibia, without being associated with malformations of other systems of most times [25].

The most common cause of acquired amputations are caused by traumatic etiology [27]. In the US, 111,600 child amputees presented to the emergency room between 1990 and 2002, with most presenting around age 1, with a decline thereafter. The offending agent was represented in 22% of cases by a lawnmower and only 16% was represented by a traffic accident [28]. Thus, the definitive surgical treatment was amputation in 77% of lawnmower accidents [29].

The environment of origin has a major impact on the causes of traumatic amputations in children. Thus, in rural patients, the major cause is represented by: accidents with agricultural machinery, lawnmowers, or live cables, while in the urban environment amputations secondary to gunshot wounds or fireworks occur more frequently [30].

Ewing's sarcoma, rhabdomyosarcoma, and osteogenic sarcoma are tumors that occur between 12-21 years of age and can be treated by amputation; secondary to the development of chemotherapy, the incidence of such amputation has greatly decreased [28].

Other pathologies that occur in children and that can lead to amputations are: purpura fulminans secondary to sepsis caused by meningococcus or the association between streptococcus and staphylococcus, with the formation of emboli that lead to ischemia and necrosis with spontaneous amputations [25].

Regarding lower limb vascular damage in the adult population, equal rates of amputation were observed between the 2 sexes, with higher rates in African-American patients than in non-African-American patients, in this population males being more affected [31]. It has also been noted that the African American age group over 85 years is approximately 12 times more likely than the general population to have an amputation secondary to vascular injury [20]. Diabetes mellitus causes vascular damage at the level of small vessels, causing retinal and nerve damage by damaging nerve vessels, as well as at the level of large vessels by accelerating atherosclerosis, thus increasing the risk of cardiovascular diseases and diabetic foot. Patients with diabetes have a 10-fold increased risk of amputation, and African-Americans and Hispanics with hyperglycemia have a higher lifetime risk of lower extremity amputation compared to Caucasians with the same blood glucose values [32,33]. Higher rates were observed in the male population and with more than 3 comorbidities, especially the association with end-stage chronic kidney disease leads to a 10-fold higher risk compared to diabetic patients whose creatinine clearance is maintain above 30 ml/kgc/min [34,35].

Peripheral occlusive disease is the manifestation of atherosclerosis in the vessels of the lower limbs, the main symptoms of which are intermittent claudication and gait disturbances that can progress to irreversible ischemia [36]. Among the risk factors that can lead to its development are smoking (which causes a rapid evolution of the disease, with smoking patients having a 2 to 4 times higher risk than non-smokers) hypertension (with modest influence on the development of the disease), hypercholesterolemia and diabetes [37,38]. With the evolution of the disease, the blood requirement of the limbs remains constant, but the intake is low, so that the progressive alteration of the myocytes occurs along with their remodeling [39]. At rest, blood flow can be sufficient even in the presence of a marked stenosis, due to the low degree of contraction of the calf muscles, thus achieving a small degree of extrinsic compression [40]. During physical exertion, when the oxygen demand is greater and the pressure exerted on the vessels by the muscles is greater, ischemia occurs. This causes the release of reactive oxygen species and the accentuation of anaerobic metabolism, which leads to the subsequent decrease in contractility, and by irritating the nerve endings, ischemia occurs, while through toxic metabolites, pain occurs during exercise [41]. The final stage of this disease is called critical ischemia characterized by the presence of at least two of the following: pain at rest, non-healing ulcers/lesions, or the presence of gangrene in a finger, which can lead to high rates of lower limb amputation [42,43].

The association of male sex, black race, diabetes, and chronic kidney disease in a patient with peripheral occlusive disease leads to a higher rate of amputations as independent predictors of the disease [44].

Limb loss can also be the consequence of curative resection in the case of neoplastic pathology. In the US, malignant tumors of the bone system account for about 6% of all cancers in the population under 20 years of age. The main histopathological types for which amputations are indicated are osteosarcoma and Ewing's sarcoma, with predominant localization in the lower limbs [45]. Osteosarcoma occurs secondary to abnormal development of osteoid tissue or immature bone tissue, occurring mainly in men [46]. The causes of osteosarcoma are still unknown, but genetic factors are suspected, the RB1 mutation (which also leads to retinoblastoma) increasing 500 times the risk of developing a form of bone cancer [44-48]. Li-Fraumeni syndrome, characterized by the alteration of the gene encoding the p53 protein (an inhibitor of tumor development), leads to a wide range of neoplastic pathologies including: breast cancer, sarcomas, leukemias, etc. [49,50].

Environmental factors can have a marked influence on bone development, thus ionizing radiation administered accidentally or for therapeutic purposes can lead to the appearance of osteosarcoma, especially in patients with Ewing's sarcoma whose treatment is largely based on radiotherapy [51,52]. The goal of the intervention in such a pathology is to obtain a resection margin as large as possible, followed by the reconstruction of the remaining limb as physiologically as possible. That is why it is preferable that the resection be done within oncological safety limits but no more [53]. Finally, amputation remained an intervention of last resort in the treatment of oncological pathology, as survival rates are similar between conservative and surgical treatment [54].

Prevention

Amputation is a surgical intervention of last resort, irreversible, being caused by various etiopathologies, for which a better understanding of the pathophysiological mechanisms involved can reduce the need for such procedures.

The increase in blood sugar over a long period can lead to the appearance of peripheral neuropathy and arteriopathy, with a reduction in pain sensation and at the same time susceptibility to infections, which favors the appearance of injuries that are difficult to heal even in the case of minor trauma. Thus, by injuring the skin and subcutaneous tissue, abrasions, blisters, or pressure necrosis may occur, which may become superinfected and cause bacterial infection and gangrene [55,56]. In the diabetic patient, a series of intrinsic changes occur that predispose to injuries and their unfortunate evolution. These are represented by advanced age and weight, reduced mobility of the patient, duration of the disease. There are also extrinsic factors involved such as: smoking, trauma, occupational and social factors, procoagulant drugs, factors that can be influenced by different methods in order to reduce the need for amputations [57,58].

Among the simplest methods of preventing amputations in patients with diabetes, it is essential to wear comfortable, soft shoes. It turns out that patients who wear them have a 58% reduction in amputations compared to others who wear regular shoes [59]. In addition, many centers have introduced mandatory podiatry assessment, which aims to assess gait and reduce pressure on protruding bones, prescribe appropriate footwear and educate the patient about foot hygiene.

The reduction of plantar pressure can be achieved by using soft shoes, with orthotics and padded stockings, a critical element in preventing the development of pressure ulcers, a fact confirmed by pedobarography and gait pressure analysis [60-62]. Another essential element is represented by education. The patient must be informed about the possible complications of the disease, about the factors precipitating and determining the appearance of the ulcer, the treatment he can perform at home and the proper hygiene of the feet. Therefore, patients must know the importance of a periodic and detailed inspection of the lower extremity of the body, with the maintenance of proper hygiene and the prompt treatment of new lesions [63].

Another strategy in reducing the number of amputations is represented by reducing the general cardiovascular risk, thus favoring the blood flow to the periphery and thus decreasing the mortality and morbidity of these patients [64]. Reducing the general cardiovascular risk can be done by quitting smoking (an independent factor that predisposes to amputations), appropriate drug treatment (statins, antiplatelet treatment, converting enzyme inhibitor) and, if indicated, antihypertensive and antidiabetic treatment with appropriate maintenance of the hemoglobin level glycosylated [65]. Otherwise, inadequate or absent treatment increases the risk of major amputation or death approximately 8-fold if patients have end-stage peripheral arterial disease [66]. Administration of Voraxapar (an antiplatelet agent) reduces the risk of major lower limb events, including the risk of acute ischemia and major amputations [67]. A low dose of Rivaroxaban in combination with aspirin led to similar results, so antiplatelet and antithrombotic treatment plays a major role in the prevention of amputations, especially in the case of peripheral arterial disease [68].

For an optimal supply of oxygen to distant tissues, a good vascularization is necessary. This can be achieved by revascularization methods, thus increasing the healing rate of chronic ulcers and thus reducing the risk of major amputations [69]. The therapeutic options consist of revascularization through surgical methods or through a minimally invasive, endovascular approach. Regarding the option between the two procedures, there are no differences in terms of amputation-free survival at 1, 3 and 5 years [70]. Patients who survived more than 2 years and underwent surgical treatment had better amputation-free survival (quality of life) compared to those who underwent the minimally invasive procedure. For this reason, the AHA/ACC recommended endovascular treatment in patients not expected to survive more than 2 years because of comorbidities [71]. The consequence of this fact is the reduction of the number of surgical interventions and the increase of the number of minimally invasive interventions, without influencing the survival of patients without amputation but with the decrease of mortality in the hospital [68].

If revascularization treatment has failed, alternatives may be stem cell treatment, injection of growth factors, or hyperbaric oxygen treatment, but results are mediocre. Stem cells have shown relative improvement in symptoms, but secondary/extensive studies could not yet be performed on large groups of patients [72]. The hyperbaric oxygen treatment used by Cochrane et al. showed mild healing of chronic ulcers in a short time, but the study was later shown to have several flaws in its study methodology [73]. The current guidelines do not recommend the use of hyperbaric chambers with oxygen, because they have inconclusive results and very high costs [74].

Regarding the amputation rate in the pediatric population, it can be reduced by implementing age-varying measures. For the population under 12 years of age, it is necessary to use rubber bands on the door frames, protection on doors or windows with quality hinges, and of course an adequate preparation of the parents [75]. Another measure is the establishment of a minimum age for the use of various agricultural tools, chainsaws or lawn mowers. They must be used by people over 12 years old, to prevent accidents and thus amputations [76]. Many teenagers drive aggressively, sometimes under the influence of prohibited substances, they can be easily distracted by other passengers and lack of experience and concentration can lead to traffic accidents more frequently. In order to prevent amputations in traffic accidents, careful training (both theoretical and practical) is needed in terms of driving, probably with increasing the degree of difficulty of the driving license exam [77].

Surgical treatment

Amputation of the upper and lower limbs can be performed both electively and as an emergency. A good knowledge of the local anatomy is mandatory, and when it is necessary to save the patient's life (traumatic etiology, sepsis, etc.) an intensive supportive treatment is necessary.

Regarding the traumatic etiology, the first priority is to resuscitate the patient with maintenance of ventilation, patency of the airways and circulatory support by administration of intravenous fluids. The next step is to collect cultures to determine the pathogen that might superinfect the remaining tissues, and to administer antibiotic treatment that should cover as broad a spectrum of germs as possible [78]. The limb must be moved as little as possible, avoiding contamination and overlapping lesions, after which it must be photographed, lightly cleaned and bandaged. Obtaining a radiological image is mandatory to assess the state of the skeletal system.

If the amputation is complete, the amputated limb is wrapped in a sterile dressing and kept on ice with sterile water because frostbite may occur when it is used. To identify the largest artery in the limb, it must be cannulated, irrigated with saline at 10 degrees Celsius with a pressure of 120 cm water, and the patient redirected to the nearest plastic surgery center that could reimplant the limb. If this can no longer be achieved, it is recommended that the patient be sent to a center where definitive amputation can be performed [79].

The second major cause of amputations is infection that cannot be controlled by conservative or minimally invasive methods. The first step is to assess the severity of the infection; therefore, it is necessary to evaluate the patient in terms of clinical and paraclinical parameters. Thus, if the patient shows signs of sepsis or metabolic instability, they must be corrected by administering crystalloid solutions, electrolytes, possibly intravenous insulin to correct the hyperglycemia [80]. If the patient has chronic anemic syndrome, it must be corrected by blood transfusions, and careful hemostasis must be achieved intraoperatively, thus minimizing blood loss.

Once the critical patient is stabilized, it is transferred to the operating room, and the intervention should not be performed more than 48 hours after presentation. Exceeding this range increases the rate of mortality and morbidity, especially in cases where necrotizing fasciitis or gangrene occurs [81,82]. The collection of bacterial cultures should not prevent or delay the administration of antibiotic treatment, which should be recommended by the infectious doctor based on the patient's history, the clinical appearance of the lesion and the possible germs that may be contacted in the hospital. Thus, broad-spectrum antibiotic treatment is required to cover both gram-positive and gram-negative germs, cocci and bacilli, as well as anaerobic flora [83]. In patients susceptible to infection with methicillin-resistant Staphylococcus aureus, a specific antibiotic should be considered because MRSA infection is generally associated with a poor prognosis [84]. After the result of antibiogram and cultures, antibiotic treatment should be administered accordingly.

Regarding scheduled interventions, it is considered necessary to administer antibiotic treatment only in the case of major amputations, choosing vancomycin or first-generation cephalosporins [85]. For minor amputations, there are no clear studies showing a better outcome using prophylactic antibiotic therapy [86].

The upper limb is made up of a complex neurovascular, lymphatic and muscular system (which allows various movements), so knowledge of biomechanics and anatomy is essential in understanding the principles of amputations.

The shoulder joint is made up of the scapula and the clavicle to which the proximal portion of the humerus joins, the contention being made by several muscles (deltoid, supraspinatus, infraspinatus, pectoralis major and minor, coracobrachialis, biceps and triceps brachii). These muscles receive nerve fibers from the cervical plexus, originating from C5-T1 [87]. The vascularization of the shoulder region is ensured by the axillary artery and its branches (acromial thoracic artery, superior thoracic artery, subscapular artery, circumflex humeral artery and some muscular branches of the subclavian artery). The venous system is a tributary of the axillary vein and the subclavian vein.

At this level, interscapulo-thoracic amputation, disarticulation of the shoulder and transhumeral amputation (at any level) can be performed [88].

Interscapular-thoracic amputation is indicated in neoplastic pathology with locally advanced disease (when the scapula can no longer be saved), failure of chemo-radiotherapy, fracture on pathological bone (secondary to a sarcoma with a low response rate to chemotherapy), palliation for ulcerations and necrotic tumor, marked lymphedema, severe pain unresponsive to major analgesic treatment, or uncontrollable bleeding [89-92].

The surgical intervention begins with the positioning of the patient in lateral decubitus, on the opposite side of the affected limb and with its mounting on the retractor. The sterile field starts from the bimamelonar line to the level of the chin region. The incision starts laterally from the sternocleidomastoid muscle and extends laterally towards the clavicle, surrounding the limb with the formation of posterior and anterior flaps. The posterior flap passes over the acromion and reaches the lower angle of the scapula where it continues with the anterior flap drawn on the deltopectoral line [90,91].

All the muscle insertions on the clavicle are dissected and sectioned by lifting the platysma, pectoralis major and deltoid muscles. The sternocleidomastoid muscle is sectioned and the lateral portion of the clavicle is mobilized and resected, obtaining good control over the subclavian vessels that are ligated and sectioned.

The subclavian muscle is retracted medially, the tendon of the pectoralis muscle is sectioned and retracted also medially, then the clavicular origin of the pectoralis major is deboned. All the muscles on the coracoid process are deboned, and the supraclavicular vessels and brachial plexus branches are ligated and sectioned [92].

The last muscles that fix the scapula to the trunk are also sectioned (trapezius, levator scapula, rhomboid, serratus anterior and latissimus dorsi) with the completion of the amputation.

The musculo-cutaneous flaps are then sutured and both compartments are drained to prevent the formation of hematomas or general complications of the wound [93]. Postoperative complications are represented by local pain, presence of phantom limb, dehiscence, wound infections and hematomas [94]. Regarding recovery, most of the time the use of a prosthesis is difficult due to its lack of anchoring and the functionality is reduced, having predominantly an aesthetic effect [95].

The main indication for disarticulation of the shoulder is malignant tumor pathology located at this level, with marked extension and which cannot be resolved by other methods of preserving the limb. From an anatomical and functional point of view, the results are similar to the previous procedure, the only advantage being the presence of the shoulder which gives it a better aesthetic appearance [96,97].

The incision made for this intervention is the top incision like a bird's beak with a myocutaneous flap whose distal end reaches the level of the deltoid insertion on the humerus. The medial flap (of the trunk) is formed by an incision that runs from the coracoid process to the tip of the axilla and then to the back. The insertions of the pectoralis major and deltoid are then released from the humerus, and the neurovascular elements of the axillary region are highlighted. The rotator cuff muscles of the arm are sectioned and through its repeated movements the dislocation of the joint is practiced with the completion of the amputation. The flaps are then sutured and drained [97].

Transhumeral amputation is similar to disarticulation of the shoulder, but differs from it in the presence of a residual abutment of at least 4 cm for prosthetic purposes. The surgical intervention begins with the formation of an anterior and posterior skin flap, with the identification of the neuro-vascular structures that are ligated and sectioned similar to the disarticulation of the shoulder. The externus muscle is resected 7 cm from the shoulder joint in order to adequately protect the humerus, thus creating a tension-free suture at this level [10].

The elbow joint is formed by the junction of the humerus, radius and ulna. Its stability is ensured by the particular shape of the humeral trochlea that comes into contact with the olecranon, thus allowing flexion and extension movements. Supination and pronation movements are allowed with a high degree of mobility at this level due to the particularities of articulation. The nerve structures that innervate the muscles at this level are represented by the musculocutaneous nerve that sends branches to the biceps brachii, and the radial nerve for lateral brachii, anconeus, supinator brachioradialis and triceps muscles [84,85].

The indications for elbow disarticulation are similar to the general ones, being usually a procedure to complete a post-traumatic partial amputation or injuries that cannot be repaired [10,11].

The technique is performed by incising 2 skin flaps starting from the level of the humeral epicondyles, which stop 3 cm from the posterior olecranon and anterior to the level of the biceps insertion. The fibrous tissue is torn and the neuro-vascular structures are individualized, ligated and sectioned. The brachialis and brachioradialis muscles are stretched, highlighting the radial nerve that is sectioned as proximally as possible. The ulnar nerve is sectioned in the same way. The extensor muscles are sectioned 7 cm from the distal joint. It penetrates the joint space and dislocates the forearm. For good coverage of the bony abutment, the posterior skin flap must be longer than the anterior one [11,98].

Regarding the amputation performed on the child, elbow disarticulation tends to reduce the degree of bone growth, causing a shorter arm than the contralateral one.

The major disadvantages of this type of amputation are represented by the unaesthetic appearance and limited prosthetic options [99].

The muscles of the forearm are divided into intrinsic and extrinsic muscles. The intrinsic muscles determine supination and pronation movements, and the extrinsic muscles determine extension and flexion movements of the fingers and hand. In total, there are 20 forearm muscles that are divided into flexor compartments located anteriorly and extensor compartments on the posterior face of the forearm. The nerves located at this level are represented by the median, ulnar and radial nerves [100].

Transradial amputation is the most common amputation of the upper limb [101]. Through it, a degree of supination and pronation is allowed, so that the prosthesis allows good functionality of the remaining limb. From a technical point of view, 2 flaps are formed with a length ratio of 1 to 1. The incision will be made so that ⅔ of the length of the forearm is maintained approximately 16 cm from the olecranon, while the radius and ulna will be sectioned equally and covered on 6-8 cm with soft tissues [102,103]. The articulation of the fist is made up of 8 bones, 4 proximal (scaphoid, lunate, triquetrum and pisiform) which articulate with the distal portion of the radius, and 4 distal (trapezium, trapezium, capitate and hamate) which articulate with the metacarpal bones. All these are located in a fibrous mass represented by the radio-carpal and ulnar ligaments [10].

Wrist disarticulation preserves approximately 100-120 degrees of pronosupination [104]. An incision is made 1.5 cm distal to the radial and ulnar styloid, with ligation of the arteries and double ligation of the nerves at this level to prevent neurinomas. The triangular fibrocartilage is maintained to prevent destruction of the radioulnar joint during disarticulation, which can compromise pronation and supination motion. After this step, the wrist is disarticulated and the edges of the radius and ulna are smoothed for better abutment closure and a better prosthesis.

The hand is made up of 5 metacarpal bones that articulate with the proximal and distal carpal bones, these in turn with the proximal phalanges of fingers 2-5 and finally with the distal phalanges that make up the fingers. Vascular-nervous structures in this region are represented by the median, ulnar and first radial nerves that give branches to the thenar eminence and branches to the first 3 fingers. The ulnar nerve through its superficial and deep branches innervates the last 2 fingers, and the radial nerve innervates the first 3 fingers. The muscles at this level are represented by the adductor muscles of the fingers [10].

Partial amputation of the hand is characterized by keeping 2 fingers, if possible two opposite fingers that allow grasping [105]. It is preferable to maintain, reconstruct or save the 3rd finger for better precision of hand movements [106].

Other minor amputations at the level of the distal region of the upper limb are represented by Ray resection, which determines the reduction of the width of the palm with a decrease in grip capacity and resistance at this level but with the maintenance of an aesthetic appearance. Transcarpal amputation, which is indicated by trauma or severe infection at this level, is preferably performed as close as possible to maintain flexion and extension of the radiocarpal joint [11].

Lower limb amputations are represented by: finger amputation, ray amputation, transmetatarsal amputation, ankle disarticulation, transtibial amputation, transfemoral amputation, hip disarticulation and hemipelvectomy.

Finger amputation is frequently encountered in diabetic patients. It is performed by forming two flaps, either plantar-dorsal or medio-lateral, depending on the quality of the tissue at this level, so that the bone is covered by soft tissue and the suture is not in tension, preferably be accomplished by resection of the distal portion of the respective metatarsus. A peculiarity occurs at the level of the hallux, where there may be sesamoid bones that can retract and cause trophic lesions, requiring resection of the first metatarsal [107].

Amputation of the radius is defined as the resection of the toe in association with the respective metatarsal; most of the time it has a good prognosis. In the case of multiple amputations of the radius, there is a risk of narrowing and devascularization of the limb, thus increasing the pressure on the remaining metatarsal and favoring the appearance of ulcers at this level. It is preferable that the closure be done in a secondary time, because most of the time the musculo-cutaneous layers are under tension, which would favor ischemia and necrosis [108,109].

In this case, an incision is made at the level of the metatarsophalangeal joint at 30 degrees from the axial plane of the metatarsal, and with extension on the posterior side along the metatarsal. The tendinous elements are resected and the adjacent vessels are ligated and sectioned. The metatarsus is sectioned 1.5-2cm from the plane of the skin incision, followed by closure of musculo-integumentary flaps with discontinuous suture [109].

Transmetatarsal (Lisfranc) and transtarsal amputation should be avoided in patients with diabetes mellitus or infected ulcers because of the high risk of infection and spread. From a biomechanical point of view, it is important that the soft tissues completely cover the bone remnants to prevent the formation of ulcers (this can be achieved by forming a long plantar flap) [107].

Indications for Lisfranc amputation are represented by the lack of soft tissues in the foot, which makes a transmetatarsal amputation unlikely, being secondary to infections, peripheral vascular diseases, osteomyelitis, etc. If the patient is not mobilizable, the procedure is contraindicated and a more proximal intervention is indicated [11]

Thus, an incision is made at the level of the middle portion of the metatarsal that extends on the sides of the foot to the level of the metatarsophalangeal joint. The vascular and nerve elements are dissected, ligated and then sectioned. The bone resection is performed 1.5 cm from the skin incision on the front of the leg, then it is closed by approaching the posterior skin flap to the anterior one [110]. The complications associated with this surgical intervention are represented by necrosis at the level of the incision line, delayed healing and postoperative infection [111].

Disarticulation of the ankle can be performed if preservation of a large part of the lower limb with high prosthetic potential is considered. Before surgery, infection must be absent and patients must have adequate vascular flow with an ankle-arm index greater than 0.5 [110,112].

The incision is made with skin flaps by joining the anterior portions of the medial and lateral malleolus with the posterior extension. It is sectioned deeply with resection of the calcaneus and astragalus, avoiding damage to the posterior tibial artery that feeds the posterior flap. The fibrous elements are sectioned with subsequent disarticulation and removal of the medial and lateral malleolus at the level of the distal portion of the tibia [10].

The migration of the remaining abutment has in the past determined the compromise of the prosthesis. At the moment, it is possible to pass through the inside of the tibia with the help of 2-3 non-absorbable thread holes to keep the flap in the desired position.

The postoperative complications that may occur are represented by local infection, the development of hematomas, skin necrosis or delayed healing, which can be treated with the removal of the support threads at the tibial level [113].

Transtibial amputation is the most common amputation of the lower limb, and often has the best results in terms of healing. Depending on the appearance of the soft tissue and the skin several techniques can be used, the most common being with posterior skin flap, which preserves the gastrocnemius muscles and the muscles from the anterior compartment over the residual tibia [114].

The surgical technique begins with an arcuate incision with a posterior flap 6 cm from the knee joint with resection of the skin, subcutaneous tissue and sectioning of the muscles in the anterior compartment. The anterior tibial artery is identified, ligated and sectioned along with the vein [115]. Afterwards, the soft tissue near the fibula is removed and cut 2 cm from the level of the tibia. The tibia is sectioned and the posterior vasculo-nervous bundle is identified, which is clamped and sectioned. The soleus muscle is dissected from the lateral and medial ends of the gastrocnemius for a better closure of the abutment. The tibial end is smoothed and the abutment is anatomically closed. Fixation of the posterior flap to the tibia can be done by means of small holes in the tibia [116].

As for transfemoral amputation, it is extremely energy-consuming, being associated with high metabolic consumption for patient walking. Approximately 60% of patients cannot wear the prosthesis correctly, being associated with a high morbidity among them. Before it is performed, a complete assessment of the vascularity of the lower limb, the state of the muscles and the post-amputation biomechanics is mandatory [117].

The surgical intervention begins with the formation of 2 equal flaps, with the sectioning of the fascia and muscles from the anterior compartment. The femur is isolated and the femoral artery and vein are identified in the medial compartment, which are ligated and sectioned. Sectioning of the femur is done with an electric saw and then the sciatic nerve and posterior muscles are identified, which are ligated and sectioned. The edges of the femur are smoothed and myorrhaphy is then practiced [10].

Hemipelvectomy together with hip disarticulation are surgical interventions of last resort and with a high mortality, useful only in cases of uncontrollable sepsis, extensive metastases or in the case of malignant bone and soft tissue diseases. Due to its complexity, it is necessary to be performed in specialized centers with multidisciplinary teams [117]. In contrast to hip disarticulation, hemipelvectomy does not preserve any pelvic element, so prosthetics are impossible. In the first case, the incision begins at the base of the affected limb in the shape of a tennis racket with the formation of a posterior skin flap; the incision begins at the upper edge of the anterior-superior iliac spine, towards the inguinal and inferior ligament towards the ischial tuberosity and then goes up to the greater trochanter and the spine. The neurovascular elements are individualized and ligated and the deep muscles are sectioned medially to laterally and then posteriorly. The gluteal muscles are removed from the greater trochanter, thus allowing the dislocation of the femoral head from the acetabulum, and the rest of the gluteal muscles are sutured to the inguinal ligament and the anterior periosteum of the pelvis [118].

Conclusions

Regarding post-amputation functionality, it varies mainly according to its level. The more tissue is preserved, the better the patient's mobility and the lower the energy consumption for movement [119]. In general, patients with post-traumatic amputations are younger and with fewer comorbidities, thus having a much better functional status than those who had blood vessel disease as the cause of amputation, the survival rate being better for those in the first category [120,121].

Regarding the level of amputation, patients with more distal (transtibial) amputations had a higher speed of movement compared to those with transfemoral amputation, being able to walk even on rough terrain. Those with knee dislocations fared worse than both categories, a fact that contrasts with the major principle of tissue preservation in amputations. This fact is explained by the lack of soft tissue that must cover the area of the prosthesis, with the appearance of pain at this level, which prevents a good ability to walk [122,123].

Another consequence of amputation is the increased rate of osteoarthritis if amputation is performed unilaterally, secondary to increased pressure on the opposite joint [124]. Amputees have a rate of back pain approximately 2 times higher than the general population [125].

Among the systemic consequences of amputations, we can list the increase in global cardiovascular risk (secondary to atherosclerosis) and the development of abdominal aneurysms, as well as the increase in the incidence of diabetes and obesity [126,127]. Being an intervention performed most of the time in an emergency, it has a major emotional impact (being compared to the loss of a family member), a fact for which patients who suffer amputations, especially of the upper limbs, are prone to develop post-traumatic depression [128]. Secondary to the psychological impact, decompensations may also occur in terms of the appearance of associated chronic pain and the appearance of the phantom limb in such patients [129-132].

In conclusion, the amputee patient must benefit from an interdisciplinary management (including cardiologist, general surgeon, vascular surgeon, orthopedist, psychologist and/or psychiatrist, recovery doctor and physiotherapist), to ensure the best result in terms of the patient's quality of life and his integration into society.

Conflict of interest disclosure

There are no known conflicts of interest in the publication of this article. The manuscript was read and approved by all authors.

Compliance with ethical standards

Any aspect of the work covered in this manuscript has been conducted with the ethical approval of all relevant bodies and that such approvals are acknowledged within the manuscript.

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