Introduction

Sarcomas of the extremities are relatively infrequent tumors, accounting for 1% of adult malignancies [1]. Three decades ago, sarcomas were frequently primarily treated by limb amputation, due to the absence of other therapeutic options to minimize local recurrence rates. However, with the advent of multimodality treatment, limb-salvage strategy has been favored [2]. In a prospective randomized study [3], found no statistically significant differences in survival rates when comparing limb-sparing surgery plus radiotherapy with limb amputation.

Achieving adequate resection margins is of paramount importance, although there are no standardized guidelines that define ideal margins [4]. The objective is to perform a wide resection with negative margins (no residual microscopic disease). For this reason, it is sometimes inevitable to have to resort to amputation of the limb to reach acceptable margins of resection. It is in these cases when the “spare parts concept” intervenes, being it defined as reutilizing tissues from amputated or unsalvageable limbs to reconstruct large defects or to obtain an optimal proximal stump with the needed length for subsequent prosthetization. Either of them can be achieved without causing additional donor-site morbidity [5]. This publication aims to perform a complete and systematic revision of the main techniques encompassed in this concept, as well as incorporating our own-experience tips on its surgical approach.

Methods

This systematic literature review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) [6] and AMSTAR 2 guidelines [7]. Two electronic databases (PubMed and Cochrane Central) were queried from January 14, 2019 to April 25, 2019. Research was performed with the terms “Spare Parts Surgery”, “Sarcoma Surgery”, “Fillet Flap”, “Sarcoma Reconstruction” and “Sarcoma Reconstructive Surgery”. All resulting articles – from inception to January 2019 – were compiled, and duplicate titles removed. The database searches yielded 132 non-duplicated results.

Two reviewers screened the remaining titles and abstracts, collecting all articles which included data about surgical techniques encompassed in spare parts concept, indications, outcomes, prognosis, surgery-related complications and technical details. Full-text revision of 74 publications was performed. Finally, 31 articles were selected according to aforementioned criteria.

Operative Techniques

Although techniques included in the spare-part surgery concept allow primary reconstruction of the limb and improve functional results after amputation, there is neither a surgical manual nor a standardized algorithm for the surgeon to follow. The unique aspect of spare-part surgery is that the surgeon has to assess and create a strategy on the spot to maximize the use of tissues that...
otherwise would be discarded [8]. However, there are certain requirements to perform these techniques successfully in sarcoma surgery:

- The chosen spare parts need to be free of tumor infiltration, having performed the necessary imaging techniques to ensure it.
- Spare-parts surgery does not exclude utilizing remote healthy tissue if it is necessary to obtain optimal reconstruction quality.
- The technique used should offer aesthetic and/or functional results superior to simple amputation.
- General condition of the patient makes possible a prolonged spare parts surgery.
- The time of cold ischemia – in cases of total amputation of the limb – should be as low as possible.

Regarding this last point, in fillet flaps with no muscle component; ischemia time is not such a critical factor as it is in replantation surgery [9]. However, surgical approach must be meticulously planned with ablative surgeons to minimize flap ischemia. Thus, it may be recommendable to perform subtotal flap elevation prior to complete limb devascularization. However, in cases in which prolonged ischemia is expected, some reasonable options may be cooling the flap on ice, flap “banking” in another area by vascular anastomosis to other recipient vessels or performing the definitive anastomosis of the flap prior to total resection of the tumor and/or limb amputation [10].

Due to the heterogeneity in the location, size and infiltration of structures of limb sarcomas, it is not possible to go beyond than exposing some principles. These, will allow the surgeon to individualize the ideal approach for each patient. The techniques encompassed in the concept of spare parts surgery can be classified according to their complexity and the components they incorporate in.

**Non-vascularized grafting of spare parts**
Individual tissues may be used as grafts, performing their extraction previously or after limb amputation. Those include skin grafts (either split or full thickness), arterial or vein grafts, nerve grafts or tendon or bone grafts. This way of graft obtainment has been widely reported in cases of traumatic amputations of extremities. However, its application in oncological surgery is feasible, provided that the tumor non-infiltration of these structures has been assured.

**Fasciocutaneous and musculocutaneous flaps**
One or several of the conventional-pattern fascio or musculocutaneous flaps can be used as fillet flaps. However, the sometimes inevitable amputation of the limb makes it possible to harvest flaps whose morbidity in a potential donor area would be unaffordable under other conditions. Another advantage – mainly in proximal amputations – is the possibility of using large donor and recipient vessels, which facilitates surgery and increases reconstruction reliability.

**Fascio- and myocutaneous forearm fillet flap**
The entire forearm skin can be elevated as a free fasciocutaneous flap based on radial artery axial circulation. Another possibility is to base it on the radial and ulnar vessels with their common stem, the brachial artery, proximal to the bifurcation. For venous drainage, the cephalic and/or basilic veins, or brachial vein, can be used [11]. suggested that taking the skin incision toward the ulnar edge of the forearm would be a useful way to avoid edge necrosis, especially at the upper third of the forearm. Another option involves a dorsal incision on the posterior compartment of the forearm between radius and ulna. From our own experience, the inclusion in the flap of the flexor carpi ulnaris (FCU) muscle eases and speeds up ulnar artery dissection. The use of the whole forearm skin as a fasciocutaneous flap has the advantage of being sparingly bulky, widely expandable, and effective in covering a large scapulothoracic defect [12]; as is shown in Figure 1.

The pedicled myocutaneous forearm fillet flap provides a good combination of large tissue coverage with maximum perfusion of muscle bulk, with the advantage of being less complex than a microvascular reconstruction [13]. To execute it, a longitudinal ulnar incision and elevation of the myocutaneous flap around the ulna is performed. Then, the ulna is desarticated from the elbow and the wrist. When this step is complete, the flap is raised from the radial side, ligating vessels from the interosseous membrane, including the posterior interosseous artery. A radiocarpal joint disarticulation is then performed and the radius is removed. The fillet flap is rotated, adapting it to the defect, so that the distal aspect of the forearm remains in the upper portion of the defect. In a similar way, a free musculocutaneous flap of the forearm can be raised [14].

One of the main indications of forearm fillet flaps are the defects after extensive forequarter amputation. However, they can also be indicated for stump coverage after above-elbow amputations [15, 16].

**Upper arm fillet flap**
Either pedicled or free musculocutaneous arm fillet flaps have been described with similar indications to the aforementioned. However, its use is contraindicated in cases of local invasion or vascular invasion of axillar vessels. This is due to its proximity to the tissue resected en bloc in a scapulothoracic disarticulation. If upper arm flap is posed as a reconstructive option, preoperative meticulous discarding of tumor infiltration is mandatory [17].

For flap elevation, a longitudinal posterior incision along the arm shaft can be used. After this, the subclavian, axillary, and brachial vascular pedicles must be identified and preserved. The dissection can be done through either the lateral intermuscular septum, or between the heads of the triceps [18]. After reaching the humerus, subperiosteal dissection and bone removal are performed. After that, the flap can be adapted to the proximal defect. If necessary, the incision can be prolonged, including the forearm and hand in flap design. This allows for the coverage of even larger axillary or scapulothoracic defects [12, 18].

**Musculocutaneous leg fillet flap**
The free fillet lower leg flap (FFLLF) has been described for the coverage of complicated soft tissue defects such as that resulting from external hemipelvectomy. In this...
surgical situation, the reconstructive surgeon is challenged with coverage of a massive area with exposed pelvic girdle, orthopaedic/spinal implants, and pelvic viscera [19].

First, an anterior longitudinal pretibial incision is made, and dissection proceeds laterally in the subfascial plane. The tibia and the fibula are dissected in a subperiosteal fashion, and the fibula is removed. Then, transverse circumferential incisions are made at the level of the proximal tibial epiphysis and the ankle. If additional pedicle length is required, an incision can be made at the medial aspect of the thigh for direct dissection of superficial femoral artery (SFA). At the distal level, the anterior tibial, peroneal and posterior tibial vessels are ligated, and the soft tissue attachments are divided, except for the Achilles tendon. At this time, oncologic hemipelvectomy can be performed, during which the iliac vessels are identified and initially maintained in continuity. Later, when the oncological resection is sufficiently advanced, iliac vessels are divided and the vascular pedicle from the filleted extremity is prepared. The anastomosis is typically performed in a terminoterminal fashion to the iliac vascular system.

Lastly, the “Pedicled fillet lower leg flap” has been described for the reconstruction of traumatic or neoplastic hemipelvectomy defects, and also for recurrent or extensive pressure ulcers coverage [20]. However, in oncological surgery, vessels must be sometimes segmentally resected to achieve adequate margins. This fact makes it impossible to perform a pedicled flap. In addition, after large proximal oncological resections, a pedicled flap may have an excessively long pedicle, with the risk of kinking or twisting. These problems can be solved by vascular section and reanastomosis.

**Osteocutaneous flaps**

**Forearm osteomusculocutaneous fillet flap**

In tumor resections involving a very proximal amputation of the upper limb, the free forearm osteomusculocutaneous fillet flap has been described for humeral stump elongation. This reconstructive option may allow to preserve a functional shoulder joint with adequate range of motion [21]. It consists of the skin of the anterior aspect of the forearm, as well as the two bones, radius and ulna, fixed...
together by a proximal radioulnar screw. This flap is based on the radial pedicle dissected to the antecubital fossa or even to brachial artery. Also, ulnar vessels can be included to increase flap vascularization. Afterwards, proximal osteosynthesis is performed by a humeroradial plate, and vascular anastomosis is carried out.

Distal lower limb osteocutaneous fillet flaps
Calcaneal osteocutaneous fillet flaps and distal tibial turn-up plasties have been utilized to lengthen proximal tibial stumps after below-knee amputations. Those usually allow viable knee joint salvage and residual limb quality optimization [22].

The calcaneal osteocutaneous fillet flap involves calcaneum – with or without talus – and skin from the foot sole and the posterior aspect of the leg, maintaining the tibial nerve for stump sensation, and the posterior tibial artery to ensure nerve and flap vascularization (Figure 2). However, due to significant limb shortening and flap rotation by 180°, pedicle coiling or kinking may occur. Thus, posterior tibial artery can be sectioned and reanastomosed more proximally. Microanastomosis of the distally intact peroneal vessels to the proximal anterior tibial vascular pedicle is also described in the literature as a way to ensure survival [23]. After flap dissection, articular surfaces of talus and/or calcaneus must be chiselled or resected, and then, bony fixation is performed. The most posterior part of calcaneum – calcaneal tuberosity – can be placed most inferiorly. However, from our personal experience, placing it anteriorly leaves foot sole as total weight-bearing surface, which confers maximum stability and a more aesthetic proximal leg shape (Figure 3).

Calcaneal osteocutaneous fillet flap can be used as a vascularized intercalary bone fragment by its combination with a tibial turn-up plasty [24]. This technique creates two osteosynthesis sites with both the aims of distal tibial bone elongation and soft-tissue coverage. First, a longitudinal incision is carried down from the proximal aspect of the tibia and extending distally on both the medial and lateral aspects of the leg down to the foot. The central segment of the tibia and the forefoot are excised, along with the talus, the dorsal aspect of the foot, and the anterior soft tissue of the ankle. The anterior tibial vessels are ligated. The distal tibial articular surface as well as the proximal and distal edges of the calcaneus are sectioned. Then, a 180° distal-to-proximal rotation of the sectioned calcaneus and the distal aspect of the tibia is performed. Thus, the heel pad is transposed to the anterior and proximal aspects of the tibia, and the calcaneus is placed between the proximal segment and the inverted distal aspect of the tibia. Bone fixation is then performed.

Rotationplasty
The rotationplasty is defined as a segmental resection of a proximal joint, followed by a rotation and fixation of the distal joint in place. Thus, the distal joint acts with the function of the proximal one when it is fitted with a prosthesis. Although there are several types of rotationplasty, established by [25], the most used is the knee rotationplasty or type A. Its main indication is the treatment of bone malignancies around the knee (either the proximal tibia or the distal femur), in the skeletally immature patient (8–10 years), with significant potential growth inequality [26]. Classically, the major prerequisite for this procedure is an intact and tumor-free dissection of the sciatic, tibial, and peroneal nerves. However, in case of focal tumor involvement of the nerves, the free rotationplasty technique has already been described by the authors [27], as it is shown in Figure 4.

Other requirements for optimal prosthetic function are adequate plantar flexion strength, functional ankle range of motion, and a sensate foot. The preoperative calculation of the remaining bone growth is a critical point. This is due to the lower growth potential of the distal tibial physis, compared with the distal femoral and proximal tibial physis.
A double oblique incision, with the major axis along the anterior aspect of the thigh and the proximal calf is performed. Dissection begins on the lateral side, identifying the common fibular nerve posteromedially to the distal portion of the biceps femoris. This is followed up to its origin with the sciatic nerve, where the tibial nerve can be identified and distally dissected. On the medial side, the popliteal artery and vein can be identified by dissecting the posterior margin of the vastus medialis and by performing a longitudinal incision of the adductor magnus muscle insertion. Both vessels are dissected proximally and distally, and the upper, middle and lower geniculate arteries are ligated. Once the neurovascular structures are protected, quadriceps muscles section is performed. The gracilis, sartorius, semimembranosus, and semitendinosus are divided at the level of the adductor canal. Femoral and tibial transverse osteotomies are performed, and the medial and lateral heads of gastrocnemius are dissected from the posterior aspect of the femur, being especially careful with their vascular supply (Figure 5).

At this time, the extremity is rotated 180°, leaving the neurovascular structures on the medial side of the femur. Another equally valid possibility at this point is to perform section and reanastomosis of the vessels. Tibiofemoral fixation is then performed by a locking compression plate [28].

Figure 3: A) Pedicled osteocutaneous talocalcaneal fillet flap insetting. Note that calcaneal tuberosity is placed most anteriorly to increase foot sole weight-bearing surface. B) Radiography at 6 months postoperatively, showing stable bone consolidation in the two osteosynthesis sites.

Figure 4: An 8-year-old patient presented an osteosarcoma in tibial metaphysis, with skip metastasis in distal femur and fibula. Segmental knee resection and free Van Nes rotationplasty were performed. A) Piece of resection. B) Distal lower limb after tibioperoneal osteotomy, ready to perform 180° rotation and insetting.
Finally, medial gastrocnemius myoraphy to the quadriceps and biceps femoris to the anterior tibialis muscles are performed. In addition, the semitendinosus can be attached to the extensor hallucis longus and extensor digitorum longus, and the gracilis and sartorius to the fibulae. If the postoperative period is uneventful, permanent prosthesis fitting can begin after 10–12 weeks (Figure 6).

Discussion
In patients with sarcomas of the extremities, it is often necessary to plan radical surgical excision procedures, which sometimes lead to inevitable amputation. In these cases, defect reconstruction with free tissue transfers from another anatomical region, may cause additional morbidity in the potential donor area. To avoid this, tissues from amputated or nonsalvageable limbs may be used as grafts, or by raising axial-pattern flaps that can function as composite-tissue transfers [29]. When deciding the reconstructive technique, we must take into account the publication of [30], in which a total of 50 patients who underwent reconstruction after a massive oncologic resection were analyzed. In this study, it was found that patients undergoing free flap reconstruction had significantly fewer complications compared with patients reconstructed using...
other techniques. Thus, free tissue transfer may be the optimal choice for reconstruction of massive amputation defects. This may be because free fillet flaps provide large amount of soft tissue, often distant from the location of the tumor and zone of injury from prior radiation.

However, spare parts surgery benefits are not only limited to coverage of massive oncologic resection defects, but can also provide lengthening and optimization of proximal amputation stumps. Thus, in patients with lower limb sarcomas with a foreseeable short proximal tibial stump after amputation, an osteocutaneous fillet flap may be indicated. The sole osteocutaneous fillet flap is ideal for bearing and it can provide coverage for a relatively large area. Moreover, the septae between the skin and the planter fascia prevents shearing forces being transmitted to the soft tissue when the patient is walking with the prosthesis [31]. Also, the sole of the foot carries plantar innervated skin that improves prosthesis compliance and reduces prosthesis-related complications such as ulcers and painful neuromas [32].

In relation to the probability of occurrence and severity of neuropathic pain and phantom limb symptomatology associated with spare parts surgery techniques, it is important to keep in mind that, when the distance between two severed injured or sectioned nerves is large, axon regeneration and regrowth occurs in an unorganized pattern. If neurorrhaphy of the severed ends is not performed, about 61% of amputee patients report residual limb pain, of which 48.7% are estimated to be caused by a sensitized neuroma [33]. Therefore, the maintenance of nerves in continuity is essential. When nerve section is required, neurorrhaphy of the distal nerve to the proximal amputated trunk must be performed whenever possible. These strategies are the cornerstone to reduce the probability of appearance and severity of neuropathic pain.

Conclusions
The aforementioned principles are only some aspects of the multiple possibilities of reconstruction and functional improvement after the application of the spare parts surgery concept. Any reconstruction modality described in the present publication can be utilized – either alone or in combination – and adapted to each case. In addition, meticulous knowledge of the anatomy allows new designs, which contributes to the continuous improvement of this field of reconstructive surgery. However, despite the numerous advantages for the patient described previously, the application of these techniques has the drawbacks of a noticeable increase in surgical time and greater technical complexity, compared to usual amputation techniques. These aspects are partially solved if a multidisciplinary approach is carried out in reference centers, by an experienced team.

Critical Analysis
The scarcity of literature regarding this subject limits the conclusions of the present publication, given the impossibility for performing a quantitative analysis in terms of disease-free survival and outcomes between performing conventional amputation techniques and spare parts ones. Thus, the present publication aims to establish the base of this modality of surgery, in order to standardize its use. Further investigation may be required to achieve an adequate level of evidence that allows definitive conclusions.

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- Enrique Salmerón-González: database research, edited paper.
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