Chapter 5

Use of the Rectus Abdominis Muscle for Abdominal Stoma Sphincter Construction: An Anatomical Feasibility Study

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Introduction

In the few studies that have been done to investigate the feasibility of using dynamic myoplasty to provide stomal continence denervation atrophy was one of the two main problems that lead to failure.\textsuperscript{1,2} To approach this problem of denervation atrophy we conducted an anatomic study to design a muscle flap sphincter that would preserve as much innervation as possible and be anatomically situated for stoma formation. The most likely would be a muscle flap that would not need a neuro-vascular micro-anastomosis.

Muscle Selection

Following initial anatomical pilot studies we selected the rectus abdominis muscle (RAM) as the ideal muscle for creation of a stomal sphincter. The rectus abdominis muscle has been extensively used in reconstruction of breast,\textsuperscript{4} thorax,\textsuperscript{1} vagina,\textsuperscript{6,7} bladder\textsuperscript{8,9} and extremity defects.\textsuperscript{10,11} For these purposes the RAM was used to replace or cover a defect. In far less of an extent the RAM has been used for replacing lost contractile function. A part of the RAM, after neuro-vascular micro-anastomosis, has been used for dynamic reanimation in patients with facial paralysis.\textsuperscript{12,13} The RAM has also been used as a skeletal muscle ventricle in the dog heart.\textsuperscript{14} The RAM appeared to be the most promising myoplasty muscle for stomal sphincter construction for the following reasons: 1. The RAM is ideally located in close proximity to the lower abdominal quadrants where fecal stomas are most often brought out through the abdominal wall. Therefore the RAM could be transferred without the need for neuro-vascular micro-anastomosis. 2. It is a long, broad muscle that can provide adequate muscle length for a circumferential wrap around a stoma. 3. It has an axial blood supply from the deep inferior epigastric artery and veins that is very reliable and consistent.\textsuperscript{15-17} 4. Dissection can be performed through the same laparotomy incision used to expose the bowel. 5. It has minimal donor-site morbidity.

Donor-site Morbidity

The rectus abdominis muscle is one of the muscles concerned in regulating the so-called intra-abdominal pressure and in acting, together with others, as a muscle of expiration. It flexes the lumbar spine, increases intra-abdominal pressure, pushes the diaphragm upwards in forced expiration, and acts in sneezing, lifting heavy objects and during parturition and vomiting. Great exertion is demanded on the muscle when the body is raised from the horizontal to the sitting posture without the aid of the arms, and also by violent coughing and the strain of defecation.
Most of the published studies concerning the donor-site morbidity of using the rectus abdominis muscle have been after pedicled or free TRAM-flap surgery for breast reconstruction.\textsuperscript{18,19} Kroll et al. reviewed the incidence of postoperative abdominal bulge, hernia, and the ability to do sit-ups in a series of 268 patients who had undergone free (unilateral and double-pedicle bilateral) TRAM or conventional (single-pedicle and double-pedicle or bilateral) TRAM flap breast reconstruction.\textsuperscript{19} The incidence of abdominal bulges (3.8\%) and hernia (2.6\%) was similar in the four groups. However, the ability to perform sit-ups was greatest in the unilateral free TRAM group (63\%) and lowest in the double-pedicle or bilateral conventional TRAM group (27\%). At the same time there are reports about incidences of serious weakness and hernias of the abdominal wall in patients undergoing TRAM-flap breast reconstruction of up to 35\%.\textsuperscript{20} To reduce donor site morbidity, more attention has been given recently to limiting the amount of muscle resection. This has led to the development of the deep inferior epigastric perforator (DIEP) flap.\textsuperscript{21} These perforator flaps reduce donor site morbidity to the lowest level yet possible.\textsuperscript{22}

Free transfer of the segmental rectus abdominis muscle flap is one of the standard procedures for free flap coverage of medium-size defects.\textsuperscript{11} Geishauer and co-workers evaluated the donor-site morbidity of the segmental rectus abdominis muscle flap for lower extremity defects in 20 patients with an average follow-up time of 47-months. In the cases included in this investigation only the caudal segment of one rectus muscle and less than one-third of the total length of the rectus abdominis muscle had been harvested.\textsuperscript{23} In only 1 patient they found one small hernia in the region of the scar. Grading of the muscle strength of the anterior abdominal wall using the test described by Janda (three exercises, Grades 0-5) was 5 in fourteen patients (70\%) and 4 in five patients (25\%).

The amount of rectus abdominis muscle we need for stomal sphincter construction is in between one-third and half of the total length of the rectus. In contrary to Geishauer et al. we need to make an opening in the anterior and posterior rectus fascia to let the stoma pass through.

**Flap Design Rectus Abdominis Muscle: Anatomical Feasibility**

The RAM has been used for a variety of different reconstructive procedures and its anatomy has been well documented. In spite of this, a detailed anatomical description of the RAM’s nerve and blood supplies relative to it’s being used to create a fecal stomal sphincter has not been published.\textsuperscript{24-28} The purpose of the following experiment was to describe the anatomy of the RAM in the context of creating an innervated and pedicled fecal stoma neo-sphincter. To determine the anatomical feasibility of creating a flap that, in future studies, could be electrically stimulated, we performed detailed dissections in fresh human cadavers. The objectives addressed include the
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Materials & Methods

A total of 24 RAMs in 14 fresh human cadavers (9 male, 5 female) were investigated. Of the 14 cadavers, 10 underwent bilateral dissections. In the remaining four cadavers only one RAM could be dissected due to the presence of surgical scars on the contralateral side.

The first part of the investigation consisted of defining the neurovascular anatomy of the RAM. The following measurements were carried out in each mobilized RAM: 1. the vertical and horizontal distance of the point of entrance of all the intercostal nerves innervating the RAM along its posterior surface using the caudal insertion and the lateral muscle margin as reference points. 2. the number of intercostal nerves innervating the most caudal segment of the muscle (between the symphysis pubis and the most caudal tendinous intersection). 3. the vertical and horizontal distance of the point of entrance of the vascular pedicle using the caudal insertion and the lateral muscle margin as reference points.

The second part of the investigation consisted of defining the best possible RAM flap sphincter design that would both preserve the muscles’ nerve and blood supply.

A mid-line laparotomy from the xiphoid process to the pubic symphysis was used to expose one or both RAMs. The anterior rectus fascia was incised along the medial border of the muscle and was reflected laterally to the lateral margin of the RAM. Marking sutures were placed at the tendinous distal insertion and tendinous intersections to insure that the muscle was returned to its original length after detaching it from its distal insertion. The inferior insertion of the RAM was transected from its bony insertion on the pubic symphysis. The deep inferior epigastric vascular pedicle consisting of an artery (DIEA) and two veins was dissected back to its take off at the external iliac artery. Muscle mobilization was carried out by individually dissecting each intercostal neurovascular bundle laterally with the assistance of an operating microscope (Zeiss, Gera, Germany). The most caudal segment of the RAM was divided longitudinally in the para-sagittal plane. The lateral segment was wrapped around a 3-cm diameter stent that simulated a fecal stoma.

The following two sphincter configurations were compared: a peninsula flap \((n = 24)\) and an island flap \((n = 16)\). With the superiorly based peninsula flap design, the detached caudal portion of the rectus muscle was rolled circumferentially around the stoma stent with the ventral surface of the
muscle coming to lie against the stent (Fig. 1). The cranial portion of the muscle was not divided from the caudal segment that was wrapped around the stoma. The long axis of the stoma sphincter was parallel to the abdominal wall. The following measurements were undertaken: 1. the length of the most caudal segment of the rectus muscle with and without the tendinous insertion; 2. the RAM thickness of the caudal segment at its midpoint; and 3. the degree of muscle overlap around the stent after the wrap.

Figure 1
Rectus abdominis muscle, peninsula flap stoma sphincter design in human cadavers. (Left) Line drawing representation. (Right) Cadaver dissection. The detached caudal portion of the rectus abdominis muscle is wrapped circumferentially around a stoma stent, with the ventral surface of the muscle coming to lie against the stent. The solid arrows indicate the segmental intercostal nerves. The open arrow indicates the vascular pedicle.
The second sphincter configuration was the island flap \( (n = 16) \). The island flaps were constructed by modifying the last consecutive 16 peninsula flaps. This configuration is the same as the peninsula flap with the major difference that the RAM is transected at the caudal most intersection. The distal muscle segment was then rotated 90\(^\circ\) laterally to allow the stoma sphincter to stand perpendicular to the abdominal wall (Fig. 2). The following measurements were taken for this sphincter design: 1. the amount of muscle overlap after it

**Figure 2**
Rectus abdominis muscle, island flap stoma sphincter design in human cadavers. *(Left)* Line drawing representation. *(Right)* Cadaver dissection. The rectus abdominis muscle is transected at the most caudal intersection, followed by 90-degree, lateral rotation of the distal muscle segment that allows the created stoma sphincter to stand upright. The *solid arrows* indicate the segmental intercostal nerves. The *open arrow* indicates the vascular pedicle.
was wrapped around the stent; 2. the degree of nerve mobilization proximal to the rectus fascia needed to allow for tension-free stoma sphincter construction; and 3. the amount of sphincter projection above the abdominal wall.

Results

The location at which the intercostal nerves enter the RAM along its posterior surface is shown in Figure 3. The number of intercostal nerves innervating the caudal segment was two in 13%, three in 54% and four in 33% of the RAM dissections. The Deep Inferior Epigastric Pedicle was 10.0 ± 0.5 cm (VD) from the pubic symphysis and 2.7 ± 0.2 cm (HD) from the lateral margin of the RAM (Fig. 3).

The average length of the caudal rectus segment was 13.3 cm (10.5 to 18.5 cm) without the tendinous insertion of the muscle and 15.5 cm (12.5 to 20.5 cm) with the tendinous portion included. On average, the distal tendinous portion of the muscle was 2.7 cm long (1.5 to 3.5 cm). The RAM thickness of the caudal segment at its midpoint was 5.7 ± 0.5 mm (range 3.0 to 12.0 mm).

The amount of muscle overlap around the three-centimeter stent varied with the type of flap being used. Using the peninsula flap the overlap was 0.5 cm (-2.0 to 2.9 cm). In two of the 24 peninsula flap sphincters there was no muscle overlap. In all the island flap sphincters there was complete muscle overlap the extent of which depended on the length of the caudal segment. The average amount of overlap for the island flap was 4.8 cm (1.0 to 9.0 cm).

In all peninsula flap sphincters, the amount of mobilization achieved by dissecting the intercostal nerves up to the lateral border of the rectus muscle was sufficient to allow the wrap to occur without tension on the nerves. No further nerve mobilization was needed. In the island flap design, nine of the 16 flaps (56%) could not be wrapped around the stent unless one or more of the intercostal nerves were dissected from the fascial plane between the internal oblique and the transversus abdominis muscles. One nerve in seven flaps and two nerves in two flaps had to be dissected anywhere from one to three centimeters in order to permit the wrap to occur without placing undue tension on either the nerves or the vascular pedicle.

The sphincter projection as determined by the width of the island flaps, was 4.0 ± 0.2 cm (range 3.0 to 7.0 cm). In only one dissection was it necessary to use almost the entire width of the muscle due to a very medially located insertion of the vascular pedicle.
Figure 3
Location of the entrance of the intercostal nerves (solid dots) and the deep inferior epigastric pedicle (open dot) into the rectus abdominis muscle along its posterior surface. The vertical distance (VD) of the point of entrance uses the caudal insertion at the pubic symphysis (PS) as a reference point (y-axis). The horizontal distance (HD) of the point of entrance uses the lateral margin of the rectus abdominis muscle (LMR) as a reference point (black solid line). As an example, the brackets indicate the actual distance (in centimeters) at which the third intercostal nerve enters the muscle.
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Discussion

Fecal stomal incontinence continues to pose a major problem for patients who suffer with them, for health care professionals responsible for caring for these patients and for the health care system responsible for their costs. Previous attempts to create a continent stoma using dynamic myoplasty procedures have met with less than ideal outcomes. Failures were reported to have been due primarily to denervation atrophy and muscle fatigue of the newly created sphincter. In an attempt to solve the problem of muscle denervation we performed the present anatomical studies. We designed a muscle flap that required minimal muscle denervation in its creation.

Ideally, a muscle chosen for stoma sphincter construction should be situated in close proximity to the proposed stoma location so that local muscle flaps could be used to create the sphincter. In addition, a muscle flap designed for stoma sphincter construction should preserve as much innervation as possible so that sphincter function is not compromised. After carefully considering various muscles for creating a stoma sphincter we chose the rectus abdominis muscle since it appeared to be the best suited choice for this application.

In a thorough literature search we could not find anatomical descriptions of the RAM's innervation that pertained to our specific application i.e. creation of a stoma sphincter. Previous anatomical studies that described the innervation pattern of the RAM did not include exact data pertaining to the number of nerves entering the RAM and at what distance from the pubic symphysis they entered. According to Duchateau et al., six to eight intercostal nerves were found to pass into the RAM along a line extending from the costal margin and xiphoid process down to the pubic symphysis. Below the umbilicus, two to three nerves were reported to enter the segment of muscle below the arcuate line. These nerves were noted to become intramuscular shortly after passing beneath the lateral margin of the muscle. Information concerning the vertical distribution of the intercostal nerves entering the RAM, however, was not presented. Similar findings were presented by Bishop et al., Rouvière et al. and Testut et al. According to Cullen et al. at the lateral margin of the rectus sheath, there are 5 to 8 fascial perforations through which the intercostal nerves and vessels enter at fairly regular intervals. However, the location of the end distribution was noted to be highly variable. Other published anatomical studies did not provide us with the specific data needed for our application.

Our anatomical dissections revealed that the RAM is in the appropriate anatomic location for a stoma; indeed many current methods of stoma creation include delivering the intestine directly through this muscle. The RAM is a long, broad muscle that can easily be circumferentially wrapped around a stoma when lifted as a flap. The muscle has a robust vascular supply...
from the dominant deep inferior epigastric artery and veins,\textsuperscript{15,16} and as our dissections demonstrated, its nerve supply can be kept intact without limiting its arch of rotation. There were, however, some limitations encountered in positioning the sphincter on the abdominal wall. The length of the DIEA pedicle supplying the RAM sphincter limited the distance that the stoma could be positioned cephalad to the pubic symphysis. Conversely, the factor determining the cephalad position of the sphincter depends on the flap design used. With the island flap, the most cranial intercostal nerve(s) limited the mobility of the sphincter. In 9 of 16 island flaps a more extensive mobilization of the intercostal nerves was needed to provide enough mobility to complete the wrap. In case of the peninsula flap the muscle itself limited the mobility of the sphincter. The fact that the peninsula flap design consisted of not dividing the muscle above the most caudal tendinous intersection caused the muscle itself to functionally tether the sphincter superiorly. This tethering of the peninsula flap accounted for not being able to use contractile muscle for the entire wrap. Instead, part of the distal tendon had to be used to complete the wrap in two cases. This was not a problem in the island flap design.

In addition to the above a number of other key features of the island flap design made it better suited for stoma sphincter construction. For example, the island flap design was more versatile in terms of positioning. It could be positioned perpendicular to the abdominal wall allowing the stoma to be delivered to the abdominal skin over the shortest distance without acute angulations. This feature minimizes the risk of distal bowel ischemia. On the other hand, the fact that the island flap was only tethered by its nervous attachments and the vascular pedicle could conceivably place traction on one of the innervating nerves when the muscle is electrically stimulated and contracts. However, one would expect that as the sphincter heals and forms attachments to the surrounding tissues it would become fixed in position making this concern more theoretical than real.

An advantage of the peninsula flap design over the island flap was its dual blood supply. However the disadvantage of the peninsula flap design was that it causes the sphincter to lie parallel to the abdominal wall thus requiring that a greater length of bowel be used to pass through the sphincter. This could increase the risk of distal bowel ischemia. In addition, the parallel orientation of the peninsula flap relative to the abdominal wall would cause two acute angulations in the bowel resulting in further potential risk of local ischemia and resultant stenosis. Finally stimulation of the peninsula flap sphincter would likely cause the entire contiguous muscle to contract resulting in distortion and upward displacement of the stoma. This could cause discomfort for the patient.
As with other striated, voluntary fast-twitch muscles, the rectus abdominis muscle fatigues rapidly if repeatedly stimulated. To apply this method clinically as in other dynamic myoplasty applications the RAM would have to be made fatigue-resistant in order to function as a stoma sphincter. This can be achieved by “training” the muscle as is done in cardiomyoplasty or graciloplasty,\(^{32}\) in which case the latissimus dorsi and gracilis muscles are transformed from fatigue-prone to fatigue-resistant. We are currently conducting experiments in a dog model designed to define optimal electrical stimulation parameters that can be used to train the RAM flap stoma sphincter.

In summary, we have shown through detailed anatomical dissections that the RAM is ideally suited for constructing a stoma sphincter. The muscle is located in the appropriate anatomical location for stoma creation, it has a long vascular pedicle, and the preserved segmental intercostal innervation pattern allows the muscle to be tailored and mobilized in such a way to completely wrap a fecal stoma without significant muscle denervation. We found that the RAM island flap design is superior to the peninsula flap design for stoma sphincter construction. If in our future “functional” studies the RAM can be successfully trained to become fatigue-resistant, this technique could put the problem of stomal incontinence one step closer to being solved.

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References


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