**INTRODUCTION**

The latissimus dorsi (LD) flap is a workhorse flap in the reconstructive armamentarium of plastic surgeons due to its versatility. It is an expendable muscle with large surface, wide arc of rotation and convenient pedicle size, making it the flap of choice in selected cases of soft tissue reconstruction, augmentation or in functional reconstruction. However, the traditional harvesting method leaves a long conspicuous scar that can become the patients' major complaint and downgrades the excellent reconstruction result. In contrast, endoscopic-assisted harvesting of LD results in shorter incisions that improves cosmesis and increases patient-satisfaction, while reducing postoperative discomfort and pain, minimizing wound care and allowing an earlier recovery.

Even though traditional harvest has a straightforward learning curve, the endoscopic-assisted harvest requires additional learning curve if similar results with less morbidity is to be provided. Therefore robust training models are required to learn and hone the endoscopic technique. The swine model of LD harvest is ideal for training because of its comparable anatomy to that of humans. It has previously been...
described using an open harvesting technique. Recently, a model for endoscopic-assisted muscle harvesting training was described in pigs. The aim of the present study is to assess the potential of the swine model of endoscopic-assisted LD harvesting. The muscle harvesting (as pedicled and free flap) parallels the technique used in humans. The learning curve, complications and results are evaluated and the value of this model as a training tool established.

MATERIAL AND METHODS

Prior to our study, detailed swine LD muscle anatomy was taught and classic (open) harvest of swine LD muscle was performed during flap dissection training courses and learning sessions conducted by the senior authors DP and MI. The first author had endoscopic experience limited to porcine gracilis muscle harvest.

Operative instruments

A standard endoscopic setup (similar to laparoscopic surgery cart) was used: light source, 10 mm and 5 mm, 30 degrees angle endoscope, video camera, high resolution video monitor and video recorder, irrigation-suction device. The usual instrument set for flap surgery and standard laparoscopic instruments (forceps, cautery, scissors and hemoclips) were also used. For the optical cavity development during endoscopic dissection, an Emory-type retractor was used.

Animal experiments

The protocols were approved by the Joint Committee for Animal Research and Animal Care and Ethic Committee of Pius Brâneu Center in Timisoara and Center for Simulation and Training in Surgery in Iasi. Animals were housed and treated in compliance with the “Guide for the Care and Use of Laboratory Animals”, published by the National Academy Press (US NIH 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 preoperatively.

Pig’s sedation was achieved with ketamine (10-15 mg/kg) and midazolam (0.5 mg/kg) or diazepam (2 mg/kg); they were intubated after intravenous infusion of thiopental (5-10 mg/kg). Anesthesia was maintained with halothane 1-2% mixed with oxygen 2-4L/min. Isotonic solutions were perfused 5-10 ml/kg/h. 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).

Operating room setup

The pigs were positioned in lateral decubitus with forelimb free. The operator stood facing the animal's ventral side, with the assistant beside him; the later handled the self-mounted Emory-type retractor and pulled pig’s forelimb cranially and outward to expose the pedicle. The video monitor was placed at the opposite side of the operating table for both operator and assistant to see the endoscopic images.

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. 1) 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 vertebrae, 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.

The anatomy of swine LD muscle

The LD is a fan-shaped muscle on the pig’s side, arising from the lower 4 ribs and through an aponeurosis from lower 6 thoracic vertebras and inserting on the humerus (through a common tendon with teres major). (Fig. 1) The anterior border of the muscle can be identified on the posterior axillary fold, at the midpoint between olecranon and the scapular apex. From this point to the spine, coursing just under the apex, is the LD cranial border; same point united with spine landmark (upper 1/3 with lower 2/3 of spine) shows the LD muscle midline. On its cranial-dorsal area, the LD is deep to the trapezius and overlies serratus ventralis thoracis muscle. The anterior
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. (Figs. 3, 4) Adequate arc of rotation was provided by 2-3 cm open proximal mobilization of tendon and pedicle. The donor site was inspected for bleeding. Muscle was replaced, bleeding and muscle viability checked again 30 minutes later, donor site closed using 3/0 absorbable stitches and pigs were returned to animal facility (if follow-up intended) or euthanized.

**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, both above and under the muscle. (Fig. 2) 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.

![Figure 2. LD caudal border identified after incision. “OPEN” marks classic dissection area.](image)

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.

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![Figure 3. Pedicled LD delivered through incision. LD outer surface shown.](image)

![Figure 4. Pedicled LD delivered through incision. LD undersurface shown.](image)
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 1)

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

<table>
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<tr>
<th>Pig no.</th>
<th>Weight (kg)</th>
<th>Case no.</th>
<th>Side</th>
<th>Operating time (min)</th>
<th>Intraoperative complication</th>
<th>Follow-up</th>
<th>Complications</th>
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**Table 1.** Endoscopic-assisted LD muscles harvested.

<table>
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<th>Pig no.</th>
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<th>Case no.</th>
<th>Side</th>
<th>Operating time (min)</th>
<th>Intraoperative complication</th>
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**Legend:** IAP: intercostals artery perforator, VC: vena comitans, R: right, L: left
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. 5) The tendon was isolated from teres major tendon and cut. Half an hour later, the muscle was inspected for viability. For one week follow-up, LD was sutured to the serratus fascia in a position to prevent pedicle kinking, compression or torsion. After checking the donor site for bleeding, the incision was closed by separate absorbable 3/0 stitches. Pigs were returned to animal facility. If no follow-up intended, pedicle was clipped near its origin and cut, the muscle was delivered through the incision and measured. Donor site was inspected for bleeding, closed with absorbable stitches and pigs were euthanized.

Operating times were recorded from incision to skin closure but the 30 minutes observation time was not included. Complications and muscle anthropometric measurements were documented. Neither drains nor dressings were used; antibiotics and analgesics were administered for 3 days.

**Follow-up**

Vital signs, complications, ambulation and feeding habits were inspected on a daily bases. 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 operating times between the groups 1 and 2. P<0.05 shows statistically different values.

**RESULTS**

**Endoscopic-assisted harvest**

Thirty-nine LD muscles were harvested in 30 pigs, 18 bilateral and 21 unilateral. (Table 1) The first two 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 (Fig. 6a) or separately, with group 2 reset to start at case #1 (Fig. 6b). 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 (two 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 (two 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. 7)

In five 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. 8)

**DISCUSSION**

The LD is a workhorse for selected reconstructive surgeries due to its versatility. It is successfully used, either as a pedicled or free flap, in breast, chest wall, spinal, head and neck, lower limb reconstruction and scalp resurfacing. Large incisions make the muscle harvesting straightforward but leaves conspicuous scars, decreasing patient satisfaction in the face of otherwise excellent reconstructive results.1-7

Since the early ‘90s, endoscopic-assisted harvesting of LD muscle achieved shorter incisions with less postoperative discomfort or pain, earlier recovery from surgery and less expensive wound care; edema, ecchymosis, seromas and infection rates were not decreased in all studies.8-30 The advantages have encouraged surgeons to use the endoscopic method but the reports are still scarce and have not gained the same popularity within plastic surgery as it has in other surgical specialties. The main hurdle is the additional learning curve for endoscopic techniques; training models and fewer opportunities when compared to laparoscopy or arthroscopy.31,32

The swine model of muscle myocutaneous LD was described initially as an excellent model for research in physiological, pathological and pharmacological experiments. Later the similarities to human anatomy, favorable position (quickly and easily elevated) and large, accessible vascular pedicle made it an excellent model for training of the surgical skills. This too has been our experience.31-37

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.17 As Lin et al. advocate, if muscle size is smaller than 20 cm, an additional incision is unnecessary.17 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.12 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.40,41 For the first two 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. 9) 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 humans, 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 four 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. (Fig. 6) 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 two cases, the pedicle position was disregarded when operator introduced the retractor; subsequent better visual control was assured. The last two 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.

With regard to the ecchymosis occurring in two cases, no cause-effect could be established: no accompanying seromas or hematomas were noted and the comitant vein injury was non-contributory. The initial ecchymosis appeared over the severed IAP and spread as intercostal artery angiosome-type pattern. Maximum intensity, along with small area of skin necrosis, overlay the IAP. Porcine fixed-skin has rudimentary panniculus carnosus and cutaneous vascularization is tributary to the fasciocutaneous perforators. Therefore, we suspect the ecchymosis occurrence tributary to skin vascularization pattern rather than a complication or technical error. 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 and the results are good. (Fig. 10) 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.

REFERENCES