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Topographical landmarks for lateral calcaneal artery sensate flap- A cadaveric study

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ABSTRACT

Background : The lateral calcaneal artery (LCA) flap is used for treating skin defects of the foot. We aim to study the relationship between the LCA and the Sural Nerve (SN) with the lateral malleolus (LM) to delineate the topographical landmarks for identifying LCA and SN while designing the LCA flap.

Materials and Methods : The foot was dissected to identify LCA and SN in 32 formalin-fixed lower limbs. The LCA and SN were identified and separated from the superficial fascia of the foot. Measurements such as the distance between the LCA and LM, SN and LM, and LCA and SN were taken in (a) horizontal plane, (b) 45º oblique plane passing, (c) vertical plane from the most prominent point on LM, including the luminal diameter of LCA.

Results : In the horizontal plane, the LCA and SN were present at a mean distance of 24.56±5.2 mm and 22.64±6.26 mm from the LM, respectively. In a 45° oblique plane, LCA and SN were present at a mean distance of 29.10±6.12 mm and 22.68±7.05 mm from the LM, respectively. In the vertical plane, the SN was present at a mean distance of 26.59± 8.87 mm from the LM.

Conclusion : LCA was present in the horizontal plane and 45^{o} oblique plane and was absent in the vertical plane in relation to LM; hence, the LCA flap should not extend beyond the 45^{o} oblique plane, and the internal diameter of LCA should not be less than 1.02mm.

1. Introduction

India is at the top of the global map in diabetes, with 72 million cases and a prevalence of 7.3%.[1] The lifetime risk of a diabetic patient for foot ulcer is as high as 25%, with an annual incidence of 4-10%.[2] The surgical options are free flap surgery for covering defects, foot orthoses, and advanced revascularisation techniques for limb salvage.[3,4] The flap surgeries for diabetic foot ulcers include a local, pedicled, and free flap.[5] Diabetic foot ulcers and soft tissue defects of the hindfoot are difficult to heal. Poor healing in the hindfoot region is attributed to various factors, such as the frequent mobility of the ankle joint, bony and tendinous bed, and poor vascularisation.[6] Such defects must be closed by skin flaps containing expendable arteries with a large lumen and minimal donor site morbidity.[7] Tissue defects should always be replaced with like tissue. Hence, the lateral calcaneal artery (LCA) flap is better suited to replace the hindfoot defects.[8] The LCA arises as a branch of the fibular artery (FA) at about 6cm above the tip of the lateral

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malleolus (LM) and then courses downwards, forwards, posterior and inferior to the tip of LM along with the sural nerve (SN) and short saphenous vein towards the base of the fifth metatarsal bone. The LCA is among the last arteries affected by age, diabetes mellitus, or peripheral vascular disease. The LCA flap is an axial pattern flap consisting of LCA, a short saphenous vein, and SN and is used in treating hindfoot defects[6]. The LCA flap carries the advantage of covering the posterior heel defects with minimal donor site deformity.[9] However, an incorrect flap incision may result in injury to the LCA, along with the SN[10]. The LCA arising from the FA is less frequently affected by atherosclerosis than the LCA arising from the posterior tibial artery (PTA). Hence, the source of LCA should be assessed by the Doppler study preoperatively.[10] The SN is formed by the union of the medial sural cutaneous nerve (MSCN) and lateral sural cutaneous nerve (LSCN) from the tibial and fibular nerves, respectively. The SN is at risk of injury during the posterolateral approach to treat the posterior malleolar fracture, intraarticular fracture of the calcaneus and the medial displacement calcaneal osteotomy for the flat foot. The SN is also at risk of injury during the repair of the Achilles tendon (AT) by tendinoscopy or by a percutaneous repair device called Achillon device because of its close relation to the lateral border of AT.[11] Injury to SN may result in postoperative anaesthesia along the lateral aspect of the dorsum of the foot.[12] Hence, both the LCA and SN are at risk of injury during the surgical incision involving the lateral aspect of the ankle and while harvesting the LCA flap. The present study aims to determine the topographical landmarks to plot the course of LCA and SN. These topographical landmarks aid in extracting an LCA flap of ideal measurements, including the LCA along with the SN, and avoiding injury to the LCA and SN during operative procedures over the lateral calcaneal area.

2. Materials and Methods

The study was conducted in the dissection hall of the Department of Anatomy at Jawaharlal Institute of Postgraduate Medical Education and Research (JIPMER), Puducherry, India, in the voluntarily donated and unclaimed adult human cadavers between the period of December 2016 to December 2018. The study was done in accordance with the guidelines of the Institutional Ethics Committee of JIPMER (approval number JIP/IEC/2016/1124 dated 15.12.2016). A total of 32 lower limbs from 16 formalin-embalmed adult human cadavers of both genders were evaluated in this study after applying the inclusion and exclusion criteria. The cadavers with any signs of previous surgery in the lower limbs or any limb defects were excluded from this study.

2.1. Sample size

All the cadavers available for dissection in the Department of Anatomy, JIPMER, and Puducherry for two years were the total sample size for the present study. Eight cadavers were allocated per year for the dissection of undergraduate students. So, within the study period of 2 years, 16 adult human cadavers of either sex were used for the study. Hence, the total sample size of the present study was 32 cadaveric lower limbs that were fit for the dissection.

2.2. Methods

After recording the cadaver number, sex, age, and side of the ankle, the following steps were followed:

2.2.1. Position

The cadaver was placed in the supine position, and the lower limb was medially rotated at the hip joint.

2.2.2. Dissection steps

An "L" shaped curvilinear incision was made on the lateral aspect of the leg, starting from the middle of the leg, running midway between the LM and AT, and extending to the head of the fifth metatarsal bone. The skin was then dissected and separated from the underlying superficial fascia. The superficial fascia was debrided to trace the LCA, SN, and short saphenous vein.

The point of emergence of the LCA from the deep fascia in the leg was observed. The entire course and the branches of the LCA until its termination in the calcaneus were noted.

The SN was observed from the point of its emergence from the deep fascia on the lateral aspect of the leg. The course and the branches of the SN in the ankle and foot were traced until its termination on the lateral aspect of the foot. The relationship between the LCA and the SN was observed with their branches in situ.

The dissection was done using the microdissection instruments along with the magnifying lens. All the dissected limbs were photographed using a digital camera (Sony HX 10V, Japan).

2.2.3. Measurements

All the gross geometric measurements were taken with the foot in the anatomical position using a Mitutoyo digital vernier calliper to the nearest millimetre. A single observer took all the measurements of all the lower limbs included in the study, and the measurements were recorded thrice, and the mean of the measurements was taken as final. A pin was placed on the most prominent point on the lateral surface of LM as a reference point for the measurements.

The following measurements were taken:

1. The distance between the lateral border of the foot and the point of emergence of the LCA from the deep fascia (Figure 1).

2. The distance between the lateral border of the foot and the point of emergence of SN from the deep fascia (Figure 2).
3. The distance between the most prominent point on the lateral surface of the LM and LCA was measured at three planes: (i) a plane passing horizontally between LM and AT; (ii) an oblique plane passing between LM and the tip of the heel at 45^o to the horizontal plane; and (iii) a plane passing vertically between LM and heel, perpendicular to ground/horizontal plane (Figure 1).
4. The distance between the most prominent point on the lateral surface of LM and SN was measured at three planes: (i) a plane passing horizontally between LM and AT, (ii) an oblique plane passing between LM and the tip of the heel at an angle of 45^o to the horizontal plane and (iii) a plane passing vertically between LM and heel perpendicular to ground/horizontal plane (Figure 2).
5. The distance between the LCA and SN was measured at three planes: (i) a plane passing horizontally between LM and AT; (ii) an oblique plane passing between LM and the tip of the heel at 45^o to the horizontal plane; and (iii) a plane passing vertically between LM and heel perpendicular to ground/horizontal plane (Figure 3).
6. A segment of the LCA of 5 mm length was sectioned at two places: (i) at a plane passing horizontally between LM and AT and (ii) an oblique plane passing between LM and the tip of the heel at 45^o to the horizontal plane. The sectioned arterial segments were processed for histological examination. The processed tissues were stained using hematoxylin and eosin and examined under the microscope. The internal luminal and external circumferential diameters were examined using a binocular research microscope (Olympus CX41, Tokyo, Japan). The images were analysed using Image J software [Image J version 1.51] (Figure 4).

2.3. *Method of statistical analysis*

All the measured data were recorded and analysed using the IBM SPSS STATISTICS 21.0 (SPSS version 21.0). The paired t-test (normal distribution) was used to compare the right and left side variables. All the statistical analyses were done at a 5% level of significance, and a p-value < 0.005 was considered statistically significant.

3. Results

3.1. *Gender Comparison of the distance betweenlateral calcaneal artery and*

Among the embalmed cadavers taken for the study, 12 were male, and 4 were female.

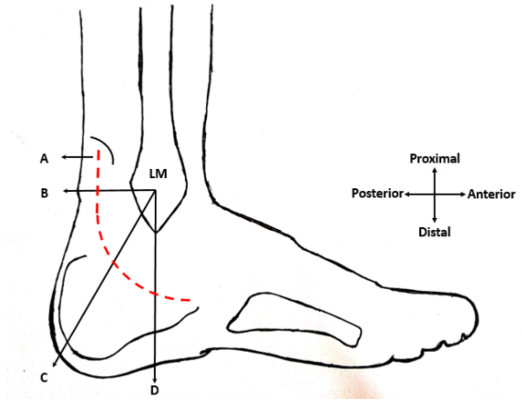

Figure 1: Schematic diagram showing the emergence of lateral calcaneal artery from the deep fascia (arrow A) and its measurement in three different planes: horizontal plane (arrow B), oblique plane (arrow C), and vertical plane (arrow D).

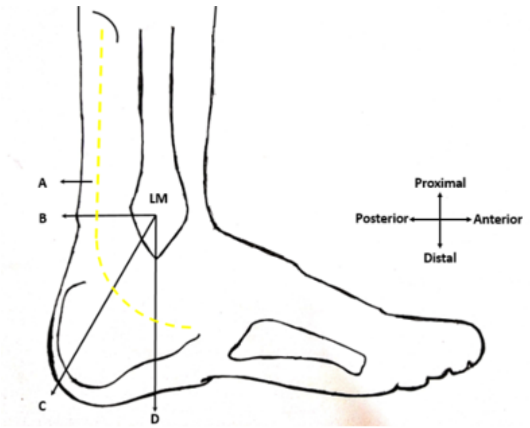

Figure 2: Schematic diagram showing the emergence of thesural nerve from the deep fascia (arrow A) and its measurement in three different planes: horizontal plane (arrow B), oblique plane (arrow C), and vertical plane (arrow D).

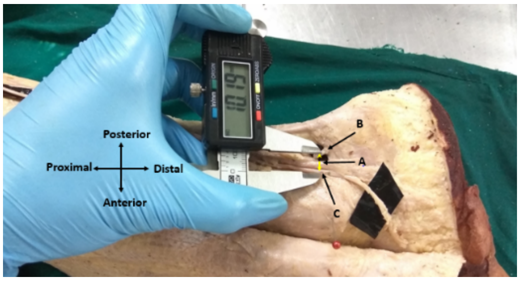

Figure 3: Measurement of the distance between thesural nerve and the lateral calcaneal artery in the horizontal plane (arrow A). Lateral calcaneal artery (arrow B), sural nerve (arrow C).

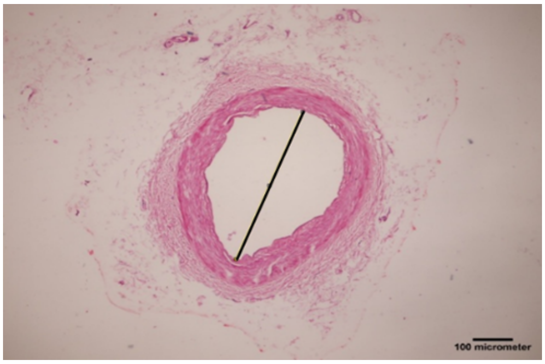

Figure 4: A photomicrograph showing the measurement of the internal diameter of the lateral calcaneal artery: Image J software.

3.2. Point of the emergence of the LCA from the deep fascia

The distance between the point of emergence of the LCA from the deep fascia and the lateral border of the foot ranged from 50.25 mm to 77.14 mm, with a mean of 61.40±6.36 mm. The LCA arose from the deep fascia at a distance of 61.54±6.14 mm from the lateral border of the foot in a line passing perpendicular to the ground on the right side. On the left side, the LCA arose at a distance of 61.27±6.77 mm from opographical landmarks for lateral calcanealr to the ground. The difference between the measurements of the right and left sides was not statistically significant (p-value 0.896).

3.3. Point of the emergence of SN from deep fascia

The distance between the point of emergence of the SN from the deep fascia and the lateral border of the foot ranged from 136.0 mm to 340.0 mm, with a mean of 261.83±49.48 mm. The SN emerged out of deep fascia at a distance of 265.20±49.40 mm from the lateral border of the foot in a line passing perpendicular to the ground on the right side. On the left side, the SN emerged at a distance 258.44±50.90 mm from the lateral border of the foot in a line passing perpendicular to the ground. The difference between the measurements of the right and left sides was not statistically significant (p-value 0.220).

3.4. The distance between the LCA-LM in the horizontal plane

Among the 32 measured lower limbs, the LCA was found to be present along the horizontal plane passing between the LM and AT in 18 lower limbs. The distance between the most prominent point on the lateral surface of LM and LCA measured on this plane ranged from 15.09 mm to 33.30 mm with a mean of 24.56±5.22 mm. The distance between the most prominent point on the lateral surface of LM and LCA measured in this plane was 23.88±5.91 mm on the right side and 25.25±4.69 mm on the left side. The mean distance on the right side was found to be greater than on the left side. The difference between the measurements of the right and left sides was not statistically significant (p-value 0.593).

3.5. The distance between LCA-LM in the 45º plane

The LCA was found to be crossing an oblique plane passing between the LM and the tip of the heel at an angle of 45^o to the horizontal plane in 15 lower limbs (right - 8, left - 7) out of the total 32 lower limbs. The distance between the lateral calcaneal artery and the most prominent point on the lateral malleolus in a plane 45^o to the horizontal plane ranged from 20.70 mm to 39.33 mm with a mean of 29.10±6.12 mm. The LCA was present at a distance of 30.99± 6.17 mm from the most prominent point on the lateral surface of LM in a 45º oblique plane on the right side and 26.93±5.70 mm on the left side. The mean distance on the right side was found to be greater than on the left side. The difference between the measurements of the right and left sides was not statistically significant (p-value 0.211).

3.6. The distance between the LCA-LM in the vertical plane

The LCA was not found to be crossing the vertical plane from the LM to the bottom of the heel perpendicular to the ground in all 32 measured lower limbs.

3.7. The distance between the SN-LM in the horizontal plane

The SN was found to be crossing the horizontal plane, passing from a most prominent point on the lateral surface of LM and AT in all 32 lower limbs (right-16, left-16). The distance between the SN and the most prominent point on the LM in the horizontal plane ranged from 11.70 mm to 36.40 mm, with a mean of 22.64±6.26 mm. The distance between the most prominent point on the lateral surface of LM and the SN in the horizontal plane passing to AT was 23.74±7.63 mm on the right side and 21.53±4.49 mm on the left side. The mean distance on the right side was found to be greater than on the left side. The difference between the measurements of the right and left sides was not statistically significant (p-value 0.311).

3.8. The distance between SN-LM in a 45º oblique plane

The SN was observed to be crossing in a 45° oblique plane, passing between the most prominent point on the lateral surface of LM to the tip of the heel at an angle of 45º to the horizontal plane in all 32 lower limbs (right-16, left-16). The distance of the SN from the most prominent point on the lateral surface of LM along a 45° oblique plane passing at an angle of 45º to the horizontal plane to the tip of the heel ranged from 5.56 mm to 36.24 mm with a mean of 22.68±7.05 mm. The mean distance of the SN from the most prominent point on the lateral surface of LM in an oblique plane passing at an angle of 45° to the horizontal plane passing to the tip of the heel was 23.54±9.01 mm on the right side and 21.82±4.46 mm on the left side. The mean distance on the right side was found to be greater than on the left side. The difference between the measurements of the right and left sides was not statistically significant (p-value 0.437).

3.9. The distance between SN-LM in the vertical plane

The SN was found to be crossing in the plane, passing vertically between the LM and heel perpendicular to the ground/horizontal plane in all 32 lower limbs (right-16, left-16). The distance measured between the most prominent point on the lateral surface of LM and SN in the vertical plane from LM to the heel perpendicular to the ground ranged from 2.45 mm to 45.64 mm with a mean of 29.46±8.21 mm. The mean distance between the most prominent point on the lateral surface of LM and SN measured at the vertical plane passing between LM and the heel perpendicular to the ground/ horizontal plane was 33.61±12.43 mm and 25.31±3.99 mm on the right and left sides, respectively. The mean distance on the right side was found to be greater than on the left side. The difference between the measurements of the right and left sides was not statistically significant (p-value 0.417).

3.10. The distance between LCA-SN in the horizontal plane

Among the total 32 lower limbs observed, the LCA was observed to be present along with the SN in a plane passing parallel to the ground in 19 lower limbs (right-10, left-9). The distance between the LCA and SN in a plane passing horizontally between LM and AT ranged from 2.14 mm to 16.63 mm with a mean of 6.75±3.90 mm. The mean distance between the LCA and SN in a plane passing horizontally between LM and AT was 5.32±3.99 mm on the right side and 8.05±3.52 mm on the left side. The mean distance on the left side was found to be greater than on the right side. The difference between the measurements of the right and left sides was not statistically significant (p-value 0.417).

3.11. The distance between LCA-SN in a 45º oblique plane

Among the total observed 32 lower limbs, the LCA was present along with the SN in an oblique plane passing at an angle of 45º to the ground/horizontal plane from LM to the heel in 14 lower limbs. The distance between the LCA and SN in a 45º oblique plane passing between the LM and heel ranged between 4.21 mm to 16.99 mm with a mean of 8.02± 4.68 mm. The mean distance between the LCA and SN in a 45º oblique plane passing between the LM and the tip of the heel was 6.98±4.41 mm on the right side and 9.39±5.06 mm on the left side. The mean distance on the left side was found to be greater than on the right side. The difference between the measurements of the right and left sides was not statistically significant (p-value 0.362).

3.12. The distance between LCA-SN in the vertical plane

Among the measured 32 lower limbs, the LCA was found to be not crossing the vertical plane that is passing from the LM and the heel, perpendicular to the ground. So, the distance between the LCA and SN could not be measured in this plane.

3.13. LCA internal diameter

The internal diameter of the LCA measured using micrometry scale ranged from 0.47 mm to 1.82 mm with a mean of 1.02±0.37 mm. The mean internal diameter of LCA was 1.03±0.37 mm on the right side and 1.02±0.38 mm on the left side. The mean distance on the right side was found to be greater than on the left side. The difference between the measurements of the right and left sides was not statistically significant (p-value 0.463).

3.14. LCA external diameter

The external diameter of the LCA measured using a micrometry scale ranged from 0.63 mm to 2.25 mm with a mean of 1.37±0.39 mm. The mean external diameter of LCA was 1.40±0.39 mm on the right side and1.34±0.37 mm on the left side. The mean distance on the right side was found to be greater than on the left side. The difference between the measurements of the right and left sides was not statistically significant (p-value 0.393).

4. Discussion

4.1. LCA

The LCA flap is a commonly performed technique for repairing posterior heel and ankle skin defects. Various modifications of the LCA flap, such as adipofascial flap, V-Y advancement flap, free flap, and island flap, offer versatility to cover the defects of the lateral and posterior heel region. The close relationship of LCA with the SN makes the LCA adipofascial flap a sensate flap often used for covering heel defects. The LCA arises most commonly from the fibular artery (FA) followed by the posterior tibial artery (PTA) or from a common branch formed between the FA and PTA.[13] In the present study, the LCA arose from the FA in all the dissected specimens. After originating from the FA or PTA, the LCA pierces the deep fascia at a distance of 45.0 mm above the midpoint of the line passing between the

LM and AT[10]. According to Woo et al., the LCA emerges at a distance of 31.10±9.8 mm above and behind the tip of the LM.[14] In the current study, the LCA arose from the deep fascia at a distance of 61.40±0.36 mm from the lateral border of the foot in a plane perpendicular to the ground. No statistically significant difference was observed between the right and left sides (p-value 0.896).

4.2. LCA-LM

The further course of LCA was mapped in relation to the LM, as the LCA passes posteriorly and posteroinferiorly to the LM. The comparison of the distance between LCA and LM reported by various authors is given in Table 1,2. The measurements observed in the present study concerning the distance between the LCA and the LM in the horizontal plane differed from the findings of Elsaidy et al., Grabb et al. and Zygouris et al.[6,15,16] However, Grabb et al. have used the tip of the LM as the reference point[6]. The findings of the present study were similar to those of Burusupat et al. in case of the distance between the LCA and LM in the horizontal plane.[10] However, the findings of the present study differ from the findings of the Burusupat et al. in case of the distance between the LCA and LM in the 45° oblique plane and the vertical plane.[10] Among all the observed specimens we found that the LCA was not crossing the vertical plane passing from LM perpendicular to the ground, unlike the findings of Burusupat et al.[10]

Comparison of the distance between lateral calcaneal artery and lateral malleolus reported by various authors in the horizontal plane:

4.3. LCA Micrometry

The knowledge about the diameter of the LCA is essential before designing the LCA flap. The adequate internal diameter of the LCA is critical for better flap survival and the prevention of postoperative ischemic complications. The dimensions of LCA were measured by various authors using a doppler study, CT angiography, and intraoperatively using vernier callipers. In the current study, the micrometry was done in the histological sections of LCA extracted from the cadavers included in the study. The histological sections were stained using hematoxylin and eosin, and the internal and external diameter of the LCA was measured.

4.4. LCA-Internal diameter

Elsaidy and Elshafey reported that the mean diameter of LCA in the Egyptian population was 1.75±0.12 mm on the right side and 1.73±0.12 mm on the left side[15].The internal diameter of the LCA varied with its origin. The mean internal diameter of LCA was 0.8±0.1 mm when the origin was from FA, and the mean internal diameter of LCA was 0.5 mm when the origin was from PTA in the Thai population[10]. Omokawa et al., in their cadaveric study in the Japanese population, found that the mean internal diameter of LCA was 1.2±0.3 mm[13].Woo et al. reported that the mean internal diameter of the LCA measured using a Doppler study was 2.0±0.8 mm[14]. In the present study, the mean internal diameter of LCA was 1.02±0.37 mm, similar to the findings of Burusapat et al. and Omokawa et al.[10,13] There was no statistically significant difference between the right and left LCA samples (p-value >0.005).

4.5. LCA-External diameter

In a Doppler study by Burusapat et al., the external diameter of the LCA was 1.2±0.3 mm when the LCA originated from the FA, and the diameter was 0.8 mm when the LCA originated from the PTA[10].Andermahr et al. estimated the external diameter of LCA as 1.0 mm by CT angiography[17].Woo et al. reported the external diameter of LCA as 1.2±0.3 mm by measuring it intraoperatively with vernier callipers[14]. In a similar intraoperative study, Chang et al. estimated that the average external diameter was 1.4 mm[18].In the current study, the average external diameter of LCA was 1.37±0.39 mm. The findings of the present study are similar to those of Burusupat et al. and Chang et al.[10,18]

4.6. Sural nerve

4.6.1. Origin

Typically, the SN is formed by the union of the lateral sural cutaneous nerve (LSCN) and medial sural cutaneous nerve (MSCN), which are the cutaneous branches from the tibial and common fibular nerves, respectively.[19] In our study, the SN had a normal origin by receiving the contribution from the MSCN and LSCN on the posterolateral aspect of the leg. The SN coursed within the deep fascia after its formation and later pierced the deep fascia to reach the superficial fascia. We observed that the SN emerged from the deep fascia at a distance of 26.18±4.95cm from the lateral border of the heel in a plane perpendicular to the ground. Near the ankle, the SN crossed the LM on its posterior aspect. The most commonly used landmark to measure the distance between SN and the LM was the tip of the LM or the most prominent point on the lateral surface of the LM. In the present study, we used the most prominent point on the lateral surface of LM as the reference point for all the measurements. The comparison of the distance between the SN and LM reported by various authors is given in Table 3. Geng et al. observed the SN course in three planes, i.e., horizontal, oblique, and vertical planes.[11] The mean values reported were 13.5±3.4 mm, 12.6±3.0 mm, and 13.1±4.1 mm in horizontal, oblique, and vertical planes, respectively. In the present study, the distance between the SN and the most prominent point on the lateral surface of LM measured in the three planes was 22.64±6.26 mm, 22.68±7.05 mm, and 26.59±8.87 mm, respectively. The measurements observed in the present study differ from

Table 1: Comparison of the distance between lateral calcaneal artery and lateral malleolus reported by various authors in the horizontal plane

S.No.	Authors	Methodology	Sample size	LCA- LM Distance (mm)	Landmark
1.	Elsaidy et al. (2009)	Cadaveric study	13	45 mm	The midpoint of the line between LM and AT insertion
2.	Grabb et al. (1981)	Cadaveric study	18	30 mm	The inferior aspect of LM
3.	Zygouris et al. (2015)	Cadaveric study	12	60 mm	The midpoint of the line between LM and AT insertion
4.	Current study	Cadaveric study	32	24.56 mm	The most prominent point on the lateral surface of the LM

LCA: Lateral Calcaneal Artery, LM: Lateral Malleolus.

Table 2: Comparison of the distance between lateral calcaneal artery and lateral malleolus in three planes

S.No.	Authors	Methodology	Sample size	LCA-LM1Distance (mm)	LCA-LM2Distance (mm)	LCA-LM3Distance (mm)
1.	Burusupat et al. (2015)	Cadaveric study	34	24.76	33.68	35.03
2.	Current study	Cadaveric study	32	24.56 ± 5.22	29.10 ± 6.12	–

Plane-1: LCA- LM1-Distance between LCA and LM in the horizontal plane Plane-2: LCA-LM2 Distance between LCA and LM in 45º plane Plane-3: LCA- LM3 Distance between LCA and LM in the vertical plane, mm- millimetre. LM: Lateral Malleolus LCA: Lateral Calcaneal Artery

Table 3: Comparison of the distance between thesural nerve and lateral malleolus distance reported by various authors

S.No.	Authors	Methodology	Sample size	SN-LMDistance (cm)	Landmark
1.	Solomon et al. (2001)	Cadaveric study	68	1.3 ± 0.7	Distal to the tip of Lateral malleolus
2.	Lawrence SJ et al. (1994)	Cadaveric study	17	7.0	Posterior to the tip of Lateral malleolus
3.	Freeman et al. (1998)	Cadaveric study	15	1.5-2.6	Posterior to the tip of Lateral malleolus
4.	Dangintawat et al. (2016)	Cadaveric study	98	2.6 ± 0.5	The most prominent point of the LM
5.	Aktanikiz et al. (2005)	Cadaveric study	30	1.27 ± 0.87	The most prominent point of the LM
6.	Current study	Cadaveric study	32	2.6 ± 0.62	The most prominent point of the LM

SN-Sural Nerve; LM-Lateral Malleolus

those reported by Geng et al. Such a difference might be because Geng et al. used the tip of the LM as a landmark to measure the distance of SN from LM in three different planes.[11] However, in the present study, the most prominent or the lateral most point on the lateral surface of the lateral malleolus was used as the topographical landmark for the measurements. We have observed that the palpation of the tip of LM was difficult in the undissected cadavers, the localisation of which is more prone to subjective bias. Hence, we have selected the most prominent point at the centre of LM as the landmark for all the measurements as it is easily observable and palpable in an undissected cadaver or a live patient during surgery, even if the patient is having morbid obesity or an edematous ankle.

4.7. LCA - SN

The relationship between LCA and SN was studied in the present study along the three planes passing from the LM: (i) horizontal plane, (ii) 45º oblique plane and (iii) vertical plane. Since the LCA crosses only the horizontal and the 45° oblique plane and not the vertical plane, the mean distance between the SN and LCA was measured in the horizontal plane and 45º oblique planes and it was found to be 6.75±3.90 mm and 8.02±4.68 mm, respectively. Behind the LM, in the horizontal plane passing from LM to AT, the LCA and SN were closer to each other, and in a 45º oblique plane, the LCA and SN were farther from each other.

4.8. Importance of LCA - SN

The LCA flap is used for covering posterior and lateral heel defects. Grabb and Argenta described a short version of the flap measuring 8.0 x 4.5cm and an extended version measuring 14.0 x 4.5cm. These flaps had the LCA and subcutaneous tissue as their primary content without separating the SN[6]. The initial modification of the LCA flap by Ishikawa et al. as a distally based lateral calcaneal flap also sacrificed the SN during the surgery, causing a technical difficulty in retaining the SN[20,21].

During the extraction of the adipofascial type of LCA flap, the SN should be preserved along with the flap to make it a sensate flap, retaining the sensory nerve supply. For preserving the SN, there was a further modification of the LCA flap as an adipofascial LCA flap of size ranging from 2.0-2.5cm in width and length 5.0- 7.0cm, which separated the SN from the donor site to include in the flap. This modification avoided the postoperative paraesthesia along the lateral border of the dorsum of the foot[22].

In the present study, the LCA was found to be emerging from the deep fascia to enter the superficial fascia at a mean distance of 61.40±6.36 mm (range: 55.04 mm to 67.76 mm). The SN was found to be emerging from the deep fascia to enter the superficial fascia at a mean distance of 261.83±49.48 mm (range: 211.52 mm to 311.31 mm) proximally from the tip of the heel. In the present study, the LCA was found to be crossing the horizontal plane passing from LM to AT parallel to the ground and a 45° oblique plane passing from the LM to the tip of the heel. The width of the flap should be wide enough to include the LCA. The width of the flap should extend from the most prominent point on the lateral surface of LM to a mean distance of more than 24.5±5.0 mm (range: 19.36 mm to 29.76 mm) posterior to the LM in the horizontal plane. The width of the flap should be extended from the most prominent point on the lateral surface of LM to a mean distance of more than 29.0±6.0 mm (range: 22.98 mm to 35.22 mm) in 45º oblique planes; this will ensure the inclusion of LCA within the LCA flap during surgery. In all the specimens, we observed that the LCA did not extend beyond the vertical plane passing from the LM to the lateral border of the foot perpendicular to the ground. Hence, the LCA flap should be limited to the horizontal and a 45º oblique plane and not beyond a 45º oblique plane from LM to the heel.

The LCAs originating from the FA were found to be comparatively resistant to the development of atherosclerosis compared to the LCAs that arose from the PTA (Burusapat et al., 2015). In the present study, it was observed that all the LCAs originated from the FA. LCA from FA reinforces the importance of a preoperative Doppler study to identify and confirm the origin of LCA from the FA. The LCA flap where the LCA arises from the FA will lead to a better postoperative outcome, owing to its larger diameter and lesser propensity for the development of atherosclerosis.

In the present study, the SN was found to be crossing the horizontal plane passing from LM to AT parallel to the ground and a 45° oblique plane passing from LM to the tip of the heel. The width of the flap should be wide enough to include the SN. It should extend from the most prominent point on the lateral surface of the LM to a mean distance of more than 22.64±6.26 mm (range: 16.38 mm to 28.9 mm) posterior to the LM in the horizontal plane. The width of the flap should be extended from the most prominent point on the lateral surface of the LM to a mean distance of more than 22.68±7.05 mm (range: 15.63 mm to 20.73 mm) in a 45º oblique plane passing from LM to the tip of the heel; this will ensure the inclusion of SN within the LCA flap during surgery. Since the LCA did not cross the vertical plane, the LCA flap should be limited to the 45º oblique plane, despite the SN crossing the vertical plane, as the flap with SN and without the LCA will not be viable.

Omokawa et al. reported that the diameter of the LCA near the ankle joint should be an average of 1.2 mm to ensure good flap survival for covering the posterior heel defects[13]. In the present study, the mean internal diameter of LCA assessed by micrometry was a mean of 1.02±0.37 mm. Hence, we can infer from the present study that the mean internal diameter of the LCA should be greater than 1.02±0.37 mm to ensure better viability of the LCA flap during surgery.

From the results of the present study, we suggest the ideal measurements of the LCA flap.

4.9. Ideal flap measurements

The point of emergence of LCA from the deep fascia ranged from 55.04 mm to 67.76 mm, proximal to the tip of the heel, and the point of emergence of the SN from the deep fascia ranged from 211.52 mm to 311.31 mm. Therefore, the location of the root of the flap needs to be within the range of 55.04 mm to 67.76 mm measured proximally from the lateral border of the foot to include both LCA and SN.

The width of the LCA flap raised from the back of the LM to cover skin defects of the foot should be at a maximum distance of 29.76 mm from the most prominent point of the LM to include the LCA in the horizontal plane. The width of the flap should be at a maximum distance of 28.9 mm from the most prominent point of LM to include the SN. Therefore, the final width of the flap should be at a distance of 29.76 mm maximum in the horizontal plane when measured from the most prominent point on the lateral surface of LM, to include both LCA and SN. Similarly, in a 45º oblique plane, the width of the flap needs to be at a distance of 35.22 mm maximum to include the LCA, and the width of the flap needs to be at a distance of 20.73 mm maximum to include the SN. Therefore, the final width of the flap in a 45º oblique plane should be at a distance of 35.22 mm maximum when measured from the most prominent point on the lateral surface of LM to include both LCA and SN within the flap. In the above recommendations for flap size, maximum measurements were given to get an LCA flap of adequate size to cover large defects, maintaining the vascularity of the flap. It is also noted that the width of the flap will be relatively narrow behind the LM in the horizontal plane compared to the width of the flap in the 45° oblique plane. The internal luminal diameter of LCA should be not less than 1.02 mm (Figure 5).

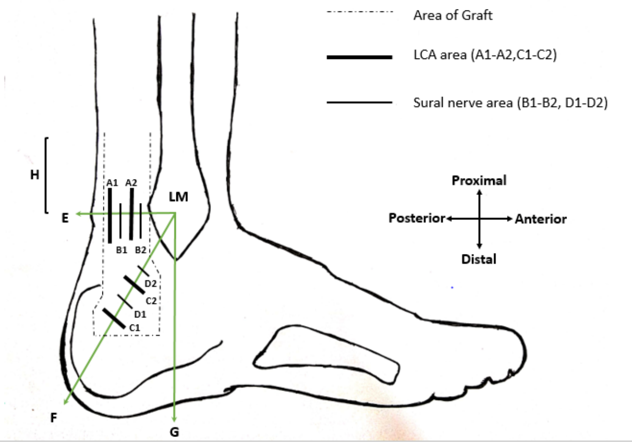

Figure 5: Schematic diagram showing the ideal lateral calcaneal artery (LCA) flap measurements. Range of LCA in the horizontal plane (A1, A2). Range ofsural nerve (SN) in the horizontal plane (B1, B2). Range of LCA in a 45° oblique plane (C1, C2). Range of SN in a 45° oblique plane (D1, D2). Horizontal plane (E), 45° oblique plane (F), vertical plane (G), Range of LCA emergence at deep fascia from the bottom of the foot (H), lateral malleolus (LM).

5. Conclusion

The LCA flaps are commonly used for the surgical treatment of diabetic foot ulcers. For a successful uptake and survival of the flap, the width of the LCA flap should be such that it includes the LCA and SN to maintain the blood and nerve supply to the flap. From the present study, we infer that the ideal flap width in the horizontal plane that passes parallel to the ground from the most prominent point on the LM to the AT should be within the range of 16.38 mm to 29.76 mm. Also, in a 45º oblique plane, passing from the most prominent point on the lateral surface of LM to the tip of the heel, the width of the LCA flap should be within the range of 15.63 mm to 35.22 mm. The ideal internal diameter of the LCA should be not less than 1.02 mm. The LCA and SN are relatively positioned closer to each other in the horizontal plane, passing from LM to AT parallel to the ground. In contrast, in the 45º oblique plane passing between the most prominent point on the lateral surface of LM and the tip of the heel, the LCA and SN are relatively farther from each other, consequently increasing the width of the flap in this plane. This knowledge about the LCA and SN will aid the surgeons in designing an ideal sensate flap that can be used to cover the skin defects of the foot.

6. Limitations

The diameter of the LCA was measured from the histological sections after staining using hematoxylin and eosin dyes. Since the tissue processing for histological staining involves alcohol exposure, there is a chance for shrinkage of the LCA specimen, resulting in a decreased luminal diameter. However, the measurements observed from histological sections of LCA taken from the cadaver were similar to those reported in certain past studies using Doppler, CT angiogram, and intraoperative measurements. The sample size of the present study was limited to the number of cadavers available for dissection within two years. However, similar studies using different races of people among the population will add to the knowledge base of the topic.

7. Strengths

The measurements were taken within a week time after embalming the cadaver using a formalin-based preservative fluid and by using the window dissection method. The dissection of LCA and measurements was not done during or just before the routine dissection meant for teaching undergraduate students. We believe this helps in taking relatively accurate measurements of LCA and SN from the nearest landmarks, as the location of the structures is well preserved and certainly not disturbed during the reflection of skin for routine lower limb dissection.

8. Ethics approval (including appropriate approvals or waivers)

This study involves human cadavers routinely dissected for teaching undergraduate students. All cadavers are procured based on the Anatomy Act, which caters to the supply of human cadavers meant for teaching and research. The human cadavers were sourced from voluntary whole-body donations and unclaimed bodies. Hence, all cadaveric studies have implied consent for research in their manner of procurement itself and do not need additional consent. This procedure is currently followed in our institution, and we have followed the same. All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

9. Authors' Contributions

Arun Prasad S: Acquisition of data; Data Curation; Data Analysis Writing-original draft; Final approval.

Rajasekhar SSSN: Conceptualisation; Methodology; Project administration; Data Curation; Data interpretation; Writing original draft; Final approval.

Sankaranarayanan G: Data Interpretation; Writing-review and Editing; Final approval.

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Aravindhan K: Acquisition of data, Final approval.

Ananthi P: Writing review and Editing; Final approval.

10. Conflicts of Interest

The authors declare no conflict of interest.

11. Source of Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

12. Availability of data and Material (data transparency)

This study involves human cadavers that are routinely dissected for teaching undergraduate students. Hence, the study material is further utilised for dissection purposes. Study data, including master charts, are available from the authors upon reasonable request.

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