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The reverse latissimus dorsi flap: An anatomical study and retrospective analysis of its clinical application

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Summary The segmental paraspinous and intercostal blood vessels form the blood supply and represent the pivot point for the reverse latissimus dorsi flap.
Aim of this study was to confirm the exact location of the blood supply and the most caudal pivot point to assess the suitability of the reverse latissimus dorsi flap for pedicled reconstructions of the trunk as well as sacral area.
Our study comprised a human cadaver study, where 30 latissimus dorsi flaps were assessed in 15 specimens, and a clinical study with 49 patients who underwent distally based latissimus dorsi flap reconstructions in our division.
74% of all perforators were located in a bilateral 7 cm broad area, which spread from the 6th intercostal space to the subcostal plane. In a second clinical part of this study we evaluated forty-nine patients, who underwent reconstruction with the reverse latissimus dorsi flap. We demonstrated that the pivot point can also be planned below the 12th rib, thus reaching tissue defects in the sacral area. To the best of our knowledge, this is the first study to define a caudal "hotspot" for the safest blood supply of the reverse latissimus dorsi flap.

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Introduction

Wounds of the chest wall and spine-region often represent a challenge to the reconstructive surgeon. These chest wall and spine-region tissue defects frequently result from preceding surgical procedures and are often chronic and contaminated, narrowing the reconstructive options.[1,2] The latissimus dorsi flap (LDF) is reliable and applicable for thoracic wall defects as well as for multiple other indications such as a pedicled or free flap.[1,3-5] It is well suited for defects in the upper portion of the thoracic wall and spine-region, pedicled on its primary, dominant thoracodorsal vessels. There are also several studies on reverse LDF reconstructions, based on the secondary segmental paraspinous and intercostal blood supply to the latissimus dorsi muscle (LDM).[4,6] Available studies reveal that this secondary blood supply of the LDM is consistent.[7] However, anatomical studies of this secondary blood supply disagree on the exact anatomical location of the segmental paraspinous and intercostal blood vessels, which form the secondary blood supply. Due to this partly controversial data, the exact location of the safest blood supply for the reverse LDF, and therefore valuable information on the arc of rotation remains undefined. How far caudally the pedicle for the reverse LDF can be chosen from in order to also reach tissue defects in the sacral area remains unclear.

The Thiel's human corps conservation technique, a special soft- fix embalming, is considered a well-established method for perforator vessel studies, as it allows the examination of perforators with a diameter of 0,1 mm. It results in seemingly natural cadavers, with true to life appearance of anatomical structures. For this technique, the vessels are injected with a mixture of latex, dextrin and lead tetroxide.[8]

Aim of this study was to evaluate the distally based blood supply of the LDM, regarding number, anatomical location and diameter of perforating paraspinous and intercostal vessels, by performing an anatomical study on human cadavers. Our analysis focused on the consistency and frequency of the most inferior perforator vessels to the LDM, in order to identify the location which marks the lowest possible pivot point. This allows the reverse LDF to also be used for tissue defects in the sacral area. To illustrate the clinical applicability and range of motion of the reverse LDF, we also report 49 patients having undergone distally based LDF reconstructive surgery.

Materials and methods

Part A - anatomical study

At the Institute of Anatomy, Medical University of Graz, 30 LDMs in 15 human cadavers, which were preserved according to Thiel's technique,[9,10] were analyzed. First, the LDMś origin was dissected at the thoracolumbar fascia, the LDM was then elevated and the plane anterior to the muscle was entered. The muscle was mobilized in a lateral direction and the perforating doral and lateral banches of the posterior intercostal artery were identified.

The number of perforators per LDM, the intercostal space at which the vessel pierced the fascia to reach the plane directly anterior to the LDM, the distance of this point from the midline, and arterial diameter were examined respectively.

All necessary computations were done within R 3.4.0.[11] Furthermore, loglinear statistical models were fitted to study the dependence of the mean number of perforators on the side and the location effect as also on its interaction. Based on the coefficients simultaneous one-sided tests with a 95% confidence range for general linear hypotheses were performed.[12] No missing observations were in the data.

Part B - retrospective study

The study protocol for both parts of the study was reviewed and approved by the local ethics committee, and patient data collection was then conducted.

Inclusion criteria consisted of: male and female patients aged from 18 to 90, who underwent reverse LDF reconstructive surgery, using the whole LDM or parts of the muscle as a reverse LDF, for various indications during 1987 and 2017 at the Division of Plastic, Aesthetic and Reconstructive Surgery, Medical University of Graz. Patient records were retrospectively reviewed. For descriptive statistics, data are expressed as median (interquartile range), mean $\pm$ standard deviation, or minimum and maximum for continuous variables and percent for categorical variables.

Preoperative flap planning mainly depends on the location of the defect. If the pivot point is below the tenth rib, imaging methods should be used to locate proper perforators. In cases where the pivot point is more cephalad, the anatomy of the perforators is considered safe enough to be sure to find appropriate perforators during dissection. If imaging methods are used, angio-CT is preferred over Doppler ultrasound, as especially in athletic individuals with strong muscles ultrasound in many instances fails to give reliable information on vascular anatomy of the submuscular plane.

After debridement of the defect, flap dissection starts with exposure of the dorsal surface of the latissimus dorsi. The muscle is divided at its tendinous insertion to the humerus. The main pedicle is dissected and ligated. Although never used in this series, the authors consider it safe to preserve a few centimetres of the thoracodorsal vessels in order to have the chance for a backup-anastomosis at the recipient area in case of flap ischemia. A deepithelialized skin-island can be raised with the flap if some volume is needed for instance to obliterate dead space.

The muscle is then raised from proximal to distal until the defect can be covered. As the submuscular layer consists of loose gliding tissue, perforators are easily identified. Depending on the location of the defect, the muscle can either be shifted or rotated into the defect or used as a turn over-flap. More distally, the submuscular plane develops into a narrower space with less gliding tissue and the perforators tend to be shorter. The further caudal flaps are based, shifting or rotating of the flap can be difficult. After the flap has been transferred to the defect, haemostasis is achieved and the donor site is closed over suction drains.

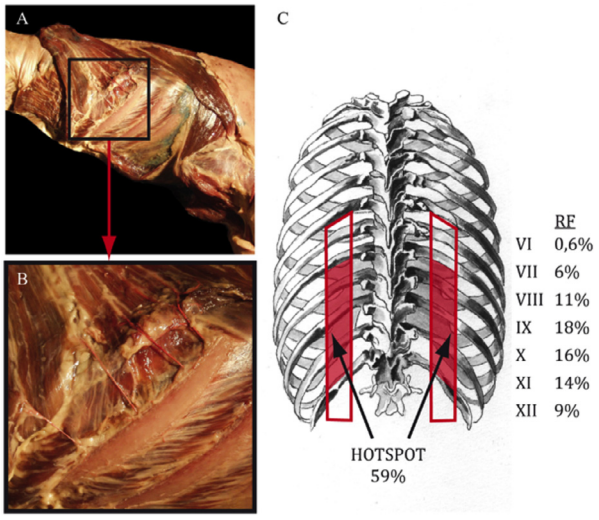

Figure 1 A+B: Latex injected perforators. C: Perforator "hotspot" and relative frequency for perforators in the different ICS. (illustration by Johanna Manz).

Results

Anatomical study (Part A)

All for this study available specimen were dissected. No specimen was excluded.

The dissection of 30 muscles revealed an average of 10.9 (min. 4; max. 17) perforating vessels per muscle, regardless of the vessels' diameter. An accumulation of vessels in the 9th, 10th and 11th intercostal space (ICS) was evident in every specimen. 62% of all perforators were found in these three ICSs. In an area arranged in a strip between 5 and 12 cm bilateral from the midline (line through the spinous processes) 74% of all perforators were located.

The "hotspot" was on this strip over the 8th, 9th and 10th and 11th ICS. In this bilateral 7 cm wide spot the relative frequency for finding a perforator was 59%. Figure 1 shows latex preserved and injected specimen according to Thiel's technique and the perforator's "hotspot" as well as the relative frequency (RF) in this area to find a perforator.

An average of five perforators (min. 1, max. 10) per specimen was found caudal to the 10th rib accounting for 48% of all perforators regardless of their location. All specimens showed at least one perforator caudal the 10th rib. 32% of these distal perforators were found within 7 cm from the midline. In 26/30 LDMs a perforator was evident in the 10th, in 25/30 LDM a perforator was seen in the 11th intercostal space and in 16/30 a perforator was found below the 12th rib (u12). The perforator vessel's diameter mean was 0.99 mm (min 0.61, max. 1.59), of all perforator vessels $>$ 0.6 mm diameter.

In order to make statistical inference on the number of perforators, we assume that the counts follow a Poisson distribution and that their means are sufficiently described by a log-linear model.

Since the side of the body is shown to be irrelevant, the mean counts only depend on their ICS ($p < 0.001$). The dots in Figure 2 relate to estimates of the differences between the mean counts observed on ICS 9 and on the six remainder ones. Also shown are the associated one-sided confidence intervals for these six differences with simultaneous confidence level 95%. Significant differences are those where their respective confidence intervals are not covering the value zero. Thus, we conclude that the mean numbers of perforators on ICS 6, 7 and u12 were significantly smaller than the number on ICS 9, but the others were not.

Table 1 Patients' characteristics.

General information		
Number of patients		49
Male patients		33
Female patients		16
Averange age (in years)		57
Number of major complications		3
Number of minor complications		6
Complications		n
Recurrence of empyema		1
Phlegmon		1
Wound infection		1
Partial flap necrosis		1
Post-pneumoectomy empyema		4
Insufficient broncial stumps		2
Addtional free flap		5
Addtional arm defect (useage of combined free flap)		1
Wound dehiscences		6
Postoperative bleeding		4
Follow up		
Condition	Time	n
Alive	40 months	36
Death (metastatic spread)	5–7 months	2
Death (septicemia)	3 days	1
Death (unrelated cause)		10
Area of defect		n
Thoracic wall		43
Spine-region		5
Pelvic area		1
Indications		n
Full thickness defect of the thoracic wall		43
Defects or infected wounds over the spine-region		4
Lumbar liquor leakage after spine surgery		1
Defect after resection of a chordoma in the pelvic area		1

Clinical study (Part B)

Forty-nine patients, who underwent reconstructive surgery using the reverse LDF at the department of plastic surgery of the Medical University Hospital of Graz between 1987 and 2017, were included in the study. Patients' information are summarized in Table 1.

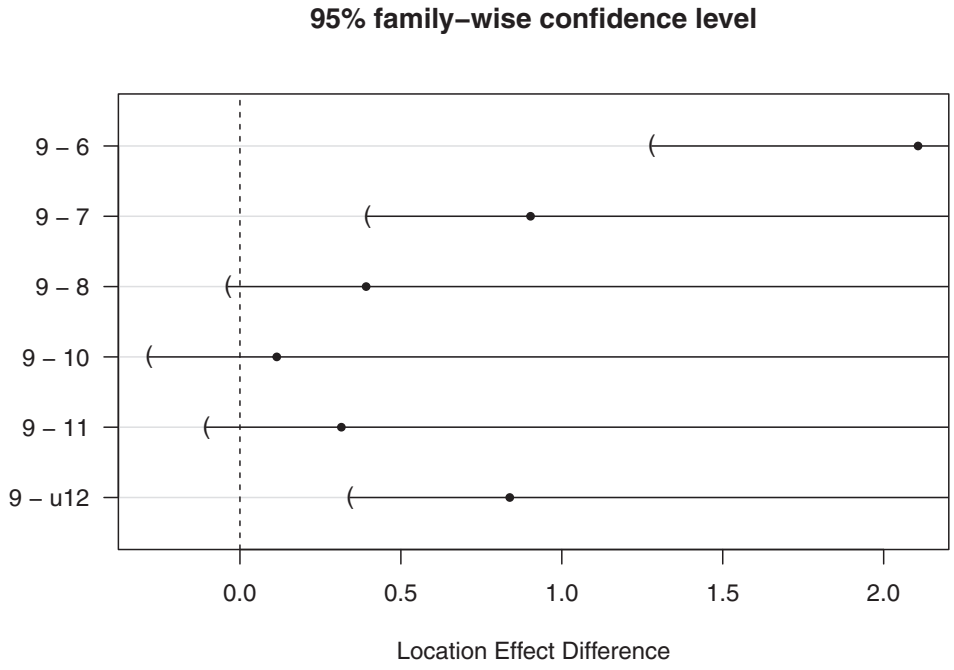

Figure 2 This figure shows 6 one-sided confidence intervals (open to the right) corresponding to the 6 location effect differences with *simultaneous confidence level* equal to 95% (family-wise confidence level). It can be seen that besides an overlapping of the two confidence intervals for the differences between ICS9 and ICS8 as also between ICS9 and ICS11, only ICS10 is a location with a minor overlap of a zero difference. The estimated differences are shown as dots in this figure. Therefore, we do have some statistical evidence that ICS9 is the hotspot and is the location hosting the maximum number of perforators.

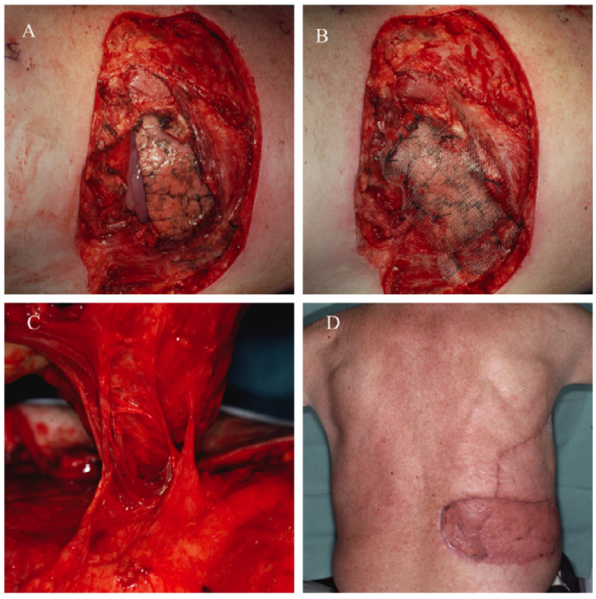

Figure 3 A: After radical resection of a malignant tumor of the perineural sheath (18 × 9 cm). B: Coverage with a non-resorbable mesh to restore skeletal stability. C: Closure with reverse latissimus dorsi flap. D: After complete wound healing.

Free flaps had to be used additionally in five cases. In four cases, a post-pneumonectomy empyema cavity was not considered clean enough to close the wound without obliteration of dead space; in two of these cases, there were insufficient bronchial stumps that had to be closed with muscle. In one case an additional defect on the arm had to be covered and a combined contralateral free LD – scapular flap on the same pedicle was chosen to cover the thoracic wall and the upper arm defects simultaneously.

Case reports

Case 1 (Figure 3)

An 88-year-old patient was referred to our department after the resection of an alleged lipoma in the right flank. The histopathologic evaluation of the specimen revealed a malignant tumor of the perineural sheath with incomplete resection. After radical resection with histopathologically proven free margins, a defect of the most distal part of the dorsolateral aspect of the thoracic wall measuring 18 × 9 cm resulted. Skeletal stability was restored using non-resorbable mesh. The soft tissue defect was closed with a reverse LDF that was covered with skin grafts. The postoperative course was uneventful.

Case 2 (Figure 4)

A 75-year-old male underwent partial resection of the rectum, subtotal resection of the sacrum and resection of the coccyx due to a chordoma. Before the surgical procedures, the internal iliac arteries had been embolized. In the first surgical step, a partial resection of the rectum with the

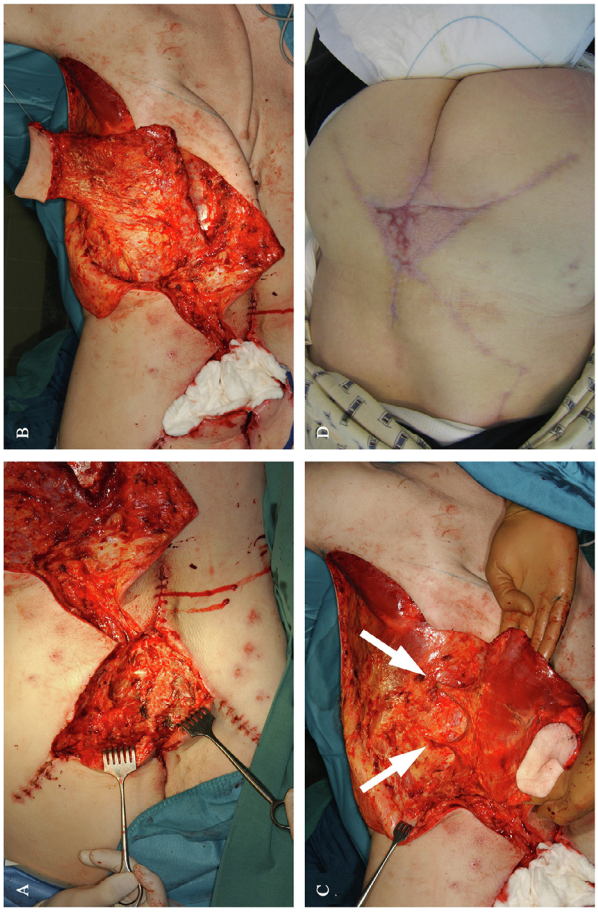

Figure 4 A: After the partial resection of the rectum, resection of the sacrum and resection of the coccyx due to a chordoma. The cavity reaches from the former sacrum well into the pelvis down to the pelvic floor. B: Reverse latissimus dorsi flap was elevated with a skin island. C: LATISSIMUS dorsi flap is turned over, the 2 arrows indicate the 2 perforators. D: After complete wound healing.

creation of a preternatural anus was done via an anterior approach. In the same operation, the internal iliac vessels were ligated. The distal stump of the rectum was covered with the muscles of the pelvic floor. In the second surgical step, performed a few days later, the sacrum was resected distally from its first segment. The skin was opened and closed in a star-shaped fashion. Postoperatively, a necrosis of the flap-tips with underlying infection developed. After debridement, a cavity reaching from the former sacrum well into the pelvis down to the pelvic floor resulted. A reverse LDF was elevated with a skin island. The skin island was deepithelialized and together with the muscle used as filling tissue for the large cavity. The flap survived completely and the wound eventually healed.

Discussion

Our anatomical study shows that the LDM has a rich blood supply in addition to its dominant thoracodorsal vessels, which concurs with the current existing literature.[13,14] The claims regarding the anatomy of the secondary blood supply of the LDM, however, create a dispersed image. McGraw et al.[15] describe an accumulation of vessels at the levels of the 7th, 9th and 11th thoracic vertebrae with a distance from the midline of approximately 8 cm. Based on the clinical experience with more than 225 LDF and 20 cadaver dissections Bostwick et al.[16] describe the presence of paraspinous perforators of the lowest seven intercostal arteries and the dorsal branches of the four lumbar arteries approximately 4 cm from the midline. Stevenson et al.[17] published a cadaver study with the results of the dissection of eleven muscles. The authors report three large perforating vessels in the 9th, 10th and 11th intercostal space piercing the lumbar fascia about 4 to 5 cm from the midline. Beer et al.[5,13] reported in two different studies, one with special emphasis on muscular branches and the other on musculocutaneous perforators, about perforators in the 9th, 10th and 11th intercostal spaces 11(medial branches) to 13 cm(lateral branches) from the dorsal midline.

In our investigation, 74% of all perforators are located in a bilateral 7 cm broad stripe, which spread proximal-to-distal from the 6th ICS to the subcostal plane. Sizeable blood vessels were evident below the 10th rib in every specimen. Thus, our anatomical study suggests that the anatomical prerequisites for the use of the LDF for defects situated far caudally are fulfilled. Moreover, we demonstrated that perforating vessels appear significantly more often in the 9th ICS than in the 6th, 7th, 12th ICS, respectively ($p < 0.001$). Thus, the pivot point can be planned in the 9th ICS with the most consistent blood supply. However, if the flap is needed for a tissue defect located in the sacral area, the pivot point can also be placed below the 12th ICS. In this case, however, the possibility of less perforators must be accounted for.

There are several methods for the reconstruction of chest wall defects including secondary healing after open window thoracostomy, defect closure with flaps or a combination with metallic prostheses or methacrylate.[18,19] Large chest wall defects can be covered by a variety of anatomically secure flaps. These flaps include pedicled flaps from the thoracic wall itself such as the LDF, the serratus anterior flap, or the pectoralis major flap. Pedicled flaps harvested from the abdomen such as the different variants of the rectus abdominis or omental flaps have also been routinely used in thoracic wall reconstruction.[18] Undoubtedly, microvascular free flaps are also used in reconstruction of the thoracic wall, but usually reserved for larger defects.

The method of choice for a specific defect depends on several factors. These involve patient-related factors such as nature and location of the defect and the patient's general condition.[20] Furthermore, flap-associated factors influence the choice of reconstructive method. Severe additional donor site morbidity should be avoided and the selected technique should not preclude future options for surgical procedures. Evidently, the morbidity of preceding surgical interventions also impacts the executed reconstructive method.

Since the 1980s Arnold et al. reported using the serratus anterior flap extensively for intrathoracic and extrathoracic reconstruction.[21] As the distal part of the muscle is often sacrificed when an open window thoracostomy is performed in the posterolateral aspect of the thoracic wall,

only the proximal part of the muscle is available for reconstruction. This portion could be used for moderate sized defects, but does not suffice for a complete open window thoracostomy or a large defect after tumor resection or trauma. If the proximal part of the serratus anterior is used in reconstruction, it must be completely dissected from its scapular attachment; this can often lead to winging of the scapula[21] and subsequently to significant impairment of shoulder function, pain and cosmetic deformity of the shoulder girdle.[22] Since the LDM is already divided, henceforth losing its function, the use of its proximal segment holds the advantage of averting additional donor site morbidity.

The pedicled pectoralis major flap is routinely used in thoracic wall reconstruction. It is very well suited to close small to moderate sized defects of the anterior thoracic wall, especially around the sternum.[23] Large defects and defects on the lateral or posterolateral aspect of the thorax, however, are often not covered completely with this flap. Furthermore, there is donor site morbidity after the elevation of this flap as a consequence of daily activities and isolated muscle testing. Nevertheless, this might be associated with the loss of sternal stability after sternotomy rather than the loss of muscle function.[24]

The various flaps based on the rectus abdominis muscle can be utilized for large defects of the thoracic wall as pedicled or free flaps.[25] The pedicled rectus abdominis flap is anatomically secure even after the internal mammary artery has been severed.[26] It provides large amounts of well-vascularized tissue and the lateral and posterolateral portion of the thorax can be accessed easily.[1] This flap does, however, encompass important disadvantages. Bulging of the abdominal wall and abdominal hernias often occur after the rectus abdominis muscle has been harvested.[27] Additionally, the duration of surgery increases when the patient must be repositioned to cover posterolateral chest defects. Moreover, a second large wound is created, consequently resulting in greater stress to patients with baseline suboptimal health.

The omentum as a flap harvested from the peritoneal cavity is routinely used for thoracic wall and intrathoracic reconstruction. It is suitable for the obliteration of dead spaces and infection control. In the series of 60 cases reported by Hultman et al., however, abdominal wound infections occurred in 10% and epigastric hernias in 11.7%.[28] Accordingly, significant donor site morbidity exists with this flap, particularly with laparotomy. Of note, some surgeons harvest the flap laparoscopically, possibly decreasing abdominal site morbidities.[29] However, these factors ultimately further stress these often critically ill patients.

Finally, free flaps are a useful option in the reconstruction of the thoracic wall, especially in large defects.[30,31] Nevertheless, microsurgical procedures are lengthier than pedicled flaps and carry significant risk of complications secondary to microsurgical anastomoses. Therefore, in comparison to the variety of pedicled flaps suitable for thoracic wall reconstruction even in large defects, free flaps are reserved for select cases that require a large amount of tissue that would be inadequately supplied by pedicled flaps alone, e.g. with a postpneumonectomy empyema cavity that has to be obliterated or an insufficient bronchial stump.

Conclusion

In conclusion, the LDM offers significant advantages in the closure of large defects located on the lateral and posterolateral chest wall. Our results confirm that based on the vascular anatomy, both the proximal and distal parts of the muscle can be used safely for reconstruction of the chest wall. No additional functional donor site morbidity is created when it is employed in thoracic wall reconstruction after thoracotomy and no intraoperative repositioning is necessary.

Furthermore, one of our clinical cases demonstrates that the pivot point can be placed below the 12th rib in order to cover tissue defects in the sacral area. Moreover, to the best of our knowledge, we are the first group to define a "hotspot" for the safest blood supply of the rLDF as the 7 cm broad area over the 8th, 9th and 10th and 11th ICS.

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Conflict of interest

None of the authors has a financialor or personal interest in any of the products, devices, or drugs mentioned in this manuscript.

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