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AUTOTRANSPLANTUL DE ȚESUTURI MUSCULARE
ASISTAT ENDOSCOPIC

(ENDOSCOPIC-ASSISTED MUSCLE TISSUES
AUTOTRANSPLANTATION)

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ABSTRACT OF THE DOCTORAL THESIS

ENDOSCOPIC-ASSISTED MUSCLE TISSUES AUTOTRANSPLANTATION

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# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Table of contents</td>
<td>3</td>
</tr>
<tr>
<td>Introduction</td>
<td>4</td>
</tr>
<tr>
<td>Background</td>
<td></td>
</tr>
<tr>
<td>A. Reconstruction using muscle flaps</td>
<td>9</td>
</tr>
<tr>
<td>B. Endoscopic plastic surgery</td>
<td>11</td>
</tr>
<tr>
<td>Endoscopic-assisted muscle flaps in swine</td>
<td>15</td>
</tr>
<tr>
<td>A. Gracilis</td>
<td>16</td>
</tr>
<tr>
<td>B. Latissimus dorsi</td>
<td>21</td>
</tr>
<tr>
<td>C. Rectus abdominis</td>
<td>27</td>
</tr>
<tr>
<td>Discussions</td>
<td>31</td>
</tr>
<tr>
<td>Conclusions</td>
<td>35</td>
</tr>
<tr>
<td>Tables and figures</td>
<td>36</td>
</tr>
<tr>
<td>References</td>
<td>47</td>
</tr>
<tr>
<td>List of published articles</td>
<td>52</td>
</tr>
</tbody>
</table>
INTRODUCTION

Endoscopic surgery is well-established in many medical specialties and developed towards self-standing subspecialties. Plastic surgery adhered to endoscopic techniques and aesthetic surgery adopted it fast. Yet, the reconstructive surgery adhered slowly to endoscopic techniques due to main focus on the success of the reconstructed site and secondarily to the donor-site, with morbidity considered acceptable. “Robbing Peter to pay Paul”, the creed of reconstructive surgery, is in continuous dialogue with patients life-quality, in demand for a better life for Peter. Recently, two phenomenon occurred: reconstructive surgery evolved to excellent results (Paul is doing fine) and the patients’ exhibited increased awareness over donor-site morbidity - concerns for Peter.

Donor-site morbidity arises from adopting strategies that go against the principles plastic surgeons longtime adopted. Scarring is not a well-controlled process, in spite of recent advances. But plastic surgeon strive to find ways to avoid conspicuous scarring, by hiding the incision in natural skin creases or lines, or by camouflaging the incision in less obvious areas. When incisions are performed along the Langer lines – relaxed skin-tension lines (RSTL) – improved cosmesis results. Conversely, whenever the incisions cross the RSTL, the chances for conspicuous scars increase.

A common example is the classic harvesting of the muscle flaps. The large incision to access the muscles and pedicles has short-term drawbacks; increased postoperative pain, higher chances for wound-related problems and longer recovery. By crossing the Langer lines perpendicularly, on a long-term evaluation, up to almost half of the patients complain of conspicuous scars. In temporalis fascia or muscle harvesting, the alopecia is the tradeoff and is obvious especially in short-hair patients. In breast reconstruction using latissimus dorsi muscle, the resulted scar is often difficult to be hidden in the bra. Conspicuous scars resulted are resented by the patients, in spite of otherwise excellent reconstruction result.

Functional deficits occur frequently in classic muscle harvesting, besides the poor cosmesis. In gracilis muscle harvesting, thigh hypoesthesia (caused by inadvertent sensory nerve injury)
occurs frequently.\textsuperscript{3,4} Harvesting rectus abdominis muscle through classic paramedian incision with large opening of the rectus sheath induce loss of abdominal wall strength. When only the muscle is harvested with rectus sheath preservation, abdominal wall contour and bulging occur. With supplementary rectus sheath deficient closure, the chances for abdominal wall bulges increase to 43\% and herniation rates increase, more in TRAM flap compared to DIEP. The physiological micturition or defecation is impaired, accordingly.\textsuperscript{8-11}

Specific categories are prone to deleterious scarring therefore extra care is advised in women and children, where conspicuous scars are undesirable. Efforts are advised to overcome the donor-site morbidity and endoscopic technique found the right niche to fill in by the multitude of its advantages.\textsuperscript{12}

The benefits of endoscopic surgery derive from shorter incision, with immediate effect such as reduced pain due to fewer sensory nerves cut that shortens period of disability and allows for earlier reeducation and shorter hospital stay. Dissection under endoscopic magnification reduces the complication rate such as hematoma and makes more precise the process of addressing the anatomical details. Small incisions counts also for low infection rates, possibly due to limited exposure and minimal contamination.\textsuperscript{12}

The learning of classical muscle flap harvesting is straightforward. Nevertheless, application of endoscopic techniques to plastic surgery requires an additional learning curve, more or less difficult according to doctors’ background. Obviously, prior experience in laparoscopic surgery, gynecology, thoracoscopy or arthroscopy can positively reflect in the speed of the learning process. Conversely, without prior endoscopic practice, the application \textit{de novo} of the endoscopic techniques can be a technical challenge.\textsuperscript{12,13}

The optical cavity is the space created around the tip of the endoscope that separates and allows tissue visualization and can be considered the primary hurdle in endoscopic plastic surgery. In most of the cases, the optical cavity does not exist, and it must be develop in the subcutaneous tissue, unlike laparoscopy and thoracoscopy, where the cavity is potential and arthroscopy where the optical cavity already exists. The optical cavity is customized to the purpose of the...
operations, tissue harvested, anatomical area, instruments and surgeons experience. Developing the optical cavity is the main step of the operations, for example creating the pocket for placing an expander, or a preparatory site to harvest a tissue (i.e. muscle flap) to be transferred for reconstruction purposes. The tension-retraction of the subcutaneous tissue must be continuously adapted to allow easier dissection of the contiguous tissues, for example the underlying muscle flap; therefore, adequate retraction helps concomitantly optical cavity development and the tissue harvesting.\textsuperscript{13}

Mechanical retraction: the external retractors hook up the skin and fix the threads in a complicated tripod-type system. Besides being cumbersome, is not flexible enough to permanently adapt the retraction to the needs of the dissection. The internal system needs and assistant to permanently adapt the retraction tension and can be tiresome. For small operations the surgeon can do the retraction by himself (forehead lift) but for large tissues harvesting when anatomical constraints are important, an assistant is mandatory to allow the operator to execute the operations with both hands. Combined internal/external retraction can be used, such as OMNI retractor plus retractor blades and retraction sutures, combining the advantages and also the drawbacks.\textsuperscript{14,15}

Ideally, the retractors must be non-traumatic and multifunctional (support the endoscope, evacuate the smoke and fit for different anatomical areas), cost-effective (applied to many operations), flexible, simple, efficient and not cumbersome. Retractors used for internal organs in laparoscopy are not adapted for subcutaneous tissue. Therefore specific retraction devices were developed. External/internal retractors use the same principal, a pull-up force that will tent the subcutaneous tissue, assisting dissection and creating working space for the endoscope and instruments.\textsuperscript{13-15}

Tissue dissection: the optical dissector had the advantage of dissecting and retracting in the same time, with the cutting blades when dense or strongly attached tissue must be separated (RA from anterior rectus sheath, LD) or blunt optical dissector when loose tissue must be separated (posterior rectus sheath from muscle). It is also safe and easy to use. Electric cautery, scissors, scissors with
cautery facility are useful and small variations among authors are noted.\textsuperscript{1,17-21}

Most important in developing the optical cavity and tissue harvesting is the retraction, and more important than the means of retraction is the assistant. As mentioned, in small optical cavities the assistant’s help is not mandatory, but in large optical cavity, multi-planar, with several tasks to be addressed, the assistant is very important. The team is critical for the operation’s success and the good coordination between the assistant and operator yields better results.\textsuperscript{2,12-16}

Due to the technique novelty and additional learning curve, when endoscopic surgery is started, the operating time is increased. Most often they are not the main step of the operations. The muscle harvested needs free transfer, or rotation, and flap inset, anastomosis, are longer than and as important as the harvesting itself. Less than two hours harvesting time in a 6 hours operation is acceptable. The original harvesting times of 3-5 hours were not acceptable. Increased operating times means increased costs and increased rate of complications. The operating times decrease rapidly after 5-10 endoscopic operations.\textsuperscript{12,15,16}

Patients must be informed about the benefits and limitations of the endoscopic methods, and the possibility to convert to classic operations in case of complications or operation taking too long. The recipient area morbidity and scarring cannot be affected so patients must be aware of improvement in the donor area where the endoscopic step of the operation focuses.\textsuperscript{12}

Criteria to follow when choosing an endoscopic operation versus a classic one were established by F. Eaves in 1994\textsuperscript{22}:

1. Scar must be smaller, ideally necessary to deliver the muscle; for LD muscle ideally scar length should range 3 to 6 cm.
2. Operating time for endoscopic should be smaller than classic. Even if endoscopic operations take longer, it can be compensated by shorter duration for wound closure
3. Similar success rate between the two techniques
4. Less or equal complication rates. Small incisions through less disrupted tissue (preservation of lymphatic and subdermal vascular
plexus) induce less edema, ecchymosis, seromas and wound healing problems.

5. Cost-equivalency, especially that endoscopic technique requires many resources and investment when starting the practice.

The differences between classic and endoscopic tissue harvesting, the special requirements for optical cavity development, instruments and dissection are particular hurdles to be overcome when endoscopic techniques are to be used by plastic surgeon. The non-addressed limitations can lead to increased risk of complications or costs. Therefore, endoscopic techniques must be mastered before clinical application.

Training models specific for endoscopic plastic surgery are needed. Virtual reality or live tissue models for training are available in almost all surgical specialties using endoscopic techniques, but they are lacking in plastic surgery; a few instructional courses in aesthetic surgery on cadaver address specific areas and operations. To our knowledge, there are no standard training models on live tissue to address endoscopic plastic surgery techniques learning and practicing, in an operating-room setup.

Animal model for endoscopic flaps harvesting: domestic swine is an excellent training model in classic flaps harvesting. Flap models were developed and detailed anatomy and operating steps recorded and standardized. Through learning sessions during preparatory dissections and the live tissue courses, gracilis, latissimus dorsi and rectus abdominis muscle flap anatomy and harvesting technique was practiced. Swine flaps harvesting is safe, reliable, and easy to learn and practice. The anatomy is constant and similar to human’s muscle anatomy. Pigs are relatively inexpensive model, strong to resist follow-up and easy to be anesthetized.

Aim of present study is to describe, evaluate and standardize three models of endoscopic-assisted swine muscle harvest – gracilis, latissimus dorsi and rectus abdominis. The final aim is to find safe, reliable, easy to learn and cost-effective models of endoscopic muscle harvesting that would provide adequate learning and training of endoscopic techniques. Upon practicing on these standard models, plastic surgeons should be able to safely translate the acquired skills in their current practice.
A. RECONSTRUCTION USING MUSCLE FLAPS

Muscle flaps are of paramount importance in the reconstructive surgery. When compared to fasciocutaneous flaps they have debatable, relative equal value in soft tissue coverage and choosing one over the other depends on surgeon’s preference. As an autologous option for tissue augmentation, muscle flaps have less complication rates compared to the alloplastic materials. For the reconstruction of lost motor function, no other option can replace the functional free muscle transfer. Due to high plasticity and versatility, muscle flaps can yield better results therefore they are favored. The use of muscle flaps encompasses the elective surgery or compulsory immediate/delayed coverage in emergency situations.

Traumatic injuries of the upper and lower limb are common presenting pathology in the emergency department. Extensive trauma patients approach is standardized and internationally accepted guidelines are followed. The care for the traumatic injury is secondary to the patient’s general status stabilization. After debridement, lesions inventory is made and priority is established according to their gravity.

Extensive soft tissue defects with multiple tissue loss, especially over exposed bones, joints, vessels and nerves, need immediate coverage with well-vascularized tissues in order to avoid the irreversible function loss. Flap surgery is a ubiquitous strategy in soft tissue coverage; besides the obvious reason for saving critical anatomical structure, it promotes tissue survival and it is the only way to maximize the chances for functional recovery. In this regard, the coverage is also a functional reconstruction. Composite tissue transfer, including two three or more types of tissues, can successfully address combined bone, muscle, vessels, nerves or skin loss. The best example is the subscapular system, which offers no less than 5 different tissues and wide combinations of flaps. One-stage reconstruction, even for complex defects, is possible due to flaps versatility.
In practical terms, pedicled latissimus dorsi can cover tissue defects from shoulder down to the elbow and by coverage prevents excessive shortening of the bone, giving patients higher chances for better stump use or better prosthesis adaptation; in this regards, this operation is also a functional reconstruction. LD reconstructs the function of shoulder muscles or totally or partially biceps or triceps loss, with minimal or no donor-site functional deficit. Breast non-microsurgical reconstruction relies heavily on anteriorly rotated pedicled LD, alone or combined with implants if larger augmentation is needed. Moreover, the muscle can reach up to the midline for sternal defect, with adequate tendon release.\(^{38-42}\)

As for the remote defects, free flap transfers are needed for optimal reconstruction provided adequate vessels are present or previously reconstructed. Microsurgery is more than a technique for vessels anastomosis. Is a strategy, a choice from many decision-making algorithms available, with different success rate, taking into account all factors, the patient, the problem, expected result, back-up solutions, surgeon, etc.\(^{38-42}\)

Rectus abdominis muscle holds similar features with LD due to its plasticity to fill the dead spaces, ideal to reconstruct complex or deep defects. By being well-vascularized tissue, the muscle improves marginally ischemic traumatic areas, increases the surrounding tissue viability and provides effective anti-microbial resistance. The muscle itself offers good quality tissue for tendons gliding and therefore promotes forearm muscles function.\(^{43-53}\) This is one example of how one muscle flap achieves two goals simultaneously: coverage and functional reconstruction.

Microsurgical reconstruction is a challenge due to technical constraint and amount of resources involved, but it is the best options in selected cases. Reconstructive flap surgery in upper limb severe trauma, with extensive or complex defects, is the rule and not the exception. Difficult enough, flap surgery is not only the best treatment for complex upper limb defects; it is also the last line treatment. When it fails, the life boat is another flap surgery. There is no down staging after flap surgery, if maximal functional reconstruction is the goal. Flap surgery is rewarding whenever the
patient is restored to optimal life quality. Patients’ satisfaction is the best evaluation tool for surgeons’ work.\textsuperscript{38-53}

The other side of the coin shows the tradeoffs. The donor-site morbidity is rightfully an important part in the overall results. Patients concern shifted from reconstructed site, as the results are constantly successful, to the donor-site; the complaints over its morbidity throw a shadow over otherwise excellent reconstruction result.\textsuperscript{2-4,7-11,53-55}

Endoscopic-assisted flap harvesting improves the donor-site outcome, but also reflects in patients’ postoperative increased comfort, and shorter hospitalization. Flap surgery and endoscopic techniques have similar effect regarding patients’ functional outcome, rehabilitation, comfort and hospitalization. When combined, the positive effects will add-up, to patients benefit, increasing life-quality and satisfaction. However, the patient is not the only beneficiary. Even if these operations per se involves large human, technical and financial resources, on a long term it was proved to be cost-effective, in reducing number of operations, hospital stay and rehabilitation time, therefore providing smaller costs for the society.

\textbf{B. ENDOSCOPIC PLASTIC SURGERY}

Twenty years ago, plastic surgeons started to use endoscopic techniques and today the endoscope is commonplace in plastic surgery and continues to grow. The use of endoscopic techniques in plastic surgery is more demanding compared to other endoscopic surgeries. The proposed advantages, such as quick recovery, less risk and downtime, shorter scar at minimal expenses, were proven.\textsuperscript{12}

The primary goals of endoscopic techniques are the decrease in scar length, morbidity and amount of dissection. The access can be performed through the remote incisions in areas less conspicuous or where future scar can be camouflaged easily, making sure the distance to the place of interest can be covered by the endoscope length and is suitable for safe dissection (not crossing vital structures such as nerves). If remote incisions are used for expander placement,
the risk of exposure or extrusion is smaller. Skin is not the primary goal in endoscopic surgery but the tissues underneath. If large amount of skin are involved in the harvested tissue (myocutaneous latissimus dorsi) or to achieve the purpose, the endoscopic approach might not be beneficial (loose skin that needs excision during abdominoplasty). If skin is good quality with limited laxity, endoscopic face lift or endoscopic rectus tightening might be suitable.

Other procedures are not mandatory endoscopic but the magnified control vision can increase safety, such as in procerus or corrugator resection, that can preserve supratrochlear or supraorbital nerves or in transaxillary breast augmentation.\textsuperscript{13}

Models of endoscopic assisted muscle harvest

Endoscopic assisted gracilis harvest

Lower limb adductor, and hip flexor muscle, arising from the pubic arch through aponeurotic origin and inserts on the tibial tuberosity as the common tendon of pes anserinus with the semimembranosus, semitendinosus, and sartorius. The gracilis muscle situates underneath the deep fascia and is related to the adductor longus muscle anterolaterally and the adductor magnus muscle posterolaterally in the proximal half of the thigh; the sartorius muscle anteriorly, the semimembranosus muscle posteriorly, and the adductor magnus muscle laterally in the distal half. The saphenous vein crosses on the overlying deep fascia of the gracilis in the distal third of the thigh. The gracilis size is length of 32-35 cm, width of 5 to 6 cm, and 2 to 3 cm thick with extra 10 cm tendon length.

Gracilis is class II Mathes and Nahai muscle, with dominant vascular pedicle the terminal branch of the medial femoral circumflex artery, entering the muscle approximately 6 to 12 cm inferior to the public tubercle. Motor innervation is supplied by the anterior branch of the obturator nerve that enters the muscle 2 to 3 cm cranial to the vascular pedicle. Minor vascular pedicles, tributary to the femoral artery or the profunda femoris artery, enter the muscle 10 to 15 cm distally from the posteromedial surface of the muscle.\textsuperscript{65}
The endoscopic harvesting time was longer compared to classic, but not the overall operating time. Yet, complication rates are smaller and the electro-physical exam proved the muscle re-innervation has similar speed between the 2 groups and muscle function recovery is similar.65

**Endoscopic latissimus dorsi (LD) harvest**

Latissimus dorsi is a broad, flat muscle originating from iliac crest, transverse process of lower thoracic and lumbar vertebrae and paraspinal fascia. From this broad origin, the muscles fiber courses to insertion on the groove of the humerus (insertion on a two-layer tendinous band). Spatial relation: anteroinferior border is free free, posteriosuperior is associated to teres major and is attached to scapula tip, and serratus muscle lies underneath.

Primary blood supply is the thoracodorsal artery, found 10 cm under the tendinous insertion, on the undersurface of the muscle; innervation is tributary to thoracodorsal nerve. Vascular branches to serratus and to teres major are severed during harvesting process. Secondary segmental pedicles are also cut during prelevation. Variation from muscle flap: the fat layer covering the muscle can be harvested to augment the volume. Under muscle the lumbar fat can also be included for same reason.37,56

Using endoscopic technique, LD is harvested as a pedicled flap and is used according to the arc of rotation, to reconstruct the breast or for functional reconstruction of the shoulder. Autologous LD, with adequate tendon release, can reach anteriorly up to the midline to cover sternal defects. As a free flap the indication extend from scalp reconstruction to head and neck and upper and lower limb resurfacing and reconstruction. Classic LD harvest, due to lengthy incision, is particularly unacceptable to women and children.56

For endoscopic pedicled LD, scar placement depends on the reconstruction purpose. If more tissue is needed, more posterior incision site is advised to enhance visualization of the posterior or caudal areas of the muscle. If the case of previous breast scars after mastectomy or lumphectomy, it is recommended to approach LD through previous operating sites. Adequate mobilization of tendon
and pedicle is performed to allow unrestrained rotation of LD to reach the defect. If free LD endoscopic flap harvest is intended, incision must be placed to allow safe and easy access for open dissection to LD pedicle, therefore closer to axillary area is recommended. Skillful assistant can expedite the harvest. 1

Initially the dissection is performed in open way until vision limit is reached; afterwards, the endoscope will assist the remaining if the dissection. Various methods of single/multiple incisions, internal and/or external retraction, balloon dissection, optical dissector, with/ out insufflation were tested and various results were reported. The use of LD is for extremities reconstruction, 57-60 breast reconstruction 61 and functional reconstruction as free muscle for facial palsy 56,62 or pedicled in rotator cuff injury 63.

**Endoscopic rectus abdominis (RA) harvest**

Few reports mention endoscopic harvest of RA but clinical experience is still limited. There is wide variety of techniques including balloon-assisted, insufflations or mechanical retractor to help in developing the optical cavity. 1,17-21,64 Two approaches were used.

Retroperitoneal approach uses single/multiple skin incision, for muscle dissection and retrieval, therefore peritoneum or posterior rectus sheath is not violated. Friedlander 17 used 3 incisions and tripod external retraction system and harvested myofascial/muscular RA superiorly based, in 5 cadavers and 5 pigs; anterior rectus sheath was repaired using mesh. To avoid rectus sheath harvesting along with the muscle, new techniques designed only sheath incision and not defect, but besides the skin incision, the sheath incision length is similar, therefore the chance for hernias is not decreased. 18,19 Later, a subcostal incision and another two ports were used to harvest the muscle through transversal incision. The muscle undersurface required insufflation and superficial is dissected helped by retraction; the inferior pedicle was addressed through endoscope using the two paraumbilical accessory ports. Five patients were operated and operating time was less than 1 hour for last 3 cases; postoperatively patients reported minimal discomfort and clinically no hernias were
noted. For dissection, Miller is using cutting blades optical dissector for superficial surface and blunt ones for undersurface, pedicle dissected under direct vision. Transperitoneal (sheath-sparing) approach was reported as an alternative to eliminate anterior rectus sheath incision. Laparoscopic approach uses 3-4 ports for pedicle and muscle dissection and section, muscle retrieval is performed through a large port or Phannenstiel-type incision in pigs and cadaver or endo-bag in clinical case. Use of ultrasonic knife in pigs seems to be responsible for hernia complication. In clinical case, avoiding the paramedian incision leads to faster recovery with less pain. The posterior sheath needs no repair; seroma is prevented by draining in the abdominal cavity. No hernia was reported in this clinical case. Noteworthy advantages are: the possibility to inspect abdominal cavity (to rule out the metastasis in case of lower limbs melanoma), total operating time similar to classic harvest (small incision closure saves considerable time), pedicle dissection is safe (used to delay TRAM flap), thanks to the magnification. The disadvantage, for both approaches, is the difficulty to address the superior half of the muscle where freeing of the tendinous intersection is tedious; last, but not least, cost-effectiveness can be an issue.

ENDOSCOPIC-ASSISTED MUSCLE FLAPS IN SWINE

Material and methods
Operative instruments: In addition to instruments used for classic harvest, we used 10 mm and 5 mm standard - 30 degrees angle - rigid endoscope, camera box, video camera, light source, cord, high resolution video monitor, video recorder (Stryker endoscopic cart), electrocautery, dissectors, clip appliers, suction and internal Emory-type retractors.

Animal experiments were approved and conducted by the Joint Committee for Animal Research and Animal Care and Ethic Committee of Pius Branzeu Center in Timisoara and Center for Simulation and Training in Surgery in Iasi. Animals were housed and treated in accordance with the “Guide for the Care and Use of
Laboratory Animals”, published by the National Academy Press (US National Institute of Health Publication No 85–23, revised 1996). The animals were caged individually in the animal facility of the research center, with 12 hourly day/night cycle and with food and water ad libitum.

They were fasted for 12 hours before surgery. Pre-anesthesia and sedation were achieved with ketamine (10-15 mg/kg) and midazolam (0.5 mg/kg) or diazepam (2 mg/kg). Muscle relaxation was induced with thiopental (5-10 mg/kg) and the pigs were intubated. Anesthesia was maintained with halothane 1-2% mixed with oxygen 2-4L/min. Isotonic solutions were perfused 5-10 ml/kg/h.67

After dissection, the muscle was attached only by its pedicle. Muscle viability and pedicle pulsations were confirmed by endoscopic inspection, 30 minutes later. The pedicle was clipped and sectioned to the desired length and the muscle was delivered through the incision.

After checking the donor site for bleeding, the incision was closed by separate absorbable 3.0 stitches. Operating times, complications and muscle anthropometric measurements were documented. Neither drains nor dressings were used; antibiotics and analgesics were administered for 3 days.

Follow-up: after 30 minutes inspection, the muscle was stitched to the underlying muscles, the incision was closed and the pigs were returned to animal facility. Vital signs, ambulation and feeding habits were recorded daily. One week later, under general anesthesia, the incision site was reopened and the muscle viability was checked and the complications were noted.

Statistics: student t-test was used to analyze the classic and endoscope-assisted operating times. P<0.05 means statistically different values.

A. GRACILIS

Material and methods

A total of 16 pigs (mean weight 25.4 kg, range 18-38 kg) underwent endoscopic-assisted harvest of 26 gracilis muscles (20 bilateral and 6 unilateral).
Landmarks: On the medial thigh, the saphenous bundle was identified as the distal landmark of gracilis muscle dissection; it runs caudally and posteriorly, from anterior thigh towards the posterior aspect of the knee, (fig. 1). With the hindlimb actively abducted and extended, the cephalic (anterior) border of the gracilis muscle was marked as the anterior skin fold running from midline towards the knee, on the medial aspect of the thigh. Less obvious, gracilis caudal (posterior) border was palpated towards the posterior aspect of the thigh and marked, from midline to the knee. Muscle origin was drawn beside the midline and the insertion was drawn distal to the saphenous bundle on the tibia, completing the muscle flap design. The 3 to 4 cm skin incision was marked at the muscle posterior border, 2 to 3 cm medial to the saphenous bundle 25,26.

Harvesting technique:

After the anesthesia, the hindlimb was prepped and draped. Skin was incised according to pre-operative drawing. Immediately under thin subcutaneous layer, the caudal border of gracilis muscle was identified (fig. 2). Dissection proceeded under direct visual control above and below the muscle. The muscle was freed from loose overlaying skin and the underlying muscles and the cutaneous branches or small perforators were cauterized. When direct vision became limited, the endoscope was inserted and the remaining of the harvest (dissection, vessels ligation, muscle release, pedicle dissection and section) was performed under magnified visual control on the monitor.

Once the superficial aspect of the gracilis was free, dissection proceeded to the muscle undersurface, from distal to proximal. The cephalic border near the saphenous bundles required careful dissection due to the minor pedicle and several perforators necessitating ligation. The remaining of this border was easily detached from the underlying muscles up to the muscle origin. While proceeding proximally with the dissection, the pedicle was noticed coursing on the muscle undersurface. The caudal border was released, from distal to proximal, leaving the muscle holding on the origin, insertion and pedicle.
With the pedicle held in between the long horns of Czerny retractor, straightforward dissection through the underlying muscles allowed adequate vessels length, up to the origins of the medial circumflex femoral artery and vein. The obturator nerve was identified slightly cranially to the vessels. Distally, the muscle was safely severed 2-3 mm proximal to the saphenous bundle. The muscle insertion was transected, taking care not to injure the pedicle in the uppermost area. Follow-up was managed for 8 muscles.

Results

Twenty-six gracilis muscle flaps (20 bilateral and 6 unilateral) were endoscopic-assisted harvested in 16 pigs, using single incision for muscle and pedicle dissection and muscle retrieval. Eight muscle flaps were followed-up for one week. Mean operating time was 118 minutes (range 75-210 minutes). Initial longer operating times decreased to almost one third over the last cases (table 1).

The operating times were fitted with a logarithmic curve to reveal the trend in general (fig. 3). The straight dotted lines are linear regressions of cases #1-10 and #11-26. The learning curve of operating time versus cases number revealed fast initial improvement that, however, gradually reached a “plateau”, as the individual experience accumulates. With constant practice, pedicle endoscopic-dissection time decreased from 45 to 10-15 minutes.

Intraoperative minor accidents occurred in the first 4 cases (injury of one vena comitans); however, all muscles were alive after 30 minutes observation. Muscles lengths ranged from 14/9 cm to 18/13 cm, vascular pedicle varied 2.5 – 5 cm with longer nerve, 4 – 7 cm (fig. 4).

First day after surgery, all animals resumed ambulation and feeding habits, minimal functional impairment was noticed for 1-2 days postoperatively. At 1 week follow-up, eight muscles were still viable with pulsating pedicles. However, 4 non-infected seromas at the donor site were observed (nota bene: no drainage used), with normal skin color.

There was no control group constituted for the comparison between the classical and endoscopic techniques. However, classical method operating times, retrospectively reviewed, showed a mean of
86 minutes (range 75-98 min). When compared to endoscopic-assisted method, classical harvesting exhibited significantly different operating times (p=0.001), but not different from the endoscopic “plateau” phase. (p=0.17).

**Discussions**

The aim of the present study was to establish a training model for endoscopic-assisted muscle harvesting.

For the swine gracilis, the rationale was not to accurately reproduce the technique used in humans, but merely develop a model for training. Operation was performed through single distal incision and dissection proceeded proximally, using the retractors to create the optical cavity. The pedicle was dissected under endoscopic control. The first author was the operator for all cases, to avoid biased results. He had no prior endoscopic surgery experience but received brief theoretical instruction on endoscopic surgery principles, techniques and instruments correct usage.

The overall learning process exhibited a biphasic mode, with the early phase (up to case #10) characterized by rapid learning of the required skill, that resulted in fast decrease in operating time; it is like “learning the ropes” phase. In the later phase (cases after #10), as the surgeon became skillful, the learning mode shifted to fine-tuning of operational details that resulted in smaller but steady decreases in operating time; with each case the surgeon is refining his approaches and skills; it is like “mastering the skill” or “perfecting the art” phase.

Expectedly, few variables appeared in the learning process. Each one of four assistants was randomly assigned to be a part of the team. Their background was not similar, two of them were residents in surgical specialties and the other two were medical students. For the first cases the operator held the endoscope and used dominant hand for dissection while the assistant was creating the optical cavity using retractors. Soon, as the team became more cohesive and familiar with the operation, the assistant took over the camera and the retraction leaving only the harvesting for the operator. Starting with the case #12, the self-mounted Emory-type retractor was used by the assistant. Variables did not impair the improving trend of the
learning process: operating times did not vary more than standard deviation with each case and the technical improvement did not affect the “plateau” phase. As the endoscopic facility was preexistent, endoscopic-assisted harvesting was performed with similar costs as traditional method.

The subcutaneous optical cavity (type 4 according to Eaves) differs from laparoscopy (virtual cavity), and arthroscopy or thoracoscopy (preexisting supporting structure); moreover, the rigid endoscope is poorly adapted to the body contours \(^{14,66}\). Dissection initiates the optical cavity and the continuous mechanical retraction maintains it while dissection proceeds, against diverse tissue requirements or constraints. These procedures need eye-hand, left hand-right hand and operator-assistant coordination to provide adequate retraction and tension for dissection. Therefore, type 4 optical cavity is more challenging and the assistant becomes a very important team member - “it takes two to tango”.

The aim of the study was not to compare the classic and endoscopic techniques; there was no control group constituted and, therefore, no complication rate comparison available. However, the almost 3-fold decrease in endoscopic operating time asked for a comparison. Retrospective classical operating times were reviewed and analyzed and classical vs. endoscopic operating times evaluated. With practice, the endoscopic-assisted harvesting became similar with classical method. In terms of Eaves criteria \(^{22}\), endoscopic-assisted gracilis muscle harvest provides shorter incision (fig. 5), similar operating times, success rates and costs.

**Conclusions**

Endoscopic-assisted harvesting of the swine gracilis muscle is a safe, reliable and cost-effective technique, comparable to classical harvesting method. It is a complex learning experience that combines rapid progress in skill with steady refinement of the skill. With practice, mastering the skill builds a cohesive operating team beyond technical constraints. Therefore, endoscopic-assisted harvesting of the swine gracilis muscle it is an excellent model to learn and practice the endoscopic techniques.
B. LATISSIMUS DORSI

Material and methods

A total of 30 pigs (mean weight 26.3 kg, range 20-34 kg) underwent endoscopic-assisted harvest of 39 LD muscles (18 bilateral and 21 unilateral).

Landmarks: with the pig on the side and the forelimb flexed cephalad, the skin fold on the posterior axillary’s line was marked as the muscle anterior border, caudally to the last ribs (fig. 6). The midpoint between the olecranon to scapular apex line is another landmark for the anterior border of the muscle. From this point, a line was drawn posteriorly, 0.5 cm caudal from scapular apex towards the midline – the LD cranial border. Slightly lateral from the midline, a line was marked over the lower 6 thoracic vertebras, and continued anteriorly, around the last ribs, meeting with the anterior border marking. Ten to twelve cm above the olecranon, the pedicle entry point to the muscle was marked. From the olecranon-apex midpoint, and 1 cm anteriorly, a 4-5 cm line marking the incision was drawn caudally.24-27

Harvesting technique:

After anesthesia administration, pig’s side and forelimb were prepped and draped. The skin was incised 4-5 cm and dissection proceeded through subcutaneous fat layer and panniculus carnosus. The anterior border of LD lies under the subpannicular thin layer of translucent fat.

From incision site, dissection proceeds in the usual open (classic) fashion (fig. 7), both above and under the muscle. Once direct vision became limited, the dissection the proceeds under endoscopic assistance, monitored carefully on the screen. Supramuscular dense attachments needed electric cautery dissection; beneath muscle, loose connections allowed easier and faster dissection. Small perforators and side-branches (to teres major and serratus) were cauterized or clipped.

Using Emory-type retractors, the apex of the scapula was visualized, slightly cranial to LD border. Systematic clockwise or anticlockwise dissection helped maintain the correct plane and
dissection of the LD, from under the trapezius and teres major and above the serratus muscle. Near the muscle vertebral border, the IAPs must be carefully cauterized or clipped to prevent bleeding; when bleeding occurred, dissection was resumed after 5 minutes gentle pressure and proper vessel hemoclips ligation. Irrigation-suction can also be useful for bleeding vessel identification.

After the LD dissection, the muscle origins were addressed. From underneath the muscle, using a hook-shape cautery, the vertebral aponeurosis of LD was cut. Caudally, the muscle was detached from the ribs, and the anterior margin liberated in a caudal to cranial direction from thin connections to the pectoralis muscles. If this sequence is not followed, the muscle will fall towards the spine, making the vertebral origin section a difficult task.

Muscle was delivered through the incision, still attached by pedicle and tendon (fig. 8,9). Adequate arc of rotation was provided by 2-3 cm open proximal mobilization of tendon and pedicle. The donor site was inspected for bleeding.

For the first 19 cases, the technique described reproduces the endoscopic-assisted harvest of LD to be used as a pedicled muscle (i.e. pedicled LD for breast reconstruction). For distinction with the subsequent cases, first 19 cases will be included in group 1 (table 2). Starting with case #20, for the next 20 cases (group 2), the LD muscle was harvested as a free flap. Muscle dissection was performed in a similar fashion and continued proximally. The forelimb was pulled cranially and upward and the submuscular plane cranial to the incision was visualized. Open dissection for 3-4 cm (limited by the incision direction) preceded the endoscopic dissection of the pedicle - artery, vein/paired veins and nerve. The pedicle was skeletonized up to the origin from the axillary vessels (fig. 10). The tendon was isolated from teres major tendon and cut.

Results

Thirty-nine LD muscles were harvested in 30 pigs, 18 bilateral and 21 unilateral (table 2). The first 2 cases were converted to open harvest due to uncontrollable bleeding from IAP (intercostals artery perforator) injury and were excluded from the study. The thirty-seven endoscopic-assisted LD muscles harvested were then
divided into 2 groups: group 1 LD muscles were harvested as pedicled flaps (n=17), and group 2 LD were harvested as free flaps (n=20).

Mean operating times were 149 minutes (range 125-181) for group 1 and 166 minutes (range 135-184) for group 2. The operating time between the 2 groups was significantly different (p<0.001).

The learning curves for the two different groups were compared: over the 37 consecutive cases or separately, with group 2 reset to start at case #1 (fig. 11). The correlation of operation time improvement with the number of cases performed is approximated by linear regression. For both groups, an improvement of operation time over the number of cases performed is noticed, and the correlation is monophasic.

With regard to the linear regressions, the predicted initial operating time of group 1 (i.e. value of y at x = 1, in this case 175.63 - 2.9583 = 172.6717) is shorter than that for group 2 (188.74-2.1654=186.5746). The slope for the curve of group 1 is slightly steeper than that of group 2 (-2.9583 vs. -2.1654), suggesting that the learning process of pedicled LD is faster than free flap LD. The pedicled LD consistently required shorter time to perform with each repetition of cases, is simpler than a free flap harvest (shorter initial time required in the first run) and easier to learn (faster rate of improvement).

Intraoperative complications occurred in the first cases: in group 1, due to the inadvertent injury of one comitant vein when inserting the retractor (2 cases); in group 2, one comitant vein injury during pedicle dissection (2 cases). The bleeding was controlled and injured vein clipped. The cases with VC injury were deliberately included in follow-up group.

First day postoperatively, all animals resumed ambulation and feeding habits, minimal functional impairment was noticed for 1-2 days postoperatively. Near the origin of LD muscle, small ecchymosis (2 cases) was noticed first day postoperatively that slightly enlarged for the next 2 days; however, when donor-site reopened at 1 week, there is no fresh bleeding at inspection and no hematomas (fig. 12).
In 5 cases, non-infected seromas were found and evacuated. All muscles were viable after 30 minutes observation and after 1 week follow-up. Muscles lengths ranged from 13/10 cm to 16/13 cm on the back table (fig. 13).

**Discussions**

The aim of this study was to evaluate the endoscopic-assisted LD harvesting model in swine. Two consecutive animal groups underwent the LD harvesting as pedicled and free flap, respectively. For all cases, each muscle was harvested through single skin incision of 4-5 cm, adequate to comfortably accommodate the instruments (endoscope, retractor, forceps and electrocautery/scissor) and to retrieve the muscle. As Lin et al. advocate, if muscle size is smaller than 20 cm, an additional incision is unnecessary. Adherent fibrofatty tissue overlaying the muscle is cut first, using electrocautery; if the undersurface is dissected first, muscle contraction during outersurface dissection would be too strong, increasing the chances for tissue injury. Anatomical and technical constraints need to be overcome for successful operation. Rigid endoscopic instruments accommodate poorly to the rigid and convex chest wall. Even if the instrument length is adequate for the optical cavity length, the straight instruments are not adapted to the three-dimensional cavity requirements. Increased difficulty is encountered in the areas most distant from the incision. For the first 2 cases, bleeding from intercostal artery perforators was ineffectively addressed, also due to inexperience in using irrigation-suction device; cases were converted to classic harvest and excluded from the study. For later cases, the use of long curved electrocautery achieved better hemostasis and a 30 degree angled scope assisted vision over the thorax convexity, where bleeding occurred. Systematic steps to free the muscle must be followed: vertebral aponeurosis, costal insertion and anterior margin; otherwise muscle mass retracted towards the spine will impair aponeurosis sectioning.
The longitudinal incision allowed access to distant sites, but limited the access proximal to the pedicle. Compared to humans, swine forelimb mobility is anatomically limited, with impossible access to the axilla without increasing the length of the incision (fig. 14). Therefore, to maintain the skin incision to the original size, group 2 underwent endoscopic dissection of the thoraco-dorsal pedicle and muscle tendon. This is different from reports in human where pedicle dissection and tendon release are performed under direct visual control.

The assistant is critical throughout the entire operation. The same operating team developed the gracilis endoscopic model, with the first author as operator and 4 assistants randomly taking turns, one for each case. Emory-type self-mounted retractor was single-handedly maneuvered. Forceful retraction was necessary, particularly near the muscle origin, due to thick inelastic thoracic skin that increased the tissue load on the retractor. The aponeurosis division allowed progressive retractor withdrawal as dissection advanced around the costal origin and the anterior margin, reducing assistant fatigue. When group 2 was initiated, assistant’s load increased, his free hand had to constantly adapt forelimb position, in abduction and cranial extension, opening the axilla virtual space and allowing endoscopic dissection of the pedicle and muscle tendon. Therefore surgeon-assistant, hand-eye and left to right hand coordination, learned during previous model training, were very helpful.

Group 2 differs from group 1 by the endoscopic dissection and section of pedicle and muscle tendon (free LD vs. pedicled LD). The performance in group 2 relies heavily on the experience accumulated during group 1 phase. For both groups, the correlation of operation time improvement to the number of cases performed is approximated by linear regression, and the process is rather monophasic. Conversely, learning process of previous swine gracilis endoscopic model had biphasic pattern, with a transition from technique familiarization to skill mastering phase. LD has no steep learning curve during the first cases: familiarization phase for LD endoscopic harvesting was achieved with previous model published (gracilis). The slightly steeper slope for group 1 shows that pedicled LD is faster, simpler and easier to learn than free flap LD.
Remarkably, group 2 maintain similar linear trend, in spite of increased difficulty and increased operating time.

Intraoperative accidents related to inadvertent injury of one comitant vein, in early cases from each group. For the first 2 cases, the pedicle position was disregarded when operator introduced the retractor; subsequent better visual control was assured. The last 2 cases represent injury of one comitant vein, due to inadequate evaluation of tissue elasticity. Team brainstorming pointed out the pitfalls leading to the vein injuries, and techniques introduced to prevent this. As a result, further vein injuries were avoided. One comitant vein proved sufficient for LD outflow, irrespective of proximal or distal level of comitant vein injury. Seromas were expected in the context of wide dissection and no drainage was used.

Our study was not conceived to compare the classic and endoscopic harvest in terms of technique superiority; several clinical reports address this issue competently and advocate the use of endoscopic harvest for LD for known advantages. Yet, the operating times improve with each case, comparable to operating times reported in clinical cases. Incision length is considerably shorter (fig. 14) and the results are good. The pre-existing endoscopic facility made the operation cost-effective.

Conclusions

Endoscopic-assisted harvesting of the swine LD muscle, as a pedicled or free flap, is a safe, reliable and cost-effective technique. Previous familiarization with endoscopic techniques makes the learning process faster. The cohesive operating team yields steady refinements of the operating skills, overcoming the technical and anatomical constraints. This endoscopic-assisted harvesting of the swine LD muscle model is an excellent learning model and will hopefully benefit future clinical practice.
C. RECTUS ABDOMINIS

Material and methods
A total of 16 female pigs (mean weight 30.6 kg, range 26-34 kg) underwent endoscopic-assisted harvest of 23 RA muscles (14 bilateral and 9 unilateral).

Landmarks:
With the pig supine and the hindlimbs free, rib margins and sternum cranially, pubic crest and symphysis caudally, and inguinal ligaments on the sides were marked (fig. 15). Slightly curved lines were drawn from 4-5 cm lateral to distal sternum to 3-4 cm lateral to public symphysis to underlie the rectus abdominis lateral margin. DIEA (deep inferior epigastric artery) arises from the external iliac artery, 2-3 cm lateral to muscle margin, identified by Doppler sound over the inguinal ligament.

Harvesting technique:
After anesthesia administration, pig’s ventral side from middle thorax to the knees was prepped and draped. Transverse incision is placed 4-5 cm from pubic symphysis, and spreads from midline laterally (fig. 16). Superficial epigastric artery runs through fat tissue and if it impedes over the operation, is ligated and sectioned. If abundant fat tissue makes the rectus sheath difficult to approach with tedious retraction needed, a block of 4/4 cm fat is excised. Through fat tissue the rectus sheath is identified and incised transversally over whole muscle width to reach the RA muscle. Cranial and caudal classic dissection of the superficial and deep aspect of the muscle was performed for 4-5 cm. Lateral from muscle sheath margin, pedicle was identified coursing from caudal and lateral and piercing the sheath before disappearing on the muscle undersurface.

Once the open vision limit was reached, the endoscopic tools were used for further dissection. Muscle fleshy areas were easy to be separated from rectus sheath. Conversely, the tendinous intersections are adherent to the rectus sheath and they were released only by electrodisection. One or two such tendinous structures were caudal to umbilicus and one just opposite to it. The later is strongly attached.
to the rectus sheath and at this level sheath injuries occur easily. Muscle dissection stops at the periumbilical tendinous intersection. Throughout the muscle superficial aspect dissection, several musculo-cutaneous branches piercing the rectus sheath were identified and carefully ligated or cauterized to prevent vessel retraction into muscle and continuous bleeding.

Lateral margin was detached easily from the sheath, taking care to ligate the segmental pedicles (fig. 17). Medial margin was more difficult to be released due to fibrous attachments to the sheath (fig. 18).

After superficial surface and both margins were release, Emory retractor was insetted under the muscle from medial border and dissection easily advanced up to periumbilical area. Muscle approach from under the lateral margin was avoided to prevent lesions to the vascular pedicle. With muscle completed liberated from the sheath, using the hook, the muscle fibers were progressively sectioned at the cranial dissection limit. Large vessels were carefully ligated before section. Using loupes magnification, pedicle was skeletonized up to the origin from external iliac artery and muscle is attached only through the pedicle (fig. 19). Muscle was retrieved through incision and placed on the abdomen skin and inspected (fig. 20).

**Results**

Twenty-three rectus abdominis muscles were endoscopic-assisted harvested in 16 pigs, 14 bilateral and 9 unilateral. Mean operating time was 173 minutes (ranges 144-196 minutes). An improvement of operation time over the number of cases performed is noticed, and the correlation is monophasic (fig. 21).

Intraoperatively, in 7 cases the rectus sheath was injured (over 1-1.5 cm) and repaired with 3/0 absorbable stitches. In 5 cases the peritoneum was inadvertently opened and repaired using same suture material. When muscle was sectioned at the periumbilical site, superior epigastric artery was injured (4 cases) but the bleeding was identified using irrigation-suction device, and controlled with hemoclips. During open dissection of the pedicle, one comitant vein was injured (in 3 cases) but the evolution of the flap was uneventful,
with complete muscle survival. All these accidents occurred in first cases. All muscles were viable at 30 minutes evaluation (Table 3).

First postoperative days all animals resumed mobilization and feeding habits. Ambulation was performed with slight difficulty only first day postoperatively. Starting day 3, animal #2 developed fevers and worse general status, and next day the animal was euthanized and diagnosed postmortem with peritonitis after open laparotomy; the RA muscle was viable at day 3. Seven animals were followed for one week and all rectus abdominis muscles were viable; no skin necrosis over the harvested RA muscle was noticed. One hematoma developed around the muscle; at endoscopic inspection no source for bleeding was identified.

**Discussion**

We decided to adapt strategy according to our experience and to the instruments used in previous endoscopic flaps and to try an original approach. Emory-type internal retractor helped developing the optical cavity. Transverse single incision was placed 4-5 cm cranial to pubic insertion of the muscle and was used for pedicle open dissection and for instruments access and muscle retrieval (fig. 16). Same incision was described as endoscopic access to repair other abdominal wall-related conditions, such as rectus diastasis. In our hands, triangulation principle, supplementary ports and insufflation seemed difficult to use as we had no prior laparoscopic experience; balloon or optical dissector was thought not to be cost-effective, as single-use devices for 16 pigs costs much more than Emory-type retractor that we used for 5 swine training models (gracilis, latissimus dorsi, RA, saphenous artery, subpectoral dissection).

As the team performing present study is the same with the one signing our previous reports, the cohesive operator-assistant team produced linear and constant positive learning curve and the slope was similar to LD and gracilis (after case #11). Once the techniques’ “secrets” learned during first cases of gracilis muscle endoscopic-assisted harvest, they were applied from the beginning in this new model, to yield constant results.
In swine, only half of the rectus muscle is viable on the inferior pedicle. Moreover, periumbilical and cranial to umbilicus, the tendinous insertions are adherent to the rectus sheath and attempts to release them leads to anterior sheath injury. Therefore, at periumbilical tendinous intersection the muscle was sectioned. Posterior rectus sheath was inadvertently injured in the first cases due rough handling of the tissues. All injuries in rectus sheath were repaired using 3/0 resorbable material.

For gracilis and RA, the inspection is more difficult to evaluate the complications, such as abdominal wall weakness, hematomas or seromas. In one case, the peritonitis was suspected due to general status worsening, rather than local examination; the diagnoses was confirmed by laparotomy and the animal was euthanized on day 3. Yet the muscle was viable before euthanasia.

**Conclusions**

The endoscopic harvest of RA muscle in swine is a safe and reliable technique and an excellent model for endoscopic surgery training. The previous experience expedited the learning curve, rushing into refining the skills phase without the need to learn the “secrets” of the endoscopic techniques again. This model effectively established the cohesiveness of the team achieved previously.
DISCUSSIONS

Muscle flaps are versatile tools in soft tissue reconstruction, tissue augmentation and cornerstone in restoring motor function. Traditional harvesting method involves long incisions, resulting in increased postoperative pain, wound-related problems, longer recovery, conspicuous scar and hypoesthesia. Patients’ satisfaction relates to overall reconstruction result and donor-site morbidity has downgrading feedbacks.\textsuperscript{3,4} New methods were designed to overcome the drawbacks of the traditional harvesting method.

Endoscopic plastic surgery is commonplace and promising field. Endoscopic-assisted muscle is a better alternative, provided following criteria are achieved: shorter incision and operative time, fewer complications, similar costs and successful rates. Smaller incisions effectively decrease postoperative pain, lower the wound-related morbidity and the recovery time, improve cosmesis and increase patient satisfaction.\textsuperscript{1,2,12,16}

Endoscopic technique has a steep learning curve. Moreover, endoscopic plastic surgery is technically challenging and learning opportunities are less common. New learning models are required for learning and training in order to achieve proficiency.\textsuperscript{14} In our experience, swine model is suitable for hands-on learning of surgical techniques, due to similarities to human anatomy and to the live tissue dissection conditions reproducing real operations.\textsuperscript{57,72}

**Aim of this study:** to develop, evaluate and standardize safe, reliable, easy to learn and practice models of endoscopic-assisted muscle harvesting.

The most used muscles in reconstructive surgery were chosen as models; they are also the most frequent muscle harvested by endoscopic techniques. Therefore they became or models to develop: gracilis, latissimus dorsi and rectus abdominis. For simplicity, single incision was chosen for dissection and muscle retrieval. Internal Emory retractor is a versatile tool, suitable for multi-planar approach therefore we adopted it for all models. Model sequence was chosen to address technical details from simple to complex. This allows team enough time to adapt and coordinate.
The triangulation principle is critical in laparoscopic surgery. Endoscopic aesthetic surgery (frontal forehead, facial lift, breast augmentation) does not use it. Moreover, these operations are performed using single incision and internal retraction. Therefore, decision was made to use the same principles from aesthetic endoscopic surgery, already proved effective, instead of laparoscopic approach with multiple ports and trocars.

Moreover, the laparoscopic triangulation principle is not lost, it was just modified:

1. Instead of using 3 different access incisions placed in horizontal plane, the triangulation in vertical plane was chosen, the entry point being the incision. When retractor is introduced and lifted, incision transversal shapes as a vertical triangle with the retractor as the superior tip. To reproduce the triangulation, the dissection instruments are introduced through the other triangle tips (incision margins).

2. The horizontal triangle is changed to a smaller vertical triangle, therefore the difficulty increases because of higher chance of instruments overcrowding or touching.

3. The effective working space is challenging: the internal triangle represented by endoscope, and the visible areas of the instruments is larger than the entry point (incision). But the coordination of fine movements with the large images on the screen must be learned within the team members.

Single incision was used for instruments access and muscle retrieval. Pedicle was dissected endoscopically (for G and LD) using instruments introduced through the same incision or by direct vision (for RA).

Hemostasis in endoscopic plastic surgery/muscle harvest is easier to be achieved due to the magnification of details provided by the camera and images transmitted on a large screen. Yet, in first two cases of LD harvest, unused to the suction-irrigation device, controlling the bleeding was ineffective, conversion to classic harvest was performed and cases removed from the study. Subsequent use was successful but the learning curve is needed. Emory retractor has attached suction canula for smoke evacuation, of small size and moving simultaneous with dissection endoscope, therefore clarifies
the operating area. Moreover, no extra hand is needed to maneuver the device, the assistant is doing it in the same time with the retraction and overcrowding of the incision site is avoided. Suction-irrigation device was used strictly for bleeding identification and exposure for easier cauterization.

Results evaluation: after muscle harvesting, muscle left attached to the animal by pedicle and/or tendons and observation underwent for 30 minutes. Fresh arterial bleeding from muscle’s distal areas showed the muscle viability. If follow-up was intended, muscle was repositioned and fixed to the surrounding tissues in safe position to avoid complications or impair muscle viability. After 7 days, under general anesthesia, the muscle viability was checked again and complications noted.

Criteria to follow when choosing an endoscopic operation versus a classic one were established by F. Eaves in 1994, as follows: smaller incision, shorter operating time, similar success rates, less or equal complication rates and cost-equivalency. Our results achieved all criteria mentioned:

- Scar length is similar to other reports in the literature. Single incision of 5-6 cm allows harvest of flap size up to 20 cm. Swine flaps harvested in this study have the size mentioned by Lin et al and were harvested through 5 cm incision;
- Endoscopic operations are longer than classic counterpart. Yet, in our gracilis model, similar operating times were noted. Even if the endoscopic phase takes longer, the wound closure time is shorter than classic incision closure and overall times are similar;
- The three models described are grafted with intraoperative complications limited to the first cases, early on the learning curve. The complications are kept to minimum and, when they occur, they are the inherent result of the lack of preventing methods such as suction drainage, very difficult to be applied in pigs;
- With regards to the success rate, and all muscles were viable at the end of the operation and at the end of one week follow-up;
Cost-efficiency is a difficult task to be addressed. In an era of cost-consciousness, balance must be kept between costs and benefits. In our study, the endoscopic cart and all instruments were graciously provided by the Pius Branzeu Centre therefore no investment was made to this regard. The only devise purchased was the Emory-type retractor. Therefore the strategy was adapted to use single retractor for all models, in fact two other models were establish thereafter (saphenous vein and subpectoral dissection) using the same device. Over one year time, more than 100 operations in swine were performed using this only retraction device, fact that testifies for the cost-efficiency of our project. Different dissection tools such as the balloon dissector have the disadvantage for us: single use and prohibitive price.\textsuperscript{16,18,60,73-75}

The models were established not taking into account the approach or exact sequence of operating steps as in human endoscopic harvest for counterpart muscles. In gracilis and in latissimus dorsi, the difference is essential, in human the pedicle is dissected under direct vision through the cranial incision and in swine model is dissected endoscopically. The choice was made to train the operator for the endoscopic pedicle dissection. In the same time, the team increases cohesiveness by increased demands of coordination between operator and assistant. That takes ten first cases from gracilis model to adapt and learn the endoscopic techniques as operator and as a team, too. The learning is even faster if we consider that the assistant was different with each operation. Information and skills acquired by the operator were rapidly passed to assistant, so when the assistant turned in the team, they adapt very fast to the new details and improvements.\textsuperscript{70,71}

Latissimus dorsi model, the free muscle endoscopic harvest, challenged the assistant even more. To get access to the pig’s axilla, the assistant must have right hand-left hand coordination. Single handed retractor in dominant hand must coordinate with non-dominant hand controlling the position of forelimb to allow best exposure for the operator to perform the dissection. Moreover, dissection planes alternate from above the muscle to under the muscle for combined dissection of pedicle and tendon.\textsuperscript{70,71}
For the rectus abdominis muscle, the operator’s task is slightly more difficult. The retraction is applied by the assistant only to the rectus sheath therefore all dissection to the muscle, dissection, muscle tension, rotation must be performed by the operator with minimal help from the assistant in this regard. The element of surprise can be the very different tissue consistency between the rectus attachments superiorly to the rectus sheath and deep to the posterior rectus sheath. The strongly adherent superficial surface of the muscle must be electro-dissected, careful at the tendinous intersection. Under the muscle, the filmy attachments are detached easily but retracting the muscle is more challenging.\textsuperscript{70,71}

Final analysis of the learning curves and slopes reveals different learning trend only in first cases of gracilis muscle harvest, with fast “learning the ropes” phase where the operator, with no prior endoscopic experience, is learning using the instruments and applying the theoretical knowledge into practice. The cases thereafter, the two groups of LD and the RA muscle have similar trend, showing that once learned, the techniques can be successfully applied to other operations. Even if the challenged targeted the assistant, as in free LD (group 2) or the operator in RA, the team is cohesive and can overcome all anatomical or technical changes.

Hopefully, the learning and training on these standardized endoscopic-assisted swine muscle harvest models will allow safer and easier translation of the endoscopic techniques in surgeon’s current practice.

**CONCLUSIONS**

The endoscopic-assisted models of the swine muscles harvesting is a safe, reliable and cost-effective technique. It is a complex learning experience that combines rapid learning progress with steady refinement of the skill. Beyond mastering the skills, the constant practice builds a cohesive operating team beyond technical or anatomical constraints.

Therefore, endoscopic-assisted harvesting of the swine gracilis, latissimus dorsi and rectus abdominis muscles are excellent standardized model for learning and training in endoscopic techniques.
Table 1: Endoscopic-assisted gracilis muscles harvesting in swine model.
Legend: L – left; R – right.

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Table 2: endoscopic-assisted LD muscles harvested.

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Table 3: endoscopic-assisted RA muscles harvested.

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38
Fig. 1: Gracilis muscle’s landmarks.

Fig. 2: Gracilis caudal border identified after incision.

Fig. 3: The learning curve of operating time versus cases number.
Fig. 4: Gracilis muscle harvested by endoscopic-assisted technique.

Fig. 5: Large incision for classical harvesting of gracilis.
Fig. 6: Swine LD muscle landmarks.

Fig. 7: LD caudal border identified after incision. “OPEN” marks classic dissection area.

Fig. 8: Pedicled LD delivered through incision. LD outer surface shown.
Fig. 9: Pedicled LD delivered through incision. LD undersurface shown.

Fig. 10: LD pedicle dissected. Endoscopic view.

Fig. 11: The learning curve of operating time versus cases number.
Fig. 12: Ecchymosis at 1 week after LD endoscopic-assisted harvest.

Fig. 13: Endoscopic-assisted harvested LD muscle free flap.

Fig. 14: Comparison between incisions of classic and endoscopic LD harvest.
Fig. 15: RA muscle drawn on the pig’s ventral side. Median access for RA harvest

Fig. 16: Small transverse incision for endoscopic-assisted harvest of RA. Rectus sheath is shown

Fig. 17: Lateral margin of the RA with secondary pedicle.
Fig. 18: Dissection of the RA medial margin from the rectus sheath.

Fig. 19: RA pedicle deep inferior epigastric artery (DIEP) skeletonized to the origin.

Fig. 20: Free endoscopic-assisted RA muscle harvested (on the back table).
Fig. 21: The learning curve of operating time versus cases number.

Fig. 22: Learning curves for three muscles endoscopic-assisted harvested in pigs, gracilis (G), pedicled (group 1) latissimus dorsi (LD) and free LD (group 2), and rectus abdominis (RA)
REFERENCES:


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