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Locating the Sural Nerve during Calcaneal (Achilles) Tendon Repair with Confidence: A Cadaveric Study with Clinical Applications

Joseph A. Blackmon, MD^{1,2}, Stavros Atsas, MPA^{2,3}, Mackenzie J. Clarkson, BA³, Jacob N. Fox, BSc³, Blake T. Daney, MD^{3,4}, Sean C. Dodson, MD³, H. Wayne Lambert, PhD^{2,3}

¹Division of Dermatology, Department of Internal Medicine, University of Kansas Medical Center, Kansas City, KS

²Department of Anatomical Sciences and Neurobiology, University of Louisville Health Sciences Center, Louisville, KY

³Department of Neurobiology and Anatomy, West Virginia University School of Medicine, Robert C. Byrd Health Sciences Center, Morgantown, WV

⁴Department of Orthopaedic Surgery, Akron General Medical Center, Akron, OH

Abstract

The sural nerve is at risk of iatrogenic injury even during minimally invasive operative procedures to repair the calcaneal (Achilles) tendon. Through 107 cadaveric leg dissections, the data derived from the present study was used to develop a regression equation that will enable surgeons to estimate the intersection point at which the sural nerve crosses the lateral border of the Achilles tendon, an important surgical landmark. In most cases, the sural nerve crossed the lateral border of the Achilles tendon 8 to 10 cm proximal to the superior border of the calcaneal tuberosity. By simply measuring the leg length of the patient (from the base of the heel to the flexor crease of the popliteal fossa), surgeons can approximate the location of this intersection point with an interval length of 0.68 to 1.80 cm, with 90% confidence, or 0.82 to 2.15 cm, with 95% confidence. For example, for a patient with a lower leg length of 47.0 cm, the mean measurement in the present study, a surgeon can be 90% confident that the sural nerve will cross the lateral border of the Achilles tendon 8.28 to 8.96 cm (interval width of 0.68 cm) proximal to the calcaneal tuberosity. Currently, ultrasound and clinical techniques have been implemented to approximate the location of the sural nerve. The results of the present study offer surgeons another method, that is less intensive, to locate reliably and subsequently avoid damage to the sural nerve during calcaneal (Achilles) tendon repair and other procedures of the posterolateral leg and ankle.

Address correspondence to: H. Wayne Lambert, PhD, Department of Neurobiology and Anatomy, West Virginia University School of Medicine, Robert C. Byrd Health Sciences Center, HSN 4052, PO Box 9128, Morgantown, WV 26506-9128. hwlambert@hsc.wvu.edu (H.W. Lambert).

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Keywords

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The sural nerve is a major cutaneous nerve of the lower limb that courses through the posterolateral leg to supply the lateral margin of the hindfoot and midfoot and the ankle joint (1). Classically, it is formed by the union of the medial sural cutaneous nerve (MSCN) and the lateral sural cutaneous nerve (LSCN), which arise from the tibial and common fibular (peroneal) nerve, respectively (1–5). After the MSCN and LSCN merge, the sural nerve accompanies the small saphenous vein as it descends in the posterior leg, traveling inferolateral as it crosses the lateral border of the calcaneal (Achilles) tendon. It then passes posterior to the lateral malleolus and terminates as the lateral dorsal cutaneous nerve supplying the lateral aspect of the foot (6–8). Numerous studies have reported the variability and frequency of formation of the sural nerve from its MSCN and LSCN components (6,9,10). According to a recent study, the formation and course of the sural nerve can be classified into 5 types (6). Type I classification is seen when the sural nerve is formed through the communication of the MSCN and LSCN in the proximal two thirds of the leg, which is the predominant variation, seen in 40.2% to 83.7% of lower extremities (2–6,9,11). Communication between the 2 nerves is also extremely variable. Reported unions have occurred in various parts of the lower leg, in the thigh, and even in the popliteal fossa; however, most communications were in the proximal two thirds of the leg (6,9,11). In type II variations, the LSCN is absent, and, therefore, the MSCN alone contributes to the formation of the sural nerve. Type III variations are seen when the MSCN and LSCN communicate in the distal one third of the leg. In type IV variations, the LSCN and MSCN pass down separately and do not communicate; thus, the sural nerve is not formed. Finally, in type V formations, the MSCN is absent, and a branch of the LSCN assumes the classic route of the sural nerve (6).

The sural nerve is at risk of iatrogenic injury, even during minimally invasive operative procedures of the Achilles tendon (12–17). Operative treatment of the Achilles tendon has a highly variable rate of paresthesia of the sural nerve, ranging from 1.7% to 23% after percutaneous procedures (18–22). However, the incidence of paresthesia can reach 60% when considering all types of operative techniques (13–17). Postoperative sural nerve dysfunction can result from traction or sharp injury, which can occur during dissection of the connective tissue of the Achilles tendon (peritendineum), at the stab incision, or while drilling the canal through the lateral calcaneus (23). However, the incidence of sural nerve damage for both open and percutaneous repairs predominantly occurs after nerve entrapment resulting from percutaneous suturing (14,15,18,24,25).

Because of the aforementioned high complication rate, the present study investigated the point at which the sural nerve crosses the lateral border of the Achilles tendon, as measured from the superior aspect of the calcaneal tuberosity. This measurement enables clinicians to identify the location of the sural nerve within 90% and 95% confidence intervals, according to the patient's leg length. It is anticipated this anatomic knowledge will assist surgeons in

preoperatively predicting where the sural nerve crosses the lateral border of the Achilles tendon, thereby minimizing the risk of iatrogenic injury.

Materials and Methods

Cadaveric Dissection

All 107 lower limbs (73 left limbs and 34 right limbs) were placed in the prone position for dissection. A longitudinal incision was initiated between the lateral malleolus and calcaneal tuberosity and was extended proximally. Reflection of the skin ensued to reveal the location of the small saphenous vein. This vein was retracted to increase visibility of the sural nerve. Careful dissection of the subcutaneous tissue was implemented to preserve the anatomic position of the sural nerve for future measurement.

Measurements

Because of the variability of the Achilles tendon inserting into the calcaneal tuberosity, the superior aspect of the calcaneal tuberosity was used as the reference point for measurement. A T-pin was placed at this anatomic landmark and labeled as 0 cm. Progressing proximally, T-pins were placed at 2-cm intervals along the midline of the Achilles tendon until a distance of 14 cm from the superior aspect of the calcaneal tuberosity was established. The horizontal distance of the sural nerve in relation to the lateral border of the Achilles tendon was measured at 0-, 2-, 4-, 6-, 8-, 10-, 12-, and 14-cm intervals. A positive value was assigned when the sural nerve was located lateral to the lateral border of the Achilles tendon. A negative value was given when the sural nerve resided medial to the lateral border of the Achilles tendon. A value of 0 was assigned to the location where the sural nerve crossed the lateral border of the Achilles tendon.

The length and circumference of the lower limbs were recorded. The lower limbs were measured from the base of the heel of the foot to the flexor crease of the popliteal fossa with the leg in 90° of flexion. Additionally, the circumference of the Achilles tendon was recorded at the closest point of insertion to the calcaneal tuberosity (Fig. 1).

Statistical Analysis

Bivariate regression analysis was performed to obtain the intercept and regression coefficient for the regression equation of the point at which the sural nerve crosses the lateral border of the Achilles tendon (snlbTA) predicted from lower leg length. Pearson's correlation coefficient, the square of the coefficient of multiple determination (R^2), the 90% and 95% confidence bands (intervals) around the regression line, and the estimated 90% and 95% confidence intervals for individual points across the lower leg length were calculated. SPSS, version 16.0 (SPSS, Chicago, IL), was used for statistical analysis.

Results

The first measurements recorded were the length and circumference of the leg and the circumference of the Achilles tendon. The mean length of the leg was 46.44 cm (range 37 to 57), as measured from the base of the heel of the foot to the flexor crease of the popliteal

fossa with the leg in 90° of flexion. The average leg circumference was 30.52 cm (range 22 to 43). Finally, the mean circumference of the Achilles tendon was measured as 3.80 cm (range 2.8 to 4.9).

The distance of the sural nerve to the lateral border of the Achilles tendon was measured, starting at the superior aspect of the calcaneal tuberosity, which was labeled 0 cm. At this location, the sural nerve was measured to be an average of 1.94 cm lateral to the Achilles tendon (Table 1), which was at its most lateral position from the Achilles tendon. In most of the lower extremities, as the sural nerve ascended from the lateral foot, it crossed the lateral border of the Achilles tendon and then coursed medial to the lateral border of the Achilles tendon before penetrating the crural fascia in the proximal leg. The average point at which the sural nerve crossed the lateral border of the Achilles tendon was 8 to 10 cm proximal to superior aspect of the calcaneal tuberosity (Table 1). On average, the sural nerve was 0.04 cm lateral to the lateral border of the Achilles tendon at 8 cm along its length and 0.32 cm (−0.32 cm) medial to the lateral border of the Achilles tendon at 10 cm along its length. Additional measurements for the average distance from the lateral border of the Achilles at various distances from the calcaneal tuberosity are listed in Table 1.

The regression analysis provided an equation of $\text{snlbTA} = 3.017 + 0.119 (\text{leg length}; p = .013, r = 0.25, \text{ and } r^2 = 0.062)$. Fig. 2 depicts the scatter graph and the 90% and 95% confidence bands (intervals) for the present analysis. As evident in Fig. 2, the scatter graph illustrates that, in general, the sural nerve crosses the lateral border of the Achilles tendon at a higher point with an increasing leg length.

The 90% and 95% confidence intervals of the individual snlbTA values predicted from the leg length are listed in Table 2. The data represent the approximate point at which the sural nerve will cross the lateral border of the Achilles tendon for various leg lengths at a 90% and 95% confidence interval for an individual. Given the average leg length in the present study was 46.44 cm, the predicted snlbTA for a person with a leg length of 47 cm would have a mean of 8.62 cm (90% range 8.28 to 8.96, 95% range 8.21 to 9.03). The width of the 90% confidence intervals for the predicted values of snlbTA was less than 1.80 cm for all leg lengths listed, and the 95% confidence bands were less than 2.15 cm, providing surgeons a method of predicting the point at which the sural nerve will cross the lateral border of the Achilles tendon before surgery, according to the patient's leg length.

Discussion

The goal of the present cadaveric study was to identify the location at which the sural nerve crossed the lateral border of the calcaneal tendon (intersection point) to enable surgeons to identify its location with confidence. In Fig. 2, the 90% and 95% confidence bands were determined from the results of 107 cadaveric leg dissections. The regression equation generated from the data in the present study showed a correlation between leg length and the point at which the sural nerve crossed the lateral border of the calcaneal tendon. Specifically, as the leg length increased, this intersection point lay more proximally within the leg. These data enable a surgeon to approximate the location of the sural nerve at the lateral border of the calcaneal tendon to within 1 to 2 cm, depending on the patient's leg length and

confidence level implemented. Therefore, these data provide the surgeon with a “danger zone” to avoid damage to the sural nerve when making incisions, placing retractors, or passing sutures along the lateral border of the Achilles tendon. When combined with other clinical and ultrasound methods of localizing the sural nerve (26), these data provide surgeons with another tool, that is less intensive, to approximate the location of the sural nerve to avoid iatrogenic damage during operative procedures.

In most of the 107 cadaveric leg dissections performed in the present study, the sural nerve crossed the lateral border of the Achilles tendon 8 to 10 cm superior to the superior border of the calcaneal tuberosity (Fig. 2). However, the formation of the sural nerve did create variability within the results. Type V formations of the sural nerve, in which the MSCN of the tibial nerve is absent, caused the sural nerve to parallel the lateral border of the calcaneal tendon, resulting in higher data points on the scatter graph in Fig. 2 (6). Higher data points were also occasionally seen with some type I formations, because the manner in which the MSCN and LSCN of the common fibular (peroneal) nerve merged resulted in the sural nerve running parallel to the lateral border of the calcaneal tendon (6). However, these type I and V formations of the sural nerve are less likely to cause surgical complications during repair of the calcaneal tendon owing to the nerve often residing lateral to the lateral border of the Achilles tendon. In contrast, types III and IV sural nerve formations (in which the MSCN and LSCN communicate in the distal one third of the leg or do not merge) result in lower points on the scatter plot and have a greater risk of iatrogenic injury (Fig. 3) (6). Despite the variability of the sural nerve formation shown in Fig. 3, the data derived from the present cadaveric study indicate that surgeons can approximate the location of the sural nerve crossing the lateral border of the calcaneal tendon within a 0.68- to 1.80-cm interval with 90% confidence, depending on the patient’s leg length, which was measured from the base of the heel to the flexor crease of the popliteal fossa. For example, a surgeon can be 90% confident that the sural nerve will cross the lateral border of the calcaneal tendon 8.28 to 8.96 cm proximal to the calcaneal tuberosity in a patient with a 47.0-cm leg length, the mean measurement in the present study (Table 2).

Damage to the sural nerve can have a profound effect on a patient’s quality of life ranging from sensory disturbance to severe pain often associated with neuromas and potentially complete sensory loss (27). Also, the communicating branches (MSCN and LSCN) and the sural nerve itself have clinical importance outside of their function as cutaneous nerves. They can be used for diagnostic purposes (i.e., nerve conduction velocity) and for biopsy for various neuromuscular disorders (28,29). Therapeutically, these cutaneous nerves can be used in nerve-grafting procedures and as a sensate composite free flap for reconstructive surgery (30–33).

Operative repair of Achilles tendon ruptures continues to remain a controversial topic (10), although conservative, nonoperative treatment has resulted in high repeat rupture rates (34). Two methods currently used are the percutaneous and open incision approaches to repair. Percutaneous repair of acute closed Achilles tendon rupture was first described in 1977 by Ma and Griffith (35) as a method to minimize many of the complications associated with open operative repair and restore tendon continuity and length seen in repeat ruptures, which is highly prevalent with nonoperative treatment. Reports have indicated that percutaneous

techniques reduce major complications, including wound-related complications compared with open incision techniques (13,19,35–38). However, a recent study reported an increased incidence in sural nerve disturbances during percutaneous repairs compared with open operative repairs, possibly owing to incorporation of the nerve in the suture as it is passed through the skin and tendon when using a closed approach (13). Despite offering better treatment outcomes, including lower repeat rupture rates (15,39,40), open operative techniques result in associated complications such as infections, delayed wound healing, necrosis, and adhesions (41,42). Techniques involving the careful placement of incisions to expose the sural nerve (27), as well as clinical mapping (43), can reduce these disturbances.

Currently, several incisions are made in the operative repair of the Achilles tendon, with varying success in preserving the sural nerve. In 1977, Ma and Griffith (35) successfully used 3 incisions lateral and 3 incisions medial to the Achilles tendon, reporting no sural nerve injuries or repeat ruptures. Using the same approach, Rowley and Scotland (44) in 1982 reported an injury incidence of 10%, and Klein et al (15) reported iatrogenic sural nerve injury in approximately 13% of patients in 1991. In contrast, Webb and Bannister (45) used 3 midline stab incisions over the posterior aspect of the tendon to avoid the sural nerve. In their 1999 study, the sural nerve was not injured in any of their 27 patients (45). In 2005, Çretnik et al (13) described a modified percutaneous approach by adding 2 incisions for simultaneous use of 2 needles to avoid possible damage to the thread. Additionally, the S-shaped incision aims to avoid the heel counter of a shoe by beginning distally along the medial edge of the tendon and crossing the midline proximal to the skin crease (46). If a posterolateral short longitudinal heel scar exists from previous surgery, the incision is started laterally along the previous scar and is ended proximally along the medial side of the tendon (26). Another method involves a percutaneous approach in which 3 pairs of 5-mm vertical stab incisions are made in the posterior aspect of the leg (27). The proximal pair is located at the musculotendinous junction, the intermediate pair at the level of the tear, and the distal pair at the level just above the calcaneus.

Furthermore, surgeons have reported decreased complications with respect to the sural nerve if the stab incisions in the proximal and intermediate levels on the lateral aspect of the leg are lengthened to 1.5 cm to expose and isolate the nerve during the surgery (27). In contrast, a limited open repair could also be reliable, because it allows direct visualization at the repair site and control of the ends of the ruptured tendon (24). Jung et al (47) used a limited open technique and reported a comparatively low rate (3.3%) of sural nerve injury in 2008. Additionally, repair of the Achilles tendon using an endoscopic camera can be useful in determining the initial gap and providing adequate apposition of the tendon ends (48,49). Although Pavic (49) suggested using an endoscopic camera to avoid sural nerve injury, a 2008 study by Fortis et al (48) did not report a significant difference in sural nerve injury rates.

Recently, a 2006 study conducted by Calder and Saxby (50) independently investigated the Achillon®, a percutaneous suture system, in a prospective study of 25 patients with spontaneous Achilles tendon ruptures. The wounds of the 25 patients healed without complications, repeat rupture, or sural nerve injury, although injury to the sural nerve had been previously documented in percutaneous and other mini-open techniques (50). This

device also reportedly eliminated the risk of injury from sural nerve entrapment, although it was still possible for the nerve to be speared by the needle during the operation (50). Likewise, Feldbrin et al (51) reported excellent functional results in 2010 using the Achillon®, with outcomes similar to both percutaneous and open techniques. Patients who underwent Achilles tendon repair with the Achillon® device did not display neurovascular defects or repeat ruptures and also had shorter scar lengths than the open and percutaneous groups (51). Garrido et al (52) reported similar functional outcomes, with all their patients regaining normal range of motion and no reports of repeat ruptures or sural nerve injury.

In addition, Flavin et al (26) suggested using clinical and ultrasound techniques to map the sural nerve before to surgery. By contorting the lower limb, the sural nerve can be palpated along its course when taut and is easily visualized posterior to the lateral malleolus and along the lateral border of the calcaneal tendon using ultrasound. However, ultrasound guidance illustrated poor sensitivity approximately 4 cm proximal to the insertion of the Achilles tendon owing to the presence of numerous subcutaneous veins (26).

Although numerous studies have been published concerning Achilles tendon repair methods, only 2 previous studies have addressed the relationship between the sural nerve and the Achilles tendon (10,53). From the findings from 30 leg dissections, Webb et al (10) described the course of the sural nerve in relation to the Achilles tendon and determined percutaneous sutures should not be placed in the lateral one half of the calcaneal tendon. In contrast, Apaydin et al (53) in 2009 determined the relationship of the sural nerve to the midline distance of the Achilles tendon by dividing the Achilles tendon into 10 equal horizontal fractions to account for the variability of the sural nerve. Both studies observed that the sural nerve intersects the lateral border of the Achilles tendon at approximately one half the length of the tendon (10). Our approach was to describe the point at which the sural nerve crossed the lateral border of the Achilles tendon, a valuable landmark for surgeons embarking on calcaneal tendon repair, within the 90% and 95% confidence intervals. Before surgery, clinicians can easily approximate where the sural nerve will cross the lateral border of the Achilles tendon according to the length of the patient's leg, which demarcates a small window to avoid during incisions or suturing. Because the superior aspect of the calcaneal tuberosity is easily palpable, the data derived from the present study can serve as a guide to reduce the risk of iatrogenic injury to the sural nerve before operative Achilles tendon repair, regardless of the operative technique.

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Fig. 1.

Photograph of dissection to identify location of sural nerve and its intersection point, where it crosses lateral border of calcaneal (Achilles) tendon. Superior aspect of calcaneal tuberosity was used as reference point for measurement, and a T-pin was placed at this anatomic landmark and labeled as 0 cm. Progressing proximally, 7 additional T-pins were placed at 2-cm intervals along the midline of the Achilles tendon. Using these reference points, the location of the sural nerve in relation to the lateral border of the calcaneal tendon was measured at each T-pin location. The small saphenous vein was reflected proximally for measurement of the intersection point.

Fig. 2.

Scatter graph illustrating regression equation of point at which sural nerve crosses the lateral border of the Achilles tendon (snlbTA) and lower leg length. *Solid line* represents regression line, $\text{snlbTA} = 3.017 + 0.119 (\text{leg length})$; *longer dashed lines* represent 90% confidence bands; *shorter dashed lines*, 95% confidence bands. All 107 dissections are represented; thus *darker circles* indicate more than 1 specimen was measured at that intersection point.

Fig. 3.

Variations in formation of sural nerve can affect the intersection point at which the sural nerve crosses the lateral border of the Achilles tendon. (A) Most common type I formation of sural nerve, in which the communication of medial sural cutaneous nerve (*MSCN*) of the tibial nerve and lateral sural cutaneous nerve (*LSCN*) occurs in proximal two thirds of the leg. (B) Type III formation, in which merging of *MSCN* and *LSCN* occurs in distal one third of leg. (C) Type IV formation in which sural nerve does not form because *MSCN* and *LSCN*

stay separate throughout their course. Type III and IV formations increase risk of iatrogenic sural nerve damage and are represented as the lower data points in Fig. 2.

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Table 1

Average horizontal distances of sural nerve to lateral border of Achilles at 8 reference points

Distance from Superior Aspect of Calcaneal Tuberosity (cm)	Horizontal Distance of Sural Nerve to Lateral Border of Achilles Tendon (cm)
0	1.94
2	1.19
4	0.77
6	0.38
8	0.04
10	-0.32 *
12	-0.67 *
14	-1.09 *

Superior aspect of calcaneal tuberosity represented as 0-cm point.

* Negative values denote sural nerve had crossed lateral border of Achilles tendon and was medial to its lateral border.

Table 2

Predicted values of point at which sural nerve crossed lateral border of Achilles tendon at 90° and 95° confidence band values from lower leg length, measured from superior aspect of calcaneal tuberosity

Lower Leg Length (cm)	Predicted Value of snlbTA (cm)	90° Confidence Bands for snlbTA (cm)	Width of 90° Confidence Bands	95° Confidence Bands for snlbTA (cm)	Width of 95° Confidence Bands
38	7.55	6.82 to 8.28	1.46	6.68 to 8.42	1.74
41	7.91	7.37 to 8.44	1.07	7.27 to 8.54	1.27
44	8.26	7.88 to 8.64	0.76	7.81 to 8.72	0.91
47	8.62	8.28 to 8.96	0.68	8.21 to 9.03	0.82
50	8.98	8.54 to 9.42	0.88	8.45 to 9.51	1.06
53	9.34	8.71 to 9.96	1.25	8.59 to 10.08	1.49
57	9.81	8.91 to 10.71	1.80	8.74 to 10.89	2.15

Abbreviation: snlbTA, sural nerve crosses the lateral border of the Achilles tendon.

Lower leg length measured from base of heel to flexor crease of popliteal fossa with leg in 90° flexion.