Evaluation of the versatility of superiorly based pedicled gastrocnemius myo- or myo-cutaneous flap, in upper leg defects after trauma or tumor excision: which is better?

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Purposes
The current study aimed to focus on the versatility of the superiorly based pedicled gastrocnemius muscle flap or myocutaneous flap, either medial or lateral head, in upper-leg defects after trauma or tumor excision and the importance of these flaps to improve bone healing in trauma and to ensure an adequate safety margin in malignant tumors with minimal complications.

Patients and methods
A prospective, randomized trial was conducted on 27 patients suffering from upper-leg defects after trauma or tumor excision to compare postoperative outcomes, especially bone healing, using superiorly based pedicled gastrocnemius muscle flap covered by a split thierch skin graft [group A; 14 (51.8%)] against myocutaneous flap [group B, 13 (48.2%) cases], either medial or lateral head. Postoperative follow-up was for 6 months.

Results
Rapid healing of the tibial fracture was noticed in 8 (57.1%) cases in group A and in 8 (61.5%) cases in group B within 2 weeks after surgery, and there was no flap loss apart from partial skin loss, minor hematomas, or infections, all were noticed significantly more in group A [5 (35.7%), 6 (42.9%), and 4 (28.6%) cases, respectively], compared with group B [1 (8%), 2 (15.4%), and 1 (8%) cases, respectively; $P < 0.05$].

Conclusion
Both gastrocnemius myocutaneous and myocutaneous flaps for upper-leg reconstruction are considered as a reliable option to ensure a good safety margin in malignant tumor cases and to help bone healing in trauma cases, and myocutaneous flaps are safer, with no redo and lesser postoperative complications.

Keywords:
gastrocnemius flaps, malignancy, tibial defect, trauma

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Introduction

All major trauma centers around the world have developed standard operative procedures for the management of open fractures of the lower extremity. In order to reduce the risk of nonunion and osteomyelitis, early vascularized soft tissue coverage is mandatory in these injuries [1–3].

Muscle flaps have gained wide popularity in this context since their first use by Ger [4]. Muscle flaps are also suitable for the coverage of open joint and exposed orthopedic implants. Muscle flaps provide good vascularity to the defect area of either soft tissues and/or bone by their excellent intrinsic blood supply and provide a good bulk that fills these defects and provides a good healthy vascular bed for skin grafting if needed [4,5].

Early cover has been found to reduce the incidence of complications [6]. The gastrocnemius muscle flap is the workhorse of all muscle flaps for soft tissue coverage around the knee [7].

These type I muscle flaps have a unique and independent vascular anatomy; one pedicle (sural artery) at the level of the knee joint situated close to its origin provides blood supply to the heads of the gastrocnemius muscle. These vessels arise from the popliteal artery above the level of the knee joint. Each vessel courses a few centimeters with its venae comitantes before entering the anterior aspect of the proximal muscle belly with the innervating branches of the tibial nerve [8,9].

The fact that the size of the muscle belly, its location in the dissection field, and its transfer does not impair the function of the limb adversely make it an ideal flap to cover wounds in the region [10].

The aims of limb sparing for either open comminuted tibial fracture or malignant tumors in the upper one-third of the leg are improvement of survival,

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achievement of adequate negative margins in malignant tumors, and improvement in the quality of life functionally and esthetically. When a bone is exposed either by trauma or by tumor excision, it is mandatory to cover these defects by bulky vascular tissue such as muscle flaps to decrease the incidence of osteomyelitis due to bone exposure in trauma cases and to resist radiotherapy postoperatively if needed in malignant tumor cases [11].

The unique vascularization of the gastrocnemius muscle (one pedicle to each head), the bulk of the muscle belly, and its presence in the operative field after that do not affect the function of the limb [12].

Vascular anatomy

There is only one vasculonervous pedicle for each muscular head (Mathes and Nahai type I) [5], composed of a sural artery (formerly a gastrocnemius artery) and one or two veins. In a certain number of cases, a secondary sural artery is present [6–8]. This pedicle is protected within the popliteal fossa with little risk of injuries. It has a mean length of 4 cm with extremes varying from 2 to 5 cm. The diameter of the sural arteries is 2–2.5 mm on average, and that of the veins is 3–5 mm [9–11]. In most cases, the sural artery terminates in two branches, occasionally three or even four, having a longitudinal course, in the muscle axis just below its deep aspect and a terminal vascular distribution [9,11].

These arteries give rise to the perforating branches destined to the cutaneous plane; some anastomose with the vascular system of the opposite gastrocnemius; some anastomose with the vascular system of the soleus [11,12]. Finally, around the distal aponeurosis of the muscle, there is a thin network of numerous blood vessels destined to the cutaneous plane [13]. These vascular characteristics are the basis of several applications on which we will elaborate later on. It is possible to safely harvest a skin paddle overlying the muscle [3].

The additional advantage is being able to raise the skin length/width ratio of the leg, which should not exceed 1/1 [9] or even 1.5/1 [14]. Therefore, a medial gastrocnemius (GM) flap harvested with the superjacent cutaneous plane shows a skin ratio of 3.5/1 (8–30 cm). During the elevation of a myocutaneous flap, the delicate distal perifascial vascularization should be preserved. It is possible to divide the muscle into two sections longitudinally according to the needs [15,16]. According to Jepegnanam *et al.* [17], the anastomosis between the medial and the lateral gastrocnemius (GL) muscles allows one to harvest a gastrocnemius that is vascularized by them. The large caliber of blood vessels is compatible with the creation of a 'local free flap' [7,18,19].

Patients and methods

Approval by the local ethical committee of Benha university and fully informed written consent from patients was obtained. This study included 27 patients with an exposed upper one-third of the tibia, who were fit for surgery, from Benha University during the period between July 2011 and August 2014, so as to allow 6 months' follow-up period for the last case operated on. All patients presenting were admitted at the General Surgery ward for clinical evaluation and laboratory assessment.

Patients included in this study were suffering from trauma (20; 74.1% of the cases, with an age range of 21–40 years) or malignant soft tissue tumor (7; 25.9% of the cases, with an age above 45 years). All were fit for surgery with good general condition. However, patients who were suffering from diabetes mellitus, peripheral arterial ischemia, or hypercoagulation disorders, those maintained on immunosuppressive therapy or corticosteroids, and patients with a traumatic crushed gastrocnemius muscle, tumor invading this muscle, or previous muscle harvesting were excluded from this study.

Operative procedures

In all cases of trauma, emergency operative procedures were performed, which included debridment and bone fixation by an external fixator; because all cases were associated with Gustilo type III fracture tibia, further debridment and preparation of wound for coverage were performed.

A swab culture of the wound was sent in all cases and any overt infection was treated first, and then flap coverage was provided 1–4 weeks after the trauma. The seven tumor cases included three cases of soft tissue sarcoma of the upper third of the leg and four cases of squamous cell carcinoma on top of old scars in the upper third of the leg proved by the preoperative pathology; preoperative evaluation of the tumor extent was achieved by a computed tomography scan; a metastatic work up was also performed intraoperatively, with a wide local excision of the tumor to achieve safety margins guided by the intraoperative pathology.

Harvesting techniques

After general or spinal anesthesia, the preoperative localization of the muscle to be harvested in an upright

position, with and without muscular contractions, gives a good indication of the amount of muscle mass available, which varies from one patient to another; the localization in the posterior median groove at the upper part of the leg of the subcutaneous adipose tissue containing the lesser saphenous vein and the medial sural cutaneous nerve (formerly, the sural nerve and vein), elements that are preserved, allow the division of the two gastrocnemius muscles. The division of the gastrocnemius and the soleus is easy to perform, and often characterized by the presence of the plantaris muscle within them. The GM muscle is longer, thicker, and more movable than the lateral muscle, has a better arc of rotation, which allows it to cover the proximal 1/3 of the leg, the knee at the medial and the lateral levels, and the medial distal femur. Its arc of rotation can be improved by being passed under the gracilis and the semitendinosus tendons. Finally, preservation of the aponeurosis of the leg during the dissection enables one to raise a medial saphenous flap at the same time or later on [20].

Open fracture of the proximal third of the tibia is; a. stabilized by external fixation; b. Elevation of a medial gastrocnemius flap; c. The flap is turned over the exposed tibia; d. Result at the end of the surgery; Longitudinal division of the soft tissue of the medial gastrocnemius (GM) or of the lateral gastrocnemius (GL) according to Francel *et al*. [11], when a tunnel has to be created within the muscle, if the skin is cicatricial, it is preferable to discard it and to use the muscle as a thin skin graft in order to prevent the loss of the flap caused by compression; when a myocutaneous flap is elevated, the 'soaping,' which may damage the perforators, should be avoided using stitches fixing the muscle to the dermis and a careful manipulation of the flap; the cutaneous plane overlying the GM can be elevated up to 5 cm from the medial malleolus [3,21,22].

In this way, the medial myocutaneous gastrocnemius enables to cover the proximal 2/3 of the leg; there are numerous thin and long blood vessels coursing distally on the aponeurosis of the gastrocnemius muscles, beyond the muscular body and which superficially run toward the skin in several locations. This perifascial vascularization will have to be preserved during the elevation of the myocutaneous flap: it is recommended to immobilize the limb when raising an innervated flap to avoid applying tension to the sutures; the pure muscular flap will be grafted as a thin skin graft, expanded or not according to the size, in the same step as the creation of the flap, or for cosmetic reasons, within 8–15 days after the phase of granulation [21,23].

The gastrocnemius is a reliable flap in the cover of the leg skin loss. However, the distal 1/3 usually remains beyond the amount of coverage it can achieve. Numerous more procedures that will be described and some tips and tricks that can be applied to the muscular flap [group A: 14 (51.8%) cases] or to the myocutaneous unit [group B: 13 (48.2%) cases] enable significant improvement in its mobility and its arc of rotation, possibly even allowing for the cover of the whole leg segment. For the GM flap (better used for large defects, being more bulky), the incision was made 2–3 cm behind the medial border of the tibia from the popliteal fossa to below the mid-calf level. The incision was deepened to the deep fascia, and the medial head of the gastrocnemius was identified and separated from the underlying soleus muscle. The distal end of the muscle was divided sharply from the Achilles tendon taking care to include the portion of the tendinous material with the muscle belly as this improved suture holding; it was then divided and separated from the GL at the midline raphae. Care was taken to avoid injury to the small nerve and the short saphenous vein; the muscle was then tunneled anteriorly to cover the defect and fixed by suturing, and muscles were covered by the thierch skin graft (group A) if not taken as a myocutaneous flap (group B). However, if taken as a myocutaneous flap, the skin graft needed to cover the donor area, the skin paddle taken with the muscle ranged from 5 to 7 cm in width and 10 to 15 cm in length. In the GL flap (better used only for small defects being less bulky), the common peroneal nerve must be positively identified and safe-guarded; the rest of the procedure was completed as on the medial side. The wound was closed over the suction drain, and then supported with a splint [21–23] (Figs. 1–4).

Outcome items

The limb was immobilized for 1 week; the flap was checked at the third postoperative day for infection

Figure 1

The traumatic defect was covered with a gastrocnemius muscle flap, which was covered by a thierch graft at the defect area, and the donor area was covered primarily.

Figure 2

A malignant ulcer (squamous cell carcinoma) in the upper leg was excised, leaving a large defect that was covered with a gastrocnemius muscle flap, with the overlying thierch graft at the defect area, and the donor area was covered primarily.

or necrosis, and the patient was followed up as an inpatient for 1 week and as an outpatient monthly for 6 months to assess the functional outcome, that is any disability or effect on the bulk of the cuff was recorded. Follow-up of bone fractures was conducted by an orthopedic surgeon by serial radiographic scanning.

Statistical analysis

Analysis of the data was performed using SPSS, version 16 (Bristol University, Bristol, UK). Qualitative data are presented as numbers and percentages and were compared between groups. *P*-value greater than 0.05 was considered insignificant, *P*-value less than 0.05 was considered statistically significant, whereas *P*-value less than 0.01 was considered statistically highly significant.

Results

A prospective, randomized trial was conducted to focus on the versatility of the superiorly based pedicled gastrocnemius muscle flap [group A; 14 (51.8%) patients] or the myocutaneous flap [group B; 13 (48.2%) patients], either medial or lateral head, in upper-leg defects after trauma or tumor excision and the importance of these flaps to improve bone healing in trauma and to ensure an adequate safety margin in malignant tumors with minimal complications. Regarding the sex distribution, there were 4 (14.8%) female and 23 (85.2%) male patients. Patients included in this study were suffering from either trauma [20 (74.1%) cases with an age range of 21–40 years] or malignant soft tissue tumor [7 (25.9%) cases with age above 45 years]. None of the patients were lost to follow-up, and data collection was complete (Table 1 and Graph 1).

Figure 3

A traumatic fractured upper tibia was fixed by an external fixator and there was an overlying traumatic defect that was covered with a myocutaneous flap, and the donor area was covered with a thierch graft. Note the rapid healing within 2 weeks.

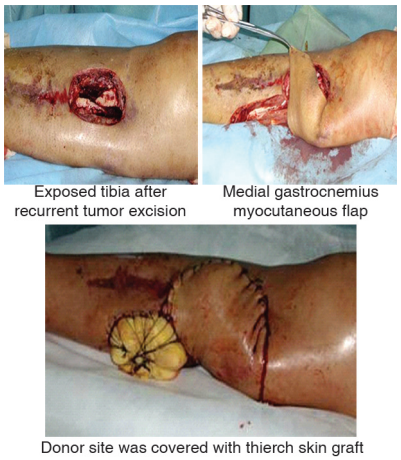
Table 1 Distribution of cases

Preoperative parameters	*N* (%)
Types of flap used	
Group A; muscle flap	14 (51.8)
Group B; myocutaneous flap	13 (48.2)
Indications	
Trauma	20 (74.1)
Tumors of upper one-third leg	7 (25.9)
Soft tissue sarcoma	2
Squamous cell carcinoma	5
Age (years)	
Between; 21 and 40 years old; trauma	20 (74.1)
Above; 45 years old; tumors	7 (25.9)
Sex	
Female	4 (14.8)
Male	23 (85.2)

All trauma patients had emergency debridment and bone fixation by an external fixator (Fig. 2), which consisted of preparation of the wound for coverage, and excision with an adequate safety margin in all patients suffering from malignancy; the flap was then applied with a means operative time of 2 ± 0.9

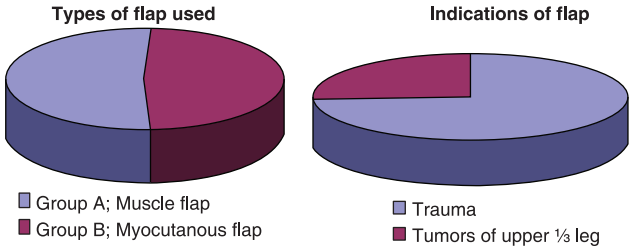
(range:1.5–3 h). The mean blood loss was 540 ± 115 (range: 400–900 ml). Most patients (22; 71.5%) required blood transfusion, with a mean number of units used being 1.8 ± 0.7 (range: 1–3 U) (Table 2). No intraoperative complications or mortality was recorded.

Figure 4



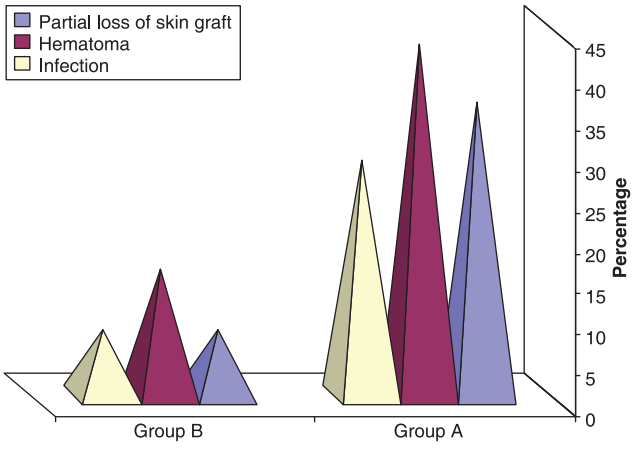
Fibrosarcoma in the upper leg was excised, leaving a large defect that was covered with a gastrocnemius myocutaneous flap, and the donor area was covered with a thierch skin graft.

Graph 1



Distribution of cases.

Graph 2



Inpatient complications

Regarding inpatient complications, no flap loss was recorded in any of the procedures. Minor complications such as partial loss of skin graft was noticed in group A in 5 (35.7%) cases at the defect area; these cases were treated conservatively and healed by secondary intension, except 2/5 (40%) cases that needed another thierch graft at the defect area; however, partial loss of the skin graft was noticed only in one case (8%) in group B at the donor area, which was treated conservatively. Also, a small hematoma was noticed in 6 (42.9%) cases in group A compared with only 2 (15.4%) cases in group B. All these cases were treated conservatively and ended with good results. Infection was encountered in trauma cases only: 4 (28.6%) patients in group A, three cases at recipient sites and one case in the donor area, and one case in group B at the donor site; the infection was controlled by appropriate antibiotics according to the culture and the sensitivity (Table 3 and Graph 2).

Regarding bone healing in cases of traumatic tibial fracture or bone defects due to tumor excision for an adequate safety margin, the results were nearly similar in both groups, that is rapid healing of fracture occurred in 8 (57.1%) cases in group A and another 8 (61.5%) cases in group B within 2 weeks after surgery as compared with the preoperative healing period (Table 4 and Graph 3). This was monitored by a serial radiography (Fig. 3). Finally, overall wound healing was noticed in 9 (64.3%) cases in group A and 12 (92.3%)

Table 2 Operative data

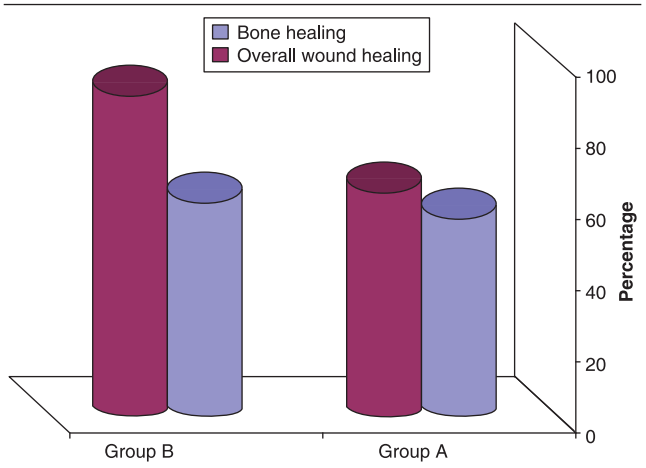
Operative time (h)	*N* (%)
Strata	
<1.5	11 (40.8)
1.5–2	9 (33.3)
2–3	7 (25.9)
Total	2 ± 0.9 (1.5–3)
Blood loss (ml)	540 ± 115 (400–900)
Replacement of red cells (U)	
Strata	
1	4 (14.8)
2	16 (59.3)
3	2 (7.4)
Total	1.8 ± 0.7 (1–3)

Data are presented as means ± SD and number; ranges and percentages are within parentheses.

Table 3 Inpatient complications

Inpatient complications	*N* (%)		*P*-value
	Group A; muscle flap (*N* = 14 cases)	Group B; myocutaneous flap (*N* = 13 cases)	
Partial loss of skin graft	5 (35.7)	1 (8)	0.022
Hematoma	6 (42.9)	2 (15.4)	0.036
Infection	4 (28.6)	1 (8)	0.028

Graph 3



Healing after 2 weeks

Table 4 Healing after 2 weeks

Healing after 2 weeks	*N* (%)		*P*-value
	Group A; muscle flap (*N* = 14 cases)	Group B; myocutaneous flap (*N* = 13 cases)	
Bone healing	8 (57.1)	8 (61.5)	0.11
Overall wound healing	9 (64.3)	12 (92.3)	0.14

cases in group B; regarding the functional outcome, no disability was recorded, with complete functions of the lower limb and minimal effect on the bulk of the cuff.

Discussion

Management of compound fractures of tibia Gustilo type III, with involvement of the knee joint, present a difficult problem to orthopedic and plastic surgeons. Reconstructive procedure is frequently required to cover the exposed bones or joints to obliterate the dead space and help eradicate infection [4].

Early cover has been found to reduce the incidence of complications [6]. The gastrocnemius muscle flap is the workhorse of all muscle flaps for soft tissue coverage around the knee [7].

The gastrocnemius muscle flap, described by Ger [13] as a muscle flap, is used in cases of exposed defects of the proximal tibia [14].

The lateral head of the muscle, compared with the medial, is used more rarely in reconstructive surgery [15]. The reasons for its restricted use are the size, the limited arc of rotation, and the potential risk of peroneal nerve palsy of the muscle, which might be caused by the surgical procedure itself. [16] The medial head of the gastrocnemius muscle, which is the part most often used, meets all requirements needed for a successful wound coverage [17].

This study was conducted to focus on the versatility of the superiorly based pedicled gastrocnemius muscle flap [group A: 14 (51.8%) patients] or the myocutaneous flap [group B: 13 (48.2%) patients], either medial or lateral head, in upper-leg defects after trauma or tumor excision; no intraoperative mortality was recorded, with a mean operative time of about 2 h and a blood loss of about 540 ± 115 ml. Throughout the first 2-week follow-up period; there was no flap loss apart from partial skin loss, minor hematomas, or infections. All were noticed significantly more in group A [5 (35.7%), 6 (42.9%), and 4 (28.6%) cases, respectively] compared with group B [1 (8%), 2 (15.4%), 1 (8%) cases, respectively; $P < 0.05$]. This finding concurs with that reported previously in the literature concerning the applicability of the gastrconemius myocutaneous flap for the reconstruction of upper-leg defects, irrespective the etiology of the defect. Han *et al.* [18] used the gastrconemius myocutaneous segment obtained by intramuscular dissection of the vascular pedicle for the reconstruction of composite and three-dimensional knee defects, and found that the flap survived completely, wound healing progressed smoothly without infection, hematoma or seroma, and patients were satisfied with their esthetic outcomes.

There are disadvantages associated with the application of the gastrconemius flap, such as deformation of the donor area, [18] but this study revealed that no major complications occurred in the donor areas apart from wound infection, which was controlled with appropriate antibiotic treatment. The advantages of the gastrocnemius flap favor its use as this surgical technique is relatively easy to perform and requires lesser time than free tissue transfers. Furthermore, the gastrocnemius flap provides better tissue coverage and greater stability to the knee joint.

Regarding bone healing in cases of traumatic tibial fracture or bone defects due to tumor excision for an adequate safety margin, the results were nearly similar in both groups, that is rapid healing of the fracture occurred in 8 (57.1%) cases in group A and another 8 (61.5%) cases in group B within 2 weeks after surgery as compared with the healing in the preoperative period. This was monitored by a serial radiography, and overall wound healing was noticed in 9 (64.3%) cases in group A and 12 (92.3%) cases in group B; regarding the functional outcome, no disability was recorded, with complete functions of the lower limb and minimal effect on the bulk of the cuff. This finding is supported by the study conducted by Liu *et al.* [19], who studied

65 patients who underwent resection of proximal tibial osteosarcoma and reconstruction of the bone defect by prosthesis: 35 cases underwent medial gastrconemius muscle flap transposition to reconstruct the soft tissues and the other 30 did not and reported a significantly lower rate of local complications, with a significantly higher functional outcome in the group with gastrconemius muscle flap transposition. Liu *et al*. [19] first explained that this good bone healing occurred because myogenic progenitors of the MyoD lineage contribute to bone repair, giving new perspectives for the treatment of fracture nonunion through the optimization of myogenic progenitor proliferation, migration, and differentiation. This eventually helps ensure a good safety margin in malignant tumor cases and helps bone healing in trauma cases.

Also, Park *et al*. [10] used an extended medial gastrconemius muscle flap including a tendinous portion of the Achilles and a saphenous neurocutaneous flap for coverage in a patient who had multiple fractures with open comminuted patellar fractures that were initially managed, but unfortunately, the fractured patella and the overlying soft tissue became totally infected with wide necrosis, requiring complete debridement of the dead tissue with removal of the patella and its tendon, leaving a large bone and a soft tissue defect on the knee joint; at 12 months postoperatively, he showed complete extension, 135° of flexion, and grade IV knee extensor power, and was able to ambulate without a walking aid.

These findings are also supported by numerous other studies conducted to isolate progenitor cells from muscles for the purpose of bone tissue engineering; these approaches often utilize ex-vivo gene therapy approaches, where the forced expression of osteogenic bone morphogenetic proteins in cultured myoblasts can lead to new bone formation after their subsequent implantation into experimental animals [20].

Hence, muscle flaps in bone fractures not only bring blood supply, but also give the fracture myokines and progenitor cells, which differentiate into osteocytes; this fact supports the concept that muscles act as a 'secondary periosteum', which is able to contribute osteoprogenitors when the periosteum itself is damaged [21].

Conclusion

We conclude that both gastrocnemius myocutaneous and myocutaneous flaps for upper-leg reconstruction are considered as a reliable option to ensure a good safety margin in malignant tumor cases and to help bone healing in trauma cases; myocutaneous flaps are safer, with no redo and lesser postoperative complications.

Acknowledgements

Conflicts of interest

None declared.

References

1 Mackenzie DJ, Seyfer AE. In: Mathes SJ, Hentz V. Reds Reconstructive surgery: lower extremity coverage. Plastic surgery. 2nd ed. Philadelphia: Saunders Elsevier 2006;1355–1381.

2 Breugem CC, Strackee SD. Is there evidence-based guidance for timing of soft tissue coverage of grade III B tibia fractures?. Int J Low ExtremeWounds 2006; 5:261–270.

3 Kumar AR. Standard wound coverage techniques for extremity war injury. J Am Acad Orthop Surg 2006; 14:S62–S62.

4 Ger RR. The technique of muscle transposition in the operative treatment of traumatic and ulcerative lesion of leg. J Trauma 1971; 11:502–510.

5 Mathes SJ, Nahai FD. Clinical application for musculocutaneous and muscle flaps. New York: CV Mosby Company Publishers; 1982; 4:119.

6 Bryd HS, Spicer TE, Cienney GA. Management of open tibial fracture. Plast Reconstr Surg 1985; 76:719–730.

7 Moscona RA, Fodor LK, Har-Shai YS. The segmental gastrocnemius muscleflap: anatomical study and clinical applications. Plast Reconstr Surg 2006; 118:1178–1182.

8 Williams PL, Bannister LM, Berry MM. Gray's anatomy. 38th ed. New York: Churchill Livingstone, London 1995:693.

9 Tsetsonis CH, Laoulakos DH, Spiliopoulou CA, Koutselinis AS. The arterial communication between the gastrocnemius muscle heads: a fresh cadaveric study and clinical implications. Plast Reconstr Surg 2000; 105:94–98.

10 Park JW, Lee YS, Oh JK. Knee extensor mechanism reconstruction with an extended gastrocnemius flap. J Orthop Trauma 2009; 23:309–312.

11 Francel TJ, VandorKolk CA, Hoopes JE, Manson PN, Yaremchuk MJ. Microvascular soft-tissue transplantation for reconstruction of acute open tibial fractures: timing of coverage and long-term functional results. Plast Reconstr Surg 1992; 89:478–486.

12 EL-Sherbiny M. Pedicled gastrocnemius flap: clinical application in limb sparing surgical resection of sarcoma around the knee region and popliteal fossa. J Egypt Natl Cancer Inst 2008; 20:196–207.

13 Ger R. The technique of muscle transposition in the operative treatment of traumatic and ulcerative lesions of the leg. J Trauma 1971; 11:502–510.

14 Boopalan PR, Nithyananth MA, Jepegnanam TS. Lateral gastrocnemius flap cover for distal thigh soft tissue loss. J Trauma 2010; 69:E38–E41.

15 Daigeler A, Drucke D, Tatar K, Homann H, Goertz O, Tilkorn D. The pedicled gastrocnemius muscleflap: a review of 218 cases. Plast Reconstr Surg 2009; 123:250–257.

16 Sanger JR, Kao DS, Hackbarth DA. Peroneal nerve compression bilateral gastrocnemius flap. J Plast Reconstr Aesthet Surg 2009; 62:e280–e282.

17 Jepegnanam TS, Boopalan PR, Nithyananth ML, Titus VT. Reconstruction of complete knee extensor mechanism loss with gastrocnemius flaps. Clin Orthop Relat Res 2009; 467:2662–2667.

18 Han SE, Lee KT, Mun GH. Muscle-chimeric medial sural artery perforator flap: a new design for complex three-dimensional knee defect. J Plast Reconstr Aesthet Surg 2014; 67:571–574.

19 Liu R, Birke O, Morse A, Peacock L, Mikulec K, Schindeler A. Myogenic progenitors contribute to open but not closed fracture repair. BMC Musculoskeletal Disord 2011; 12:288.

20 Shen HC, Peng HS, Usas AK, Gearhart BP, Fu FH. Structural and functional healing of critical-size segmental bone defects by transduced muscle-derived cells expressing BMP_4. J Gene Med 2004; 6:984–991.

21 Schindeler A, Liu R, Little D. Contribution of different cell lineages to bone repair: exploring a role for muscle stem cells. Differentiation 2009; 77:12–18.

22 Krishnamooorthy VP, Inja DB, Roy AC. Knee extensor loss and proximal tibial soft tissue defect managed auccessfully with simultaneous medial gastrconemius flap, saphenous fasciocutanous flap and medial hemisoleus flap: a case report. J Med Case Rep 2013; 7:76.

23 Pozzobon LR, Helito CP, Guimaraes TM, Gobbi RG, Camanho GL. Rotation flaps for coverage after total knee arthroplasty. Acta Ortop Bras. 2013; 21:219–222.