Refinement of Marionette sutures in gastrocnemius muscle flap to achieve early physiotherapy in coverage of complicated knee joint

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Introduction
The gastrocnemius muscle flap forms a cornerstone for knee coverage, which has been cemented in literature as the primary option among many authors.
Securing the gastrocnemius muscle flap using conventional polydioxanone suture (PDS) sutures delays passive physiotherapy after 2–3 weeks of surgery and active physiotherapy after 3–4 weeks postoperatively for the fear of dehiscence or separation of the flap.
Patients and methods
In this study, Marionette sutures were used to anchor the gastrocnemius muscle flap to the defect edges aiming at starting early passive and active physiotherapy. Marionette sutures were used to anchor the gastrocnemius muscle flap to the defect, skin surrounding the defect is undermined for 1–2 cm all around, and then PDS United States Pharmacopeia (USP) 1 is used on a round needle tip. Alternatively, anchoring of the gastrocnemius muscle flap to the surrounding structures was performed using the classical technique where PDS sutures were used to anchor the muscle flap to the surrounding subcutaneous tissue of the defect.
Results
A case series of 26 patients was performed in the period from January 2017 to January 2020. In this series of 26 patients, 15 patients had Marionette suturing of the gastrocnemius muscle flap, whereas the conventional method with subcutaneous sutures to fix the flap was used in 11 patients. In the 15 patients who had Marionette suturing fixation of the gastrocnemius muscle flap, 14 patients showed ability to start early passive physiotherapy 2 days postoperatively and early active physiotherapy at 7 days after the surgery.
Conclusion
Gastrocnemius flap is the working horse of knee reconstructive surgery, and it can be refined to encourage early physiotherapy using Marionette suturing technique, which showed effectiveness in reliable flap fixation in its recipient site, which helped patients to start early passive and active physiotherapy and avoid the common complication.

Keywords:
gastrocnemius muscle flap, knee, Marionette sutures, physiotherapy

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Introduction

Complicated knee defect either with exposure of vital structures like bones and tendons or with exposure of knee prosthesis after knee replacement surgery is an urgent clinical situation in the field of reconstructive surgery. Exposure can lead to loss of exposed bones, tendons, and cartilages out of desiccation or extrusion of prosthesis [1]. All of these complications are of grave consequences, hence comes the importance of reliable and stable coverage of complicated knee joint defects able to withstand the forces across the joint.

The gastrocnemius muscle flap forms a cornerstone for knee coverage [2,3] which has been cemented in literature as the primary option among many authors. Among the other options available for coverage are the reverse-flow anterolateral thigh flap, reverse flow-vastus lateralis flap, and free flap reconstruction [4–6]. Additional options are local perforator flaps and propeller flaps. Among those introduced in the literature are the peroneal artery perforator flap, lateral supra-genicular pedicles perforator flap, tibial artery perforator flap, and most recently, the medial sural artery perforator flap. However, they remain dependent on the state of the surrounding tissue and require microsurgical expertise as they are technically demanding [7,8].

The gastrocnemius muscle has medial and lateral heads originating from femoral condyles. Each head is supplied by a sural artery branch of popliteal artery [2]. According to Mathes and Nahai [9], it is a type one muscle flap with a single dominant vascular pedicle.

Plantar flexion can still be maintained when both heads of the gastrocnemius are sacrificed provided that the soleus muscle is intact [10]. Alternatively, one head can be solely harvested, with a hemisoleus muscle still maintaining the function. Additionally, pie-crusting or resection of the fascia on either side of the gastrocnemius muscle will allow expansion of the muscle to cover a greater surface area and also give the added benefit of allowing skin graft take.

Securing the gastrocnemius muscle flap to the defect is performed by many surgeons using conventional polydioxanone suture (PDS) sutures fixing the flap to the subcutaneous tissue surrounding the defect; usually patients can start passive physiotherapy after 2–3 weeks of surgery and active physiotherapy after 3–4 weeks postoperatively for the fear of dehiscence or separation of the flap from its recipient position [11,12].

Marionette sutures were first described in breast surgery with the purpose of inframammary-fold reconstruction [13]. This provided the basis of utilizing the Marionette sutures to help secure the flap to the skin surrounding the defect. This was aimed at providing a more solid and reliable fixation to the surrounding tissue, aiding in the delivery of early physiotherapy, complying with the general rule of the sooner the physiotherapy, the better the outcome and the lesser the chance of developing stiffness of the knee joint. In this study, Marionette sutures were used to anchor the gastrocnemius muscle flap to the defect edges, aiming at starting early passive and active physiotherapy, which ensures early ambulation, smoother postoperative recovery, and early return to daily activity.

Patients and methods

In this case series study, inclusion criteria were both traumatic exposure of knee joint, either acute (within 1 week of the initial insult) or chronic delayed cases that needed further orthopedic reconstruction, and skin defects that were suspected to cover the exposed knee joint; moreover, cases of complicated knee replacement surgeries with exposed knee prosthesis were included in this study. Each patient signed an informed consent to participate in the study and for their photographs to be published for educational purposes. The study protocol was approved by Faculty of Medicine, Cairo University Ethics Committee. All defects included in this study were around the knee joint with defects ranging between 2 and 6 cm in their widest diameters (small to medium sized wounds). The wound size is assessed preoperatively and finally following intraoperative debridement during maximal flexion, thus accounting for the distensibility.

This study includes both male and female cases with the age range from 25 to 65 years. To ensure proper healing power of every candidate, hemoglobin% has to be kept above 10 g/dl and albumin above 3.5 g/l, with a strict blood glucose control.

It is to be mentioned that cases with superficial defects not exposing the bone or prosthesis were excluded from this study, and also cases with gross necrosis of all or part of the gastrocnemius muscle or having a concomitant vascular injury to the distal popliteal artery that can affect the blood supply of the gastrocnemius muscle were excluded from this series. A history of recent deep venous thrombosis or active deep vein thrombosis (DVT) in the lower extremity is a contraindication to the use of the gastrocnemius muscle flap to cover the complicated knee joint.

It should be stressed out that in traumatic injuries, preoperative arteriography can be helpful in establishing patency of the sural vessels before the muscle is elevated in cases where there is doubt.

The muscle is exposed through an incision directly overlying the muscle. The skin is undermined, and the superficial surface of the muscle is exposed. The gastrocnemius is separated from the soleus in an areolar plane that can be dissected digitally to identify the space. Dissection starts at the medial edge of the muscle, where the plantaris tendon is visualized between the gastrocnemius and soleus muscles. Dissection then proceeds inferiorly, where the muscle is fused with the Achilles' tendon. The medial half of the Achilles' tendon is incised, leaving only a 1-cm cuff of tendon on the muscle flap. The lesser saphenous vein and sural nerve are visualized and preserved.

Muscle-only gastrocnemius muscle flap is used. Total muscle or only medial head is harvested according to the size of the defect with the freedom to dissect the whole muscle in large knee defects.

Marionette sutures were used to anchor the gastrocnemius muscle flap to the defect. Skin

surrounding the defect is undermined for 1–2 cm all around, and then PDS United States Pharmacopeia (USP) 1 is used on a round needle tip. At first, suture is passed through the skin surrounding the defect (within 2 cm from the defect edge), and then it is passed through the edge of the gastrocnemius muscle flap (within 1–2 cm from the edge), after which it is passed back through the muscle again 1 cm from the previous muscle entry point to exit from the skin 1 cm away from the skin entry point, and then both edges of the suture are tied over a Vaseline gauze under the PDS suture, cushioning it over the underlying skin; this is repeated to form a series of sutures with a 3-cm distance in-between.

Alternatively, anchoring of the gastrocnemius muscle flap to the surrounding structures was performed using the classical technique, where PDS sutures were utilized to anchor the muscle flap to the surrounding subcutaneous tissue of the defect with a series of sutures taken 3 cm apart in an inverted simple manner.

Split-thickness graft coverage from the contralateral anterior thigh was then harvested to cover the raw muscle; pie-crusting or resection of the fascia on either side of the gastrocnemius muscle was undertaken to allow the expansion of the muscle allowing it to cover relatively larger areas.

Meshing of the STG was done in a conservative manner. Vicryl USP 3/0 on a round needle is used to suture the graft to the gastrocnemius flap, and a posterior knee splint is applied or knee immobilizer is applied during the initial phase till graft take is ensured, with care taken not to cause any pressure on the flap or its pedicle. Splint is removed during physiotherapy sessions and then applied again after the session ends.

The ability to start early physiotherapy of the knee joint is assessed at 2 days postoperatively for passive movements and at 7–10 days after the surgery for active movements.

Any noted dehiscence within 1 cm in the full thickness of the muscle or leading to re-exposure of major structures or knee prosthesis or migration of the flap is an indication to stop early physiotherapy and divert to the conventional physiotherapy protocol with passive physiotherapy started at 2–3 weeks and active physiotherapy at 3–4 weeks postoperatively according to the wound healing process, which can delay physiotherapy more than the previously mentioned period.

Graft take is ruled out at 3 weeks postoperatively with a scale from 0 to 100% graft take (Fig. 1a,b).

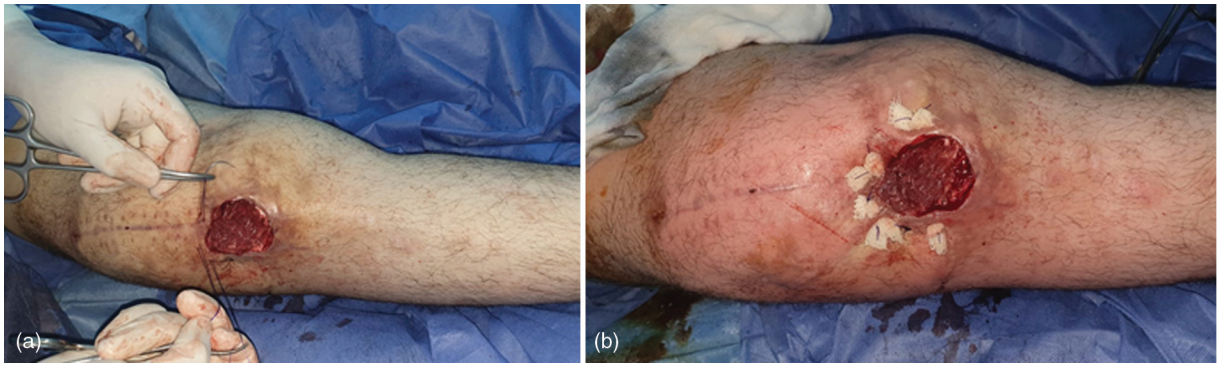
Results

A case series study on 26 patients was performed in the period from January 2017 to January 2020. Cases were done in Kasr Al-Ainy, Cairo University Hospitals, and in the authors' private practice. Ethical committee approval was obtained.

In this series, 18 patients were males, whereas eight patients were females. A total of 12 cases had knee exposure owing to an acute traumatic cause with all types of trauma included, for example, crushing injuries, Motor Car Accident (MCA), and sporting injuries; six cases were chronic delayed cases that needed further orthopedic reconstruction, and skin defects were suspected to cover the exposed knee; and eight cases had wound complications and dehiscence after prosthetic knee replacement surgeries, and the prosthesis was either partially exposed or about to be exposed and needed urgent coverage (Fig. 2).

The decision of technique choice, whether Marionette sutures or the conventional method with subcutaneous

Figure 1

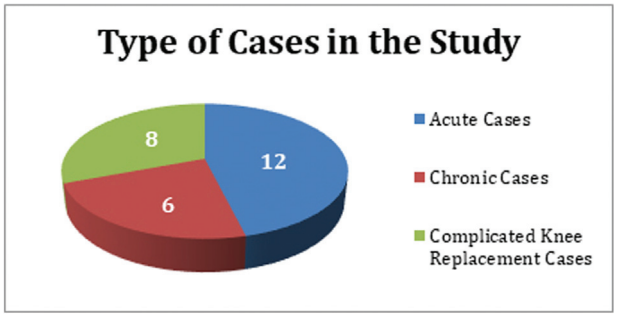


(a, b) Marionette sutures technique; it is noted that edge of defect is undermined for 1.5 cm.

sutures to fix the flap in its position, was taken intraoperatively after assessment of the local tissues. This depended on the state of the tissues at the site of the defect. Marionette sutures accordingly were performed when the surrounding subcutaneous tissues state did not ensure reliable support to secure fixation of the flap to the defect edge.

In this series, of 26 patients, 15 patients had Marionette suturing of the gastrocnemius muscle flap, whereas the conventional method with subcutaneous sutures to fix the flap was used in 11 patients, and it was as follows: in acute traumatic cases, Marionette suturing of the gastrocnemius flap was done in seven patients, whereas PDS suturing of the flap to the surrounding structures was achieved in five patients. On the contrary, six patients had a chronic delayed trauma to the knee joint; in this group of patients, Marionette sutures were performed in three cases, whereas PDS anchoring to the surrounding tissues was done in three patients. In the eight patients presented with exposed knee prosthesis after knee replacement surgery, Marionette sutures were done in five cases, whereas PDS anchoring sutures were performed in three patients.

Figure 2



Type and number of cases in the study.

In the 15 patients who had Marionette suturing fixation of the gastrocnemius muscle flap, 14 patients showed ability to start early passive physiotherapy 2 days postoperatively and early active physiotherapy at 7 days after the surgery. Only one patient showed partial dehiscence, in fear of re-exposure of vital structures or the artificial knee prosthesis; they were converted to the conventional physiotherapy protocol. Regarding graft take, 13 patients demonstrated 90% graft take at 3 weeks after the surgery, whereas one patient showed 75% graft take, with one patient demonstrating 60% graft take (Table 1).

On the contrary, 11 patients who had conventional PDS anchoring sutures to the surrounding structures, six patients showed ability to start early passive physiotherapy within 3–4 days postoperatively and early active physiotherapy at 7–10 days. Moreover, five patients showed partial dehiscence; thus, they were converted to the conventional physiotherapy protocol. Regarding graft take, five patients demonstrated 90% graft take at 3 weeks after the surgery, whereas four patients showed 75% graft take, with two patients demonstrating 60% graft take (Table 2 and Figs 3–5).

Table 1 The results of the Marionette suture group during the study

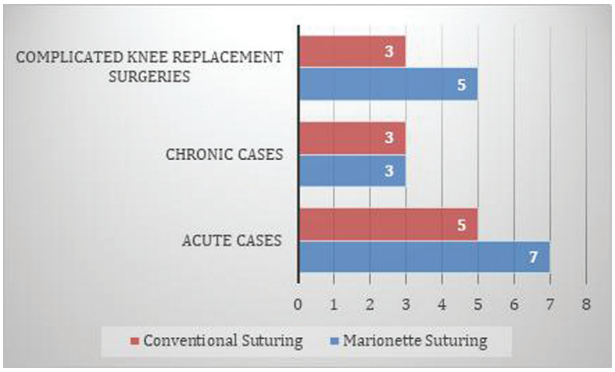
	Number of patients	Number of patients started early physiotherapy	Number of patients with dehiscence and conventional physiotherapy	Number of patients with 90% graft take at 3 weeks postoperative
Acute trauma cases	7	7	–	6
Chronic trauma cases	3	3	–	2
Exposed knee prosthesis cases	5	4	1	5

Table 2 The results of conventional PDS suture group during the study

	Number of patients	Number of patients started early physiotherapy	Number of patients with dehiscence and conventional physiotherapy	Number of patients with 90% graft take at 3 weeks postoperative
Acute trauma cases	5	3	2	2
Chronic trauma cases	3	1	2	1
Exposed knee prosthesis cases	3	2	1	2

PDS, polydioxanone suture.

Figure 3



Type of suturing in the flap fixation in different types of patients in the study.

Discussion

Coverage of exposed knee joint is of ultimate importance or else bone osteomyelitis, tendon desiccation, and loss of articular cartilages can occur. Moreover, coverage of exposed knee prosthesis is crucial to prevent alloplastic extrusion and failure [1]. Gastrocnemius flap is the workhorse flap in the management of complicated knee joint injuries, taking into consideration the proximity of the donor site in the same surgical field and the minimal donor site morbidity with the muscle-only flap, where the soleus muscle is preserved as the remaining foot plantar flexor.

Other options for coverage of complicated knee joint include reverse flow anterolateral thigh flap [14,15] and

Figure 4

A 50-year-old female patient with exposure of the prosthesis after a knee replacement surgery.

Figure 5

A 26-year-old male patient who needed patellar tendon reconstruction due to traumatic injury caused tendon rupture 6 m before and the overlying skin was scarred and fibrosed so flap coverage was expected to be needed after exposure and tendon reconstruction.

reverse flow-vastus lateralis flap [6], but they both carry the risk of imperfect circulation encountered with reverse flow flaps. Additionally, free flaps can be used but microvascular expertise and setting must be available, and also they carry the risk of total flap loss with atherosclerotic vessels, especially in old patients requiring knee replacement surgery [16]. Other consideration is that free flaps are lengthy operations, whereas the gastrocnemius flap coverage is a straightforward surgical approach that adds between 40 and 60 min, therefore not prolonging the operative time considerably [17,18]. Perforator flaps, based on tracing of a local perforator by echo Doppler, serve as an alternative with comparatively low morbidity for coverage of knee defects. However, they remain dependent on the state of the surrounding tissue and require microsurgical expertise as they are technically demanding [7,8].

The muscle-only flap was resorted to in this study in all cases both owing to the great morbidity posed from sacrificing the skin over the gastrocnemius muscle even for the sake of defect coverage [19] and to allow the tucking of the muscle under the undermined skin envelope of the surrounding defect to allow the fixation using Marionette sutures in cases where it was the technique of choice. In addition, the suturing of a skin paddle to the surrounding skin bordering the defect can subject the suture line to undue tension and forces during early physiotherapy, leading ultimately to wound dehiscence and break down, being in the proximity of the knee joint. Moreover, in this series of cases, total gastrocnemius muscle or the medial head alone was used; the medial head is the larger and the longer of the two heads [20,21]. Lateral head is smaller and shorter, and also elevation must be done very cautiously so as not to be complicated with a common peroneal nerve neuropraxia or even injury leading to foot drop.

In this study, extremes of age were excluded as increased healing power in young age and also decreased healing capacity in old age can affect the results regarding graft take and re-exposure of major structures. During selection of cases for this series, it was noted that hemoglobin is to be kept above 10 g/dl and albumin above 3.5 g/l, with strict blood glucose control, so as to exclude any general cause for decreasing healing capacity.

Included in this study were small wounds less than 4 cm that mandated coverage due to exposure of prosthesis or deep wounds with bone and patellar exposure. Moreover, moderate-sized wounds ranging from 4 to 6 cm, where the wounds were deep creating a dead space or with prosthesis or bone exposure, allowed for filling the defect and obliterating the dead space and played a role in combating infection. Larger wounds more than 6 cm or severely battered were considered for free flaps and were not included in this study [22,23]. Therefore, the small and moderate sizes of the defect allowed for ample coverage, where the gastrocnemius muscle flap has been reported to cover up to 60 cm^2 in one study, and also its proximal arc of rotation can reach up to 15–17 cm proximal to the knee joint [24]. This all helped toward minimizing the tension across the defect and permitted the start of early physiotherapy. This also allowed us to assess the effectiveness of the Marionette sutures and if they played an additional role toward the stability of the coverage.

Marionette sutures were first described in breast surgery to create a new inframammary fold, with sutures between the deep pectoral fascia and the skin surface where the new inframammary fold is desired [12]. In this study, Marionette sutures were used to anchor the gastrocnemius muscle flap to the defect edges in 15 patients. PDS USP 1 is used, as this suture can hold the tension exerted between the flap and the defect. Round needle tip was used, with the intention of preserving the muscles integrity and cutting or reverse cutting needle can cut through the muscle.

With the help of Marionette sutures, tension between gastrocnemius muscle and defect edges is held at all layers of the skin, thus decreasing the risk of dehiscence. Vaseline gauze is used under the knot so the knot is not with direct contact with the skin surface, preventing pressure ischemia and necrosis of the skin and subsequently dehiscence.

In this series, 11 cases had PDS suspension of the muscle to the subcutaneous tissue of surrounding structures. The use of this method sacrifices skin as a tough layer to hold sutures, leading to increased liability for dehiscence, re-exposure of vital structures, and decreased ability to start early physiotherapy.

Classically in these cases, passive physiotherapy starts after 3 weeks of surgery and active physiotherapy at 4 weeks postoperatively to ensure complete healing of the gastrocnemius muscle to the defect [10,11].

This delay in physiotherapy can lead to knee stiffness as the joint is kept immobilized for so long [10]. It is here where the role of Marionette sutures comes, which allows early start of passive and active physiotherapy.

In all cases of this patient series, a split-thickness graft coverage is used to cover the raw gastrocnemius muscle flap. Contralateral anterior thigh is used as a donor site. The use of this contralateral site away from the pathological limb is beneficial to prevent any further insult to the diseased side. Meshing is carried out to prevent any collection under the graft, which can decrease the percentage of graft take. Vicryl on a round needle is used to fix the graft to the raw muscle; it has the advantage of preventing cutting through the graft, which can happen with cutting needles.

Posterior splint or knee immobilizers [1] were applied during the initial phase till graft take is ensured to prevent any uncontrolled movement that may move the graft away from its bed.

At 2 days postoperatively, the ability to start early passive physiotherapy and early active physiotherapy at 7 days denotes good healing of the muscle flap to the recipient site. Any dehiscence or re-exposure of vital structures or knee prosthesis denotes increased tension between the muscle flap and the donor site beyond the capacity of the muscle fixation technique to withstand. Patients with this type of dehiscence were converted to the conventional physiotherapy protocol. It is also to be noted that cases showing necrosis of the flap were excluded from this study, so major dehiscence is not affected by flap viability. Moreover, at 3 weeks after flap elevation, graft take is ruled out. Increased percentage of graft take denotes increased stability of the muscle in its new position, with no muscle necrosis is noted in this series, and muscle viability is not contributing to the percentage of graft take.

During this study, it was concluded that Marionette sutures led to increased ability to start early passive and active physiotherapy in 87% of patients in comparison with conventional PDS sutures to the surrounding structures (64% of patients). Moreover, Marionette suture application led to decreased number of patients with dehiscence leading to re-exposure of important structures or knee prosthesis (13% of patients) in comparison with conventional PDS sutures (36% of patients). Moreover, the application of Marionette sutures led to increased number of patients with a 90% graft take percentage (75% of cases) in comparison with PDS sutures (35% of patients) (Fig. 6).

Conclusion

Gastrocnemius flap is the working horse of knee reconstructive surgery, and it can be refined to encourage early physiotherapy using Marionette suturing technique that showed effectiveness in reliable flap fixation in its recipient site which helped patients to start early passive and active physiotherapy

Figure 6

A 33-year-old male patient who needed coverage after a complicated knee replacement surgery. Marionette suturing was used to reliably fix the flap to encourage early physiotherapy.

in small-sized and moderate-sized defects and avoid the common complication that can result after knee surgeries, especially knee joint stiffness.

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Conflicts of interest
There are no conflicts of interest.

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