The innervated rectus abdominis flap for quadriceps reconstruction

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Summary *Background:* The vertical rectus abdominis myocutaneous (VRAM) and transverse rectus abdominis myocutaneous (TRAM) flaps have traditionally been excluded from consideration of reconstructions with functional potential, because of their segmental innervation. We present a case series that aimed to demonstrate that segmental innervation does not preclude successful neural anastomoses and can deliver a functional reconstruction of a total compartment in the anterior thigh.

Methods: This review included all patients who required total anterior thigh compartmentectomy and reconstruction between December 2009 and February 2016 were included from the first author's prospective database.

Results: Eleven cases were identified, with innervated rectus abdominis flaps used for anterior thigh reconstruction. During the median follow up period of 12 months, all patients had reinnervation of the rectus with six reaching M5, one M4+, one M4, two M3 and one M2, according to Medical Research Council power grades.

Conclusion: All patients had successful functional reconstruction in the thigh using the rectus abdominis myocutaneous flap.

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Introduction

Limb-sparing surgery for the treatment of extremity soft tissue sarcoma has evolved rapidly since the mid-1970s, when amputation rates were in the order of 40-50%.[1] Reconstruction of limb sparing radical, complex, large defects has come to represent the major microsurgical challenge faced by reconstructive surgeons.[2]

Reconstructive surgery aims are increasingly ambitious. It has long been recognized that pedicled and free tissue transfers improve patient outcomes by aiding wound closure, filling surgical dead-space and providing coverage for otherwise exposed critical structures.[2-4] These characteristics of transferred tissue now represent only the basic and immediate aims of reconstruction. In the future objectives must now shift toward reconstructions that are functional, sensate, cosmetically well-matched and thereby resemble the resected tissue as closely as possible.

The rectus abdominis muscle has usually been excluded from functional reconstructive surgery, because of its segmental innervation, which has been viewed as an obstacle to delivering an extremity reconstruction with reinnervation potential.

The innervated functional rectus muscle transfer has thus been reserved for either total or subtotal segmental resection, and/or denervation of the majority of the quadriceps compartment. The idea of the use of a functional rectus muscle reconstruction ironically began as an attempt to preserve the innervation to the rectus during the raising of deep inferior epigastric artery perforator flaps in breast reconstruction and subsequent anatomical dissections.[5] These previous dissections had shown that even though the rectus abdominis does indeed have a segmental supply, each nerve does not supply a purely transverse segment of muscle as quoted in traditional anatomical textbooks.[6] In fact there are usually one or two dominant nerves which can each independently cause contraction of the entire length and width of the muscle when stimulated.[7] This functional anatomical finding actually makes the innervated rectus muscle very well suited to contractile reconstructive techniques.

We aimed present the first case series of patients with innervated rectus abdominis myocutaneous flaps, to assess function when used for anterior thigh compartmentomy defects and to assess donor site morbidity. We hypothesized excellent anterior thigh functional recovery.

Methods

All patients who underwent sarcoma resection and required a functional quadriceps anterior thigh reconstruction were identified from the first author's prospective database, from a period between December 2009 and February 2016. Approval was obtained from St Vincent's Hospital Human Research Ethics Committee. All patients gave their informed consent. Inclusion criteria for this series included a quadriceps compartmentectomy and reconstruction with a free or pedicled innervated rectus abdominis flap (Figures 1 and 2). On routine follow up, neural recovery was measured based on power assessment by the first author based on Medical Research Council (MRC) grading[8] (Videos 1 and 2).
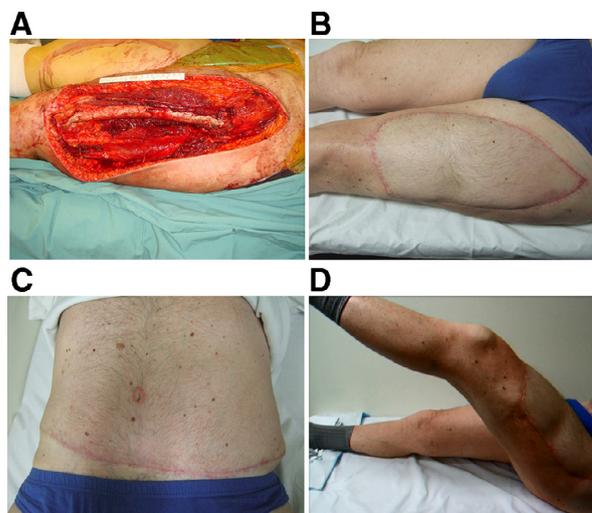
Figure 1 (a) 66 year old man (case 7) showing complete left anterior thigh compartmentectomy, periosteal stripping and 40 × 15 cm skin defect. This was reconstructed with a free TRAM flap, raised with 3 nerves to rectus abdominis neurolysed and dissected laterally for 9 to 10 cm. Recipient vessels were lateral circumflex femoral artery and venae commitantes and recipient nerves were 3 remaining proximal ends of motor nerves to the anterior compartment.
(b) Free left innervated TRAM flap at 3 months.
(c) Donor site at 3 months.
(d) Functional result at 12 months exhibiting straight leg raise with M5 power, can walk several kilometers unaided.
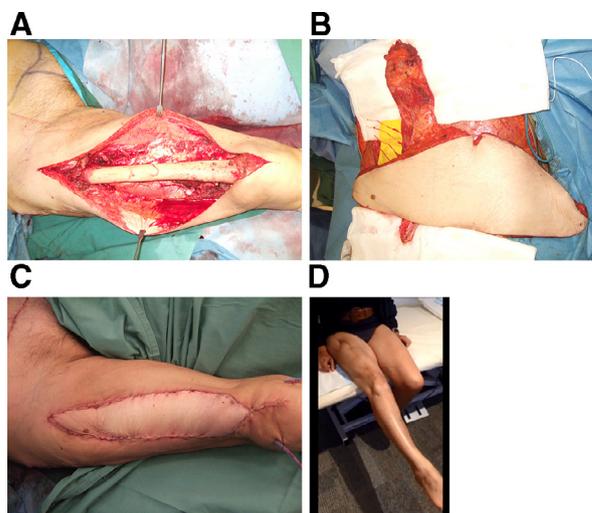
Figure 2 (a) 59 year old female (case 4) with right anterior thigh defect; complete removal of quadriceps and wide periosteal stripping. A femoral rod has been inserted in order to prevent a pathological fracture of the femur.
(b) Free right TRAM flap design and harvest, with nerve stimulation and neurolysis of 3 lateral intercostal nerves.
(c) Flap inset to right thigh, secured to the proximal and distal quadriceps tendons, anastomoses to branch of the profunda femoris artery and three motor nerves from branches of the femoral nerves.
(d) Functional result at 2 years showing full knee extension, with power M5 and able to perform unassisted squats.
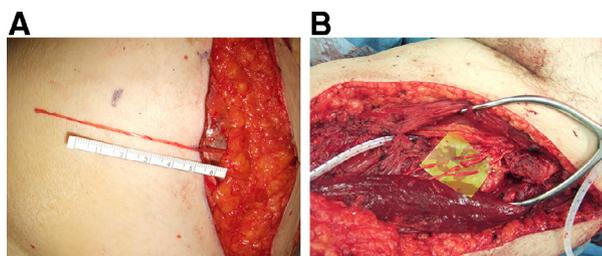
Figure 3 (a) A nerve harvest as part of a free left TRAM. (b) The multiple recipient motor nerve branches from the femoral nerve isolated as part of an anterolateral thigh compartmentectomy for sarcoma (right) prior to multiple neurorrhaphy.

Comprehensive functional recovery was assessed using the Musculoskeletal Tumour Society (MSTS) rating score, using established criteria graded 0 to 5 for each of six factors (pain, function, emotion, supports, walking, gait).[9]

Surgical technique

The surgical methods used to raise rectus muscle with either standard vertical or transverse skin paddles as a pedicled or free flap have been well described.[10] The flap is raised based on the deep inferior epigastric arteries (DIEA) and their accompanying venae commitantes. The decision to use either the transverse skin paddle (TRAM) versus the vertical skin paddle (VRAM) is based on the size of the skin defect and amount of dead space that requires filling, with larger defects requiring a transverse skin island. All donor sites are closed directly with the addition of mesh to the anterior abdominal wall where required.

The difference from the standard rectus abdomninis flap raise, compared to when innervation is required, as in our series, is the neural dissection, selection and subsequent neurorrhaphy. The anterior rectus sheath is opened laterally and the lateral edge of the rectus muscle exposed. The segmental innervation by the intercostal nerves are dissected and isolated. A hand held nerve stimulator is applied to assess the dominant motor nerves which give the largest contractions. An assessment is made at the recipient site as to the number of femoral nerve recipients are available in the thigh and then the equivalent number of dominant nerves are dissected at the appropriate site in the muscle (Figure 3). The linea semilunaris is divided with sharp diathermy dissection on either side of the nerve and then a loose areolar tunnel subsequently dissected around the nerve in the neurovascular layer of the abdomen between transversus abdominis and internal oblique. A length of 10-12 cm is easily obtained.

The tendinous intersections of the rectus muscle are then sutured out to length under tension with large nonabsorbable sutures to the remnant tendons of the quadriceps apparatus proximally and distally. The inset of the skin flaps are also performed using a three layer closure. It must be noted that the TRAM flap skin paddle is very mobile and can easily be turned 90° in order to run in the same line as the underlying muscle if required.

The need for pedicled or free flap transfer with vascular anastomoses is determined by the precise position of the defect. Recipient vessels include the circumflex femoral arteries (CFA), branches of the profunda femoris and superficial femoral arteries (SFA). The neural anastomoses are also performed in a conventional fashion onto motor branches of the femoral nerve. The number of nerve anastomoses per flap can vary (in our series ranged from one to four). These are performed as an end to end microsurgical neurorrhaphy with an 8-0 nylon epineural suture. Two patients in our series also had other accessory neural reconstructions to the remnant of a single quadriceps muscle in the form of either a nerve graft or nerve transfer.

The postoperative regime for rehabilitation includes bed rest and elevation for six days immediately postoperatively. The patient then has a six week period of complete immobilization of the knee joint in an extension knee splint. At seven weeks post-operatively, the patient starts mobilization of the knee and strengthening of all remaining muscle groups. The splint is removed at three months and physiotherapy performed to strengthen the re-innervated quadriceps muscles until 12 months post operatively.

Results

Eleven patients were identified, with median age 66 years. All patient's tumours were soft tissue sarcomas, and all had received neoadjuvant radiotherapy. All involved removal of the majority of the quadriceps with denervation of any residual musculature such that the innervated rectus muscle reconstruction was the only knee extensor. Several also involved resection of part of the adductor compartment. In addition one patient's tumour extended laterally to a degree that the tensor fascia lata was necessarily resected. All other tumours within the group did not require a resection margin beyond the lateral border of vastus lateralis, and all were adequately excised by our orthopaedic colleagues.

Eight required free flaps including and three required pedicled flaps. There were four VRAM flaps and seven TRAM flaps. One patient required bony reconstruction, as the tumour had invaded the femoral periosteum. This was reconstructed with double free flap utilizing a free fibula and innervated free VRAM flap.

All muscle flaps survived with no anastomotic failures. There were no immediate complications following any of the operations. One patient developed small partial flap loss of the distal 2 cm of the flap in zone four which required a simple excision and direct closure under local anaesthetic as an outpatient.

During the median follow up period of 12 months, all patients had reinnervation of the rectus with six reaching M5, one M4+, one M4, two M3 and one M2, according to MRC power grades (Table 1). Six patients achieved a complete functional recovery with MSTS score of 30 (Table 2).

One patient died 8 months after her operation, of causes unrelated to her surgery or sarcoma.

In terms of donor site, all had mesh repair and there were no hernias (protrusion of abdominal contents through abdominal wall with fascial defect). Two patients developed donor site bulge (abdominal contour defect without fascial defect).

Table 1   Demographics, flap and power at last follow up.

Patient case number	Age (years)	Gender	Side	Flap	Follow up (months)	Power (MRC grade)[5]
1	65	F	R	VRAM, free with fibula	9	M4
2	67	F	R	TRAM, pedicled	14	M4+
3	45	F	R	TRAM, free	18	M5
4	59	F	R	TRAM, free	36	M5
5	76	F	R	TRAM, free	12	M3
6	69	F	R	VRAM, pedicled	24	M5
7	66	M	L	TRAM, free	60	M5
8	62	M	R	TRAM, free	18	M5
9	83	F	L	TRAM, pedicled	12	M3
10	66	F	L	VRAM, free	8	M2
11	54	F	L	VRAM, free	7	M5

TRAM = transverse rectus abdominis myocutaneous flap.
VRAM = vertical rectus abdominis myocutaneous flap.
R = right, L = left.
M = male, F = female.
MRC = medical research council.

Table 2   Musculoskeletal tumour society (MSTS) rating score.

Patient case number	Pain	Function	Emotion	Supports	Walking	Gait	Total
1	4	5	4	3	3	3	22
2	5	5	5	5	5	3	28
3	5	5	5	5	5	5	30
4	5	5	5	5	5	5	30
5	5	3	5	1	3	3	20
6	5	5	5	5	5	5	30
7	5	5	5	5	5	5	30
8	5	5	5	5	5	5	30
9	4	1	5	1	3	3	17
10	5	1	5	3	3	3	20
11	5	5	5	5	5	5	30

As we are reporting the reconstruction, oncological results have not been rated as one the outcomes of significance among this group of patients at this early stage.

Discussion

The outcomes of greatest significance in this series is the presence and quality of neural recovery in all transplanted tissue, as assessed by MRC grading, and good functional recovery as shown in MSTS scores. With eight of 11 patients achieving M4 power or greater indicates these patients can walk unaided including upstairs and perform normal activities of daily living.

The single factor which most significantly reduces the recurrence rate of soft tissue sarcoma are wide clearance margins on histological examination, and margins are shown to be widest where it is understood by the resecting surgeon that a reconstruction will comfortably fill the defect.[11,12] Limb preservation in soft tissue extremity tumours has been shown to predict a greater disease-free survival rate among patients where a free flap reconstruction is used, probably because the surgeon resecting the tumour tends to be more aggressive with margins.[11]

One major advantage of the rectus muscle is the large skin paddle that can be raised. When raised as a TRAM flap, a large skin paddle can be taken while still allowing direct donor site closure, which would not be possible with any other flap choice.

The traditional soft tissue reconstructions for anterior thigh defects include local rotation or advancement flaps of the adjacent thigh muscles, with or without skin grafts. Alternatives for larger defects include fasciocutaneous or myocutaneous free and pedicled options from either regional of distant sites.[13] In our series, all eleven patients had extremely large defects. This is not only typical of soft tissue sarcomas, it is a common theme of oncological surgery. Adequate soft tissue coverage from a more conventional donor site would have been quite challenging, perhaps excepting latissimus dorsi.[14,15] Latissimus dorsi free flaps have been considered useful in reconstructive surgery for over three decades.[16] However, the donor morbidity with latissimus dorsi free flaps in some papers has been shown to be greater, both immediately and long term, than that of a rectus abdominis free flap.[7] Disadvantages are that it often necessitates intraoperative changes of position of the patient, it has oblique orientation of muscle fibres, has a higher seroma rate and has only one nerve available for coaptation.

The morbidity associated with donor flaps involving the rectus has been well-described in the literature, largely due to their use as autologous breast reconstructions.[17,18] Reported rates of abdominal wall hernia rates range from 0 to 10.5% and bulge 0-13.4%, with rates reduced by the use of mesh for abdominal wall reinforcement as was performed in all cases in our series. None of our cases developed a hernia and two donor site bulge.[19] While donor site functional assessment was not performed in the present study, it is reasonable to suggest that the functional gain seen in these results, aiding knee extension, justify use of the rectus. It has been demonstrated previously that resection of two quadriceps will not greatly influence knee extension power. However, resection of three or more of the quadriceps compartment causes a severe reduction in the power of knee extension.[20]

Our 100% re-innervation of rectus abdominis rate may be explained by a number of reasons. Firstly, there is a relative redundancy of axons needed to stimulate the muscle, with overlapping innervation, so the outcome is not depending on a single nerve anastomosis.[5] Other reasons for our success may be abundant recipient neurons, our careful selection of the dominant nerves and a short distance to re-innervate the target organ.

While all cases have been relatively successful in this series, a larger sample size and longer follow-up will aid to assess objectively the benefits and possible complications of the rectus abdominis as a functional reconstruction. We are, however, optimistic that this series may represent the first of what may become a useful alternative functional reconstruction.

Conclusion

We report a series of 11 successful functional, innervated reconstructions using rectus abdominis for anterior thigh defects. This demonstrates that the segmental innervation of the rectus abdominis does not preclude its use as an innervated, functional free flap reconstruction and should be an addition to the spectrum of flaps being used to reconstruct functional defects. It is of particular significance in oncological extremity reconstruction surgery, due to its size as it offers a large myocutanous flap reconstruction in the context of increasingly ambitious limb preservation surgery, and location as a possible pedicled flap to the thigh region.

Conflicts of interest

Nothing to declare, no funding disclosures.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.bjps.2019.03.002.

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