Dynamic reconstruction of complex abdominal wall defects with the pedicled innervated vastus lateralis and anterolateral thigh PIVA flap

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Summary  Background and aim: Reconstruction of large and chronically infected recurrent abdominal wall defects with exposed bowel in a scarred wound environment, when component release has been previously performed but failed, is a veritable challenge. We use a pedicled innervated vastus lateralis muscle with a fasciocutaneous anterolateral thigh flap (PIVA flap) to restore the continuity of the abdominal wall with vascularised tissues and create a dynamic component that improves the functional outcome.

Materials and methods: A one-stage PIVA flap was used in 15 patients with grade 4 transmural chronically infected defects. They had a mean of 4.53 previous laparotomies and important co-morbidities. We determined post-operative reconstruction abdominal wall strength using a validated quality-of-life (QoL) hernia-related questionnaire and modified it to quantify donor-site morbidity at the thigh. We measured the maximal force generated at 60°/s and the force velocity at 120°/s by isokinetic dynamometric analysis at 3 and 12 months. Electromyography (EMG) was performed 12 months after the reconstruction to analyse the contractile integrity of the vastus lateralis segment. A two-sided sign test was used to analyse data.

Results: All transmural chronic wounds healed without recurrence. Dynamometric strength increased significantly in the abdominal wall musculature (p < 0.016) and in the donor thigh (p < 0.023) between 3 months and 12 months after the intervention, which reflected in the EMG outcome and the high scores in the QoL measurements after 12 months.

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Introduction

Most of full-thickness abdominal wall defects can be restored with a perforator-saving component release and an inlay or wide onlay synthetic or bioprosthetic mesh to provide structural support.\(^1\) However, abdominal wall reconstruction after a previous component release and mesh grafting in a scarred and infected environment or after oncologic resection involving radiotherapy and the presence of a colostomy and urostomy is very challenging because further undermining leads to more tissue hypoxia and spreading of infection.\(^4\)–\(^6\) The Ventral Hernia Working Group developed a grading system for the assessment of risk for surgical site occurrences when using meshes. Wound infection plays a key role in the grading system: grade 3 is a potentially contaminated milieu due to previous wound infection, the presence of a stoma and violation of the gastrointestinal tract; grade 4 is an infected area with septic dehiscence and deep infection involving the muscle and/or the fascia.\(^6\) Awad et al. estimated that >75% of all recurrence is due to infection and inadequate fixation of the mesh.\(^5\) Luijendijk et al. reported a hernia recurrence rate of 80% among patients with post-operative infection versus 34% for those without infection.\(^6\) The presence of individual co-morbidities, such as smoking, diabetes, chronic obstructive pulmonary disease (COPD), advanced age, obesity and chronic use of corticosteroids, increase the risk of post-operative infection as much as fourfold.\(^7\) It was suggested that the biologic meshes might offer an advantage over synthetic meshes in a contaminated field.\(^8\)

Nevertheless, recent data show that the long-term durability of a single-staged approach to repairing contaminated abdominal wall defects with a biologic mesh was less favourable than initially thought,\(^9\) as over 50% of patients had recurrent hernias within 3 years and an overall wound complication rate of 48%.\(^10\) Further analysis with medium-term follow-up revealed a near-universal failure rate with biologic meshes when placed as a bridge.\(^11\)

Therefore, chronically infected abdominal wall defects with exposed bowels in patients with important co-morbidities are also treated with negative-pressure wound therapy (NPWT).

Long-term use of NPWT may gradually close the abdominal wall defect over the bowels generating granulation tissue that can be skin grafted. There is a considerable risk of fistula formation if the vacuum-assisted closure (VAC) is in direct contact with the bowel. In addition, the generated granulation tissue does not result in a soft transmural reconstruction of the abdominal wall.\(^12\)

Ideally, in such adverse milieu, vascularised tissues should be introduced that treat the infection after further debridement, induce healing in the chronic defect and restore the transmural tissue continuity.\(^12\)–\(^14\) A tensor fascia lata (TFL) flap used to be the workhorse to reconstruct abdominal wall defects but the reach, tissue bulk and vascularity of a pedicled TFL flap are poor and other strategies impose.\(^12\)

Free musculocutaneous flaps revascularise and clean the wound environment and supply coverage.\(^15\)–\(^17\) An innervated dynamic muscular component can even be incorporated in the harvest.\(^18\),\(^19\) Due to temporary denervation following neurovascular suturing, free innervated flaps require a long recovery time while further atrophy and weakening occur. Pedicled innervated locoregional flaps may avoid this delay, but conventionally they are not expected to reach the upper abdomen in Mathes zone IA.\(^13\)

We report a series of 15 pedicled innervated vastus lateralis and anterolateral thigh (PIVA) flaps used to induce healing in chronically exposed severely scarred defects where previous component release was used to restore the transmural defect but failed. The PIVA flap restores the abdominal wall in a dynamic transmural fashion with innervated myofasciocutaneous tissues.

Materials and methods

This study was approved by the ethical committee/institutional review board of Leuven University Hospitals. Between 2007 and 2013, 15 patients were treated with a composite PIVA flap for recurrent complex midline abdominal wall defects in zone IA and IB\(^2\) (Table 1). Four of five zone IA defects reached the xiphoid process. There was a mean of 4.53 (range 3–8) abdominal operations per patient prior to the reconstruction. All 15 patients had previous closure of the abdominal wall defect using component release. All had a colostomy and nine had a urostomy. In all 15 defects, omentum was missing or could no longer cover the bowel, which caused direct exposure (Table 1).

We used a Hernia-Related Quality-of-life Survey (HerQLes) questionnaire to evaluate quality of life (QoFL) as it relates to abdominal wall function. This survey is validated to measure the qualitative outcome of hernia repair.\(^20\) Patients circled their agreement in six grades (‘strongly disagree’ to ‘strongly agree’, score 1–6) preoperatively and after 12 months for 12 statements related to the impact of the abdominal wall on health, physical pain, strenuous activities, moderate activities (e.g., bending, bowling), walking and climbing stairs, daily activities (dressing, cooking, taking a shower), sexual activity, the accomplishment of work at home and overall well-being.\(^20\)

As no validated surveys exist to measure donor-site morbidity at the thigh, we transposed these 12 statements for use at the thigh. Patients circled their agreement or disagreement on 12 statements in the context of loss of
quadriceps and flexion at the knee and thigh and impact on health, pain, walking, climbing, dressing, moderate and strenuous activities, the accomplishment of work at home and overall well-being. To facilitate interpretation, scores were transformed to a 100-point scale (factor 1.2 on a standard normal distribution). Linear mixed models were used to account for data clustering: the optimal covariance structure was selected using Akaike information criterion (AIC).

A sign test was used to test whether the difference between the measurements on the various parameters taken at 3 months and at 12 months was different from zero.

A cyclo-ergospirometry and Quadriceps Fatigue (QF) test of the donor thigh was performed to evaluate the long-term impact of muscle harvest. We measured the maximal force generated during knee extension and flexion at 60°/s and the force velocity generated at 240°/s on the right (donor) side versus the left (intact control) side. Isokinetic tests of the abdominal wall were performed at 3, 6 and 12 months after the surgery. We measured the maximal force generated at 60°/s and the force velocity at 120°/s during abdominal wall flexion versus lumbar extension.

Electromyography (EMG) was performed 12 months after the reconstruction to analyse the contractile integrity and action of the VL segment after stimulation.

### Statistical methodology

A sign test was used to test whether the difference between the measurements on the various parameters taken at 3 months and at 12 months was different from zero. Measurements of acceleration time and deceleration time were inverted so that a positive difference indicates an increase in strength for all parameters. Measurements were transformed into z-scores (by subtracting the mean and dividing by the standard deviation; z-scores follow a standard normal distribution). Linear mixed models were used for analysis with the z-score. Random effects were used to account for data clustering; the optimal covariance structure was selected using Akaike information criterion (AIC). All tests are two-sided and p-values <0.05 are considered significant. The analysis was performed using SAS software, version 9.2 of the AS System for Windows.

### Table 1 Patient chart. Overview of 15 patients treated with a PIVA flap.

| Pt  | Age y/o | Indication | Radio chemo | NPO | Co-morbidity | Defect zone | Size ALT | Size fascia | Size VL |
|-----|---------|------------|-------------|-----|--------------|-------------|----------|-------------|--------|
| 1   | 42      | RAC, FAW,AWM | Yes         | 3   | IA + IB      | 18 × 8       | 20 × 9    | 18 × 9      |        |
| 2   | 60      | Crohn colitis, C Perf, LHC, RHC, FAW | No          | 4   | Smoker       | IB          | 16 × 8    | 16 × 8      | 16 × 8 |
| 3   | 53      | RAC, FAW    | Yes         | 3   | IB           | 17 × 7       | 18 × 8    | 17 × 7      |        |
| 4   | 74      | RAC, LHC + SBR, FAW | Yes         | 5   | COPD, ITP, AHT | IB        | 15 × 7    | 16 × 8      | 16 × 8 |
| 5   | 68      | CP, Bricker, invasion abd wall | Yes         | 4   | IB           | 12 × 7       | 15 × 7    | 15 × 7      |        |
| 6   | 63      | CU, LHC, RHC, FAW | No          | 8   | Bechterew    | IA + IB     | 26 × 12   | 24 × 12     | 23 × 12 |
| 7   | 42      | RAC, FAW    | Yes         | 3   | Urosepsis    | IB          | 17 × 7    | 17 × 7      | 17 × 6 |
| 8   | 74      | RAC, FAW    | Yes         | 3   | IB           | 16 × 8       | 16 × 7    | 16 × 7      |        |
| 9   | 77      | CP, Bricker, radiorectitis, FAW | Yes         | 4   | AHT, smoker  | IB          | 17 × 7    | 19 × 7      | 18 × 6 |
| 10  | 62      | CS + obstr 3x, SBR, FAW | No          | 6   | AMI, AHT, smoker | IA + IB  | 25 × 13   | 26 × 13     | 26 × 12 |
| 11  | 64      | Crohn colitis, C Perf, LHC, RHC, FAW | No          | 4   | IB           | 18 × 9       | 18 × 9    | 17 × 7      |        |
| 12  | 58      | RAC, FAW    | Yes         | 5   | IA + IB      | 24 × 11      | 23 × 11   | 23 × 11     |        |
| 13  | 59      | Crohn colitis, C Perf, LHC, RHC, FAW | No          | 5   | Smoker       | IA + IB     | 20x10    | 21x11       | 20 × 10 |
| 14  | 66      | CP, Bricker, Radiorectitis, FAW | Yes         | 5   | AHT          | IB          | 18 × 8    | 19 × 9      | 18 × 9 |
| 15  | 68      | RAC, FAW    | Yes         | 6   | IB           | 17 × 8       | 17 × 8    | 16 × 8      |        |

AHT: arterial hypertension; AWM: abdominal wall metastasis; COPD: chronic obstructive pulmonary disease; CP: cystoprostatectomy; CS: colon strangulation; UC: ulcerative colitis; FAW: fistulas to the abdominal wall; ITP: idiopathic thrombocytopenic purpura; LHC: left hemicolectomy; NPO: number of previous operations; Obstr: colon obstruction; Perf: colon perforation; RAC: rectum adenocarcinoma; RHC: right hemicolectomy; SBR: small bowel resection.
Results

The PIVA flap covered defects located in the mid- and upper abdomen. In four cases, the flap reached the xiphoid process (Figures 1 and 2). There was no flap loss. Partial flap loss (24 cm²) occurred in the proximal cutaneous segment of one flap while the VL muscle remained well vascularised. This segment was skin-grafted and healed well. No secondary dehiscence and no clinically relevant infections or thrombosis occurred in the follow-up period. One patient had an acute myocardial infarct 1 year post-operatively. This event was not related to the abdominal wall, which had healed by then.

The subjective impact of the reconstruction of the abdominal wall was measured in the QoL assessment of the HerQLes scores. The mean HerQLes score for abdominal wall-related QoL 12 months post-operatively was 73.44% (48.36–94.95%). There was no correlation with size of PIVA flap and QoL. Interestingly, 14 of 15 scores fell in the 1–4 range, meaning that patients ‘strongly disagreed’ towards ‘moderately agreed’ to the statements, including ‘my abdominal wall interferes when I perform strenuous activities’.

The mean QoL score for donor-site morbidity at the thigh 12 months post-operatively was 90.78% (80.04–98.9%). One patient ‘strongly agreed’ (value 6) till 9 months after reconstruction but after recovery ‘slightly disagreed’ (value 3). There was no correlation between size of PIVA flap and donor-site morbidity at the thigh.

Abdominal wall function

A significant improvement was seen for all parameters of maximal force development at 60°/s and for the speed of force developed at 120°/s (Figure 3a and b). Peak torque,
average peak torque and peak torque in relation to body weight, as well as average power development and total work, more than doubled for the 60°/s tests over a 12-month period. Total muscular force output for the repetition with greatest amount of work and average power had the greatest improvement between 3 and 6 months after surgery. The acceleration time and deceleration time followed a similar pattern of increase (not shown). Based on the dynamometric data of PIVA flaps larger than 20 × 10 cm, we found evidence of a significantly increased strength in the abdominal wall between 3 and 12 months after the intervention (p < 0.016). EMG confirmed a viable VL segment that could be individually activated leading to contraction and flattening of the abdominal wall.

Donor site at the right thigh (Figure 4a and b)

Maximum force at 60°/s and speed of force development for the quadriceps at 240°/s showed a strong improvement in peak torque, peak torque/body weight, average power, average peak torque, work and total muscular force output. The average power, torque at 0.18 s, work in the first third and work in the last third for the donor thigh were within 70% of the values of the control thigh at 12 months. We measured overall increased strength in quadriceps function between 3 and 12 months after the intervention (p < 0.023). The clinical impact was compared with the subjective outcome based on the QoL questionnaire.

The patient shown in Figure 1 (pt 6 of Table 1) had a biodex isometric force development of 96% of the predicted
value (PV). A value of 80% or more of the PV is considered normal.

The MRC-SUM for hip flexion was 5/5 and knee extension 4/5. Value 4 represents a total range of motion under submaximal resistance and value 5 under maximal resistance.

The Compufet peripheral muscular force measurements for hip flexion were 201.5 N (PV was 114 N) and knee extension 250 N (PV was 230 N). Cyclo-ergospirometrics were evaluated as normal: no ventilatory or cardiac limits were reached. QF test: no diminished quadriceps twitch force (qTw) was noted at the donor site; 12 kg pre- and 11.30 kg post exercise represented a QF of only –11% (–15% or higher is regarded significant).

Discussion

The reconstruction of chronic abdominal myofasciocutaneous defects after previous treatments with component release is complex because of the scarred, poorly vascularised and infected tissue environment with colostomies and bowel exposition.1–6 In such wound environment, the first goal is the treatment of the infection and the coverage of the bowel resulting in a stable closure. Vascularised tissues are the first choice to attack a chronic infection and guide the antibiotic treatment to the core of the defect via the intrinsic vascular networks. Vascularised flaps also generate the ideal milieu for meshes that may deliver extra strength. A mesh is required to diminish bowel protrusion during the healing period of the PIVA flap, but also to generate long-term strength.6,22,23 There is a need for new-generation more durable and less costly biologic meshes that deliver long-term strength also in addition to a PIVA flap reconstruction.6,9,10,21

The anterolateral thigh zone is ideal for flap procurement for abdominal wall repair as the thigh area remains unscarred even after multiple laparotomies. We have been using the pedicled ALT flap extensively for perineal, abdominal wall and groin defects. When the pivot point of the vascular pedicle is medialised from the rectus femoris and sartorius muscle, the PIVA flap may reach to the xiphoid process.12,24,25 The reach depends on the ratio of length of thigh versus abdomen (Figures 1 and 2).

The donor-site morbidity of a conventional ALT flap is reported to be low.6,26–28 Still, donor-site data after procurement of an ALT with VL are scarce. To minimise the donor site of the PIVA flap, all femoral motor nerve branches to the other quadriceps muscles must remain intact during flap procurement. Tsuji et al. reported...
minimal donor-site knee-function morbidity after harvesting a mixed group of 12 ALT flaps for head and neck reconstructions. Only two flaps were musculocutaneous.

The HerQLes questionnaire is a measurement tool that allows for assessment of QoL as it relates to abdominal wall function. Both the functional impact of the abdominal wall reconstruction and the donor-site morbidity are essential parameters in the QoL analysis linked to this technique. After 12 months, patients scored a high QoL for the abdominal wall reconstruction, with ‘mild’ negative impact even for ‘strenuous activities’.

Several patients became active hikers and bikers postoperatively. However, in terms of donor-site morbidity, we measured an objective deficit in quadriceps function of 30% at the donor thigh after 12 months. Most likely the maximal force and power output by the quadriceps seldom exceeds 70% in this patient population and therefore this objective 30% deficit did not reflect in the QoL assessment. Moreover, patients undergoing a reconstruction for a chronically infected transmural open abdomen may consider re-establishment of gastrointestinal continuity, loss of infection and restored abdominal wall lining a successful outcome, even though donor-site morbidity may be significant.

In one patient (pt 12 of Table 1), this recovery took more than 9 months. This possible course should be taken into consideration, especially in patients with pre-operative knee or hip pathology.

In relation to the subjective QoL assessment, dynamometric studies give a realistic objective image of the functional condition and improvement after reconstruction. Isokinetic testing is the standard for muscle and joint
assessment and allows for exercise speeds that approximate function.\textsuperscript{30,31} The dynamometric analysis confirmed the subjective impression of the patients that the abdominal wall had developed into a dynamically controllable unit.

EMG demonstrated that the VL muscle was neurologically intact after 12 months and could be directly stimulated in situ which led to abdominal wall contraction.

Neuromuscular coordination takes time to recover after reconstruction and requires training. Due to the preserved motor innervation of the incorporated VL in the composite flap, the patients had to activate the quadriceps muscles consciously to tighten the abdominal wall. This process occurred spontaneously after some weeks, as the abdominal wall musculature and thigh musculature function in synergy during activities such as climbing stairs, walking or biking. Nevertheless, even with an integrated neurovascular muscular unit within the composite ALT the biomechanical balance between the three fascia layers, the abdominal musculature and their vectors of traction during movements, cannot be authentically restored with a PIVA flap. This explains the bulging at rest without activation of the VL. When the VL component in the PIVA flap contracts by activating the knee and thigh, the abdominal wall flattens. A new generation of bioprosthetic meshes with improved durability may significantly enhance the biomechanical balance at rest.

The intact femoral nerve branches innervate the VL component of the PIVA flap. It is possible to perform a neurotisation procedure by suturing an abdominal wall motor nerve into the VL to introduce more authentic static and dynamic abdominal wall function in addition to the pedicled femoral nerve. However, muscles rarely accept a second neuromotor source.

As a consequence, the femoral nerve should be sectioned, which leads to temporary denervation and atrophy. We want to avoid this using the PIVA technique.

There are some shortcomings in this study. The first is the limited number of patients included. However, a PIVA flap is not the routine procedure and only used for complex non-healing transmural defects in a hostile wound milieu when component release and mesh grafting failed. Therefore, this patient cohort is rather small. To our best knowledge, no similar series using a PIVA with intact femoral nerve. However, muscles rarely accept a second neuromotor source.

The second shortcoming is the lack of a control group for this particular patient population.

The control group could consist of patients with similar recurrent abdominal wall defects restored with a mesh and a neurotised free PIVA flap with direct neural suture to an intercostal motor nerve. Such strategy would lead to temporary atrophy whereas a pedicled PIVA with intact motor nerve to the VL allows rapid revalidation.

We could also compare treatment with a mesh and ALT coverage without a muscle component in an equally heavily scarred, contaminated and poorly vascularised wound environment. Still, the primary aim of the PIVA flap is to provide well-vascularised tissues in a one-stage approach to accelerate healing of the chronically infected transmural defect and add a dynamic component to stimulate function.

Conclusion

The pedicled innervated VL and ALT flap offers robust, well-vascularised tissues. The muscular segment in the PIVA flap induces healing and adds a dynamic component that stimulates abdominal wall contraction. The PIVA flap may reach the xiphoid process and it restores complex transmural abdominal wall defects in those cases where a perforator-saving component release and mesh reconstruction is no longer indicated, even in patients with significant co-morbidities.

Conflicts of interest

None.

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Ethical approval

N/A.

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Reconstruction of abdominal wall defects with PIVA flap

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