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Chapter 3.4

A CASAM study on the intra- and inter-surgeon variation of incision lines in the lateral approach of the calcaneus in surgical fracture treatment.

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ABSTRACT

Background: For intra-articular calcaneal fractures there is no real consensus on the treatment of choice and complication rates of surgical management are high. Surgeons are confronted with the basic dilemma between exposure and soft-tissue sparing. Our objective was to assess inter- and intra-surgeon variation in the extended lateral approach (ELA).

Methods: Dutch surgeons (N=23) were asked to draw two incisions for an ELA on embalmed ankles. Incisions were categorised, mapped and both inter- and intra-surgeon variation were quantified. Incisions were compared to the ELA gold standard and ten dissected sural nerves. Results were related to the surgeon`s experience in ELA surgery. Computer Assisted Surgical Anatomy Mapping (CASAM) was used to visualise data.

Results: Inter-surgeon variation was large, drawn incisions covered the entire lateral foot. Intra-surgeon variation was substantial, the second incision drawn varied over 6% of the dimensions of the foot. Based on four criteria of the gold standard nine incisions (22%) were accurate and 32 incisions (78%) demonstrated at least one aberration. The number of aberrations was not correlated to the surgeon`s experience. L-shaped incisions demonstrated less aberrations than J-shaped incisions. The main branch of at least one of ten sural nerves was at risk for transection in 35 of 41 incisions. In an incision following the gold standard the sural nerve would still be at risk in 10% of the specimen.

Conclusions: Even though ELA surgery is mainly performed by surgeons with many years of experience, inter- and intra surgeon variation was high. Only 22% of incisions followed the criteria of the gold standard. The main branch of the sural nerve is at risk in almost all incisions, even in an incision conform the gold standard. Consistent incision placement conform the gold standard seems teacher-based, not experience-based.

Clinical relevance: These findings suggest there is a need for an anatomy based teaching model for ELA aimed at both novice and expert surgeons in an attempt to lower current complication rates for intra-articular calcaneal fractures.

INTRODUCTION

Fractures of the calcaneus predominantly occur in young, active men. They represent one to two percent of all fractures in adults[1,2] and approximately 75% of fractures affecting the hindfoot[3]. No universal treatment or surgical approach exists that can be applied to treat all fractures of the calcaneus. Even though extensive research has been done on treatment, complications and diagnosis, no consensus has yet been reached on the treatment of choice. As many factors influence the surgeon`s treatment of choice[4] careful patient selection is important for good outcome[3, 5-7]. The lack of consensus may partially be due to the lack of a uniform classification and outcome-scoring system[1, 8]. However most surgeons consider Open Reduction and Internal Fixation (ORIF) to be the approach of first choice[9], 10. ORIF is not a uniform procedure. Many variants of ORIF have been described but the extended lateral approach (ELA) has been used most frequently[11, 12], as it provides the surgeon with good exposure for fracture management[13].

Complication rates for ORIF vary. Infection rates for a lateral approach vary between 1.3 to 21% [10, 14-16] and the rates for subtalar arthrodesis vary between zero and 15.4%[14]. Poeze et al. demonstrated that these complications were inversely correlated to institution's fracture load and the number of calcaneus fractures a surgeon operates per year[14]. Furthermore Sanders et al. stated that calcaneal surgery has a substantial learning curve as it is technically challenging[17].

Also, the skin incision is an important issue because this represents the basic surgical dilemma of creating a good exposure versus (nerve and vessel) sparing soft tissue. Arterial damage may result in necrosis of the wound or lateral hindfoot if the incision is not placed considering the angiosomes in the lateral hindfoot. Superficial necrosis is seen in 0.4 to 14% [15, 18]. Depending on the location of the incision the sural nerve might be at risk[17, 19-22] especially since the skin and soft tissue are usually mobilized as a thick soft-tissue flap[19, 23]. Sural nerve damage is seen in up to 10% of patients[22]. Iatrogenic sural nerve lesion can lead to different levels of post operative pain varying from numbness to sharp invalidating or even causalgic pain[22, 24].

The aim of the current study therefore is to explore whether:

1) there is any inter- and/or intra- surgeon variation in the skin incision when a surgeon is asked to draw an incision line for ELA and how these incisions compare to the ELA gold standard or the location of the sural nerve.

2) the results of these research questions are related to the surgeons years of experience and/or the number of ELA procedures he or she performs per year.

MATERIALS AND METHODS

Twenty three surgeons were asked to each draw an incision line, proposed for the ELA, on two different embalmed anatomic specimens. The specialty of each surgeon (trauma-, orthopaedic- or general surgery) was noted as well as his/her years of experience in ELA and the estimated number of ELA procedures performed last year. Then bony landmarks (Figure 1) and a ruler were placed. The ankles were photographed using a Canon 350D with a Canon EF-S 18-55 mm lens via a standardized protocol. Photographs were loaded into stack in Photoshop CS-4[25]. Non-bony landmarks were calculated from bony landmarks

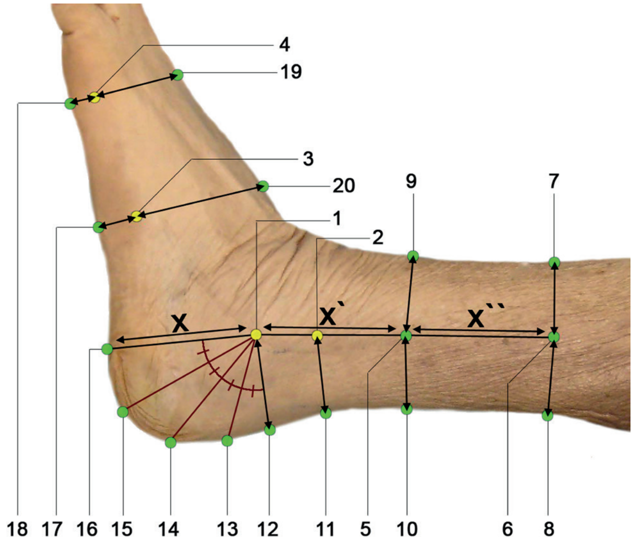

Figure 1. landmarks used for CASAM
Yellow: bony landmarks: The most distal (= malleolus tip; 1) and the most proximal part of the malleolus (malleolus top; 2), the tuberosity of the fifth metatarsal (3) and the fifth metatarsal head (4).
Green: non-bony landmarks: On the sole of the foot: The nearest point to the tip of the lateral malleolus (16), the nearest point to the tuberosity of the fifth metatarsal (17), the nearest point to the fifth metatarsal head (18). On the foot ridge: the nearest point to the fifth metatarsal head (19), the nearest point to the tuberosity of the fifth metatarsal (20). On the achilles tendon: the nearest point to the tip of the lateral malleolus (12), the nearest point to the top of the lateral malleolus (11).
The distance between landmark 1 and 16 (X) was used to create landmark 5 (X`) and 6 (X``) (in line with the tibia). Landmarks 7 and 8 are the nearest points on the posterior and anterior side of the leg to landmark 6. Landmarks 9 and 10 are the nearest points on the posterior and anterior side of the leg to landmark 5.
The angle between landmark 12 and 16 over landmark 1 was measured and divided into four segments (Red lines), thereby creating landmarks 13, 14 and 15 on the edge of the hindfoot.

to delineate the different shapes of the ankles (Figure 1). All landmarks were assessed independently by two authors and test-retest reproducibility of the landmarks was determined.

The photographed ruler was used as a reference for measurements taken with the “Ruler tool” in Photoshop. The accuracy of digital measurements had been verified in four specimens.

Statistical analysis was performed in SPSS version 17.0.

Computer Assisted Surgical Anatomy Mapping (CASAM)

CASAM[26-28] is a new method to evaluate the anatomy of multiple specimens. For this method MagicMorph 1.951029 is used to compute an average size of all specimen to which each photographed ankle is resized. As the dimensions of all ankles were the same, the individual incision lines and the relative anatomy could be compared.

Inter-surgeon variation

Incision lines were categorised as J- or L-shaped. The location of each incision was measured in relation to the landmarks (Figure 1). However, as the shape of each ankle differed, the location of drawn incisions could not be compared when expressed in absolute numbers (mm). Therefore the location of an incision was also expressed as a relative ratio related to four of the shape defining measurements (Figure 2, Table 1).

Furthermore the angle between the proximal (vertical) and the distal (horizontal) part of the incision lines was measured (Figure 2)

CASAM: Incisions were visualized in one ankle with average shape and size. An area of spreading was defined in which all drawn incision lines were located.

Statistics: The mean years of experience, number of ELA surgeries per year and angle of incision lines were calculated for J- and L-shaped incisions and the comparison was tested.

Intra-surgeon variation

In order to determine a surgeon`s consistency, the relative location of both incisions was compared (Table 1, ratio 1 - 4). The mean intra-surgeon variation was quantified as the mean difference in the relative location of both drawn incisions over all four ratios. Also the difference between the angles (Figure 2) of both incision lines drawn by the same surgeon was calculated.

Statistics: The mean intra-surgeon variation and difference in incision angle was calculated for J- and L-shaped incisions and the comparison was tested.

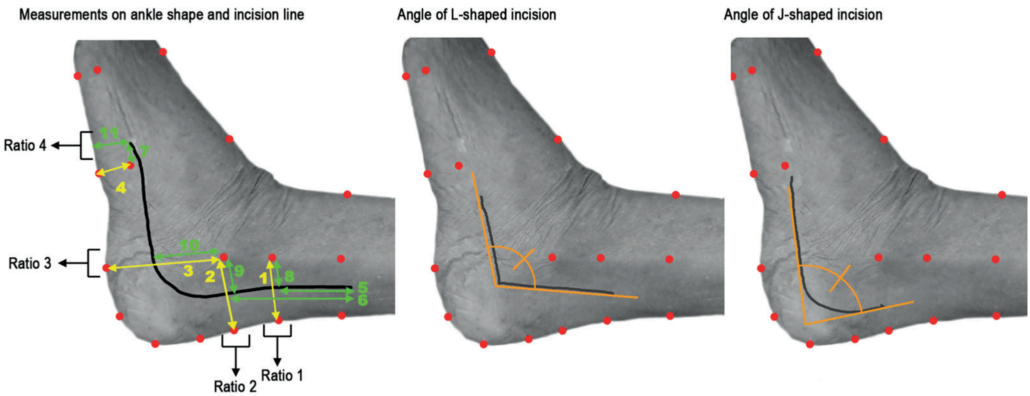

Figure 2. Measurements taken in original pictures
Black line: incision line drawn by a surgeon. Red dots: landmarks

Yellow lines/numbers: general measurements concerning the shape and size of the ankle.
Green lines/numbers: measurements regarding the location of the incision line.
orange lines: measurements regarding the angle of incision lines

Relative location of incision lines:
Ratio 1: (incision measurement 8 as a ratio of shape defining measurement 1)
Ratio 2: (incision measurement 9 as a ratio of shape defining measurement 2)
Ratio 3: (incision measurement 10 as a ratio of shape defining measurement 3)
Ratio 4: (incision measurement 11 as a ratio of shape defining measurement 3)

The correlation coefficient between intra-surgeon variation and a surgeon`s experience was calculated.

Comparison to the gold standard

Based on an ELA incision exactly conform gold standard (Figure 6)[30, 31,] ratios one to three (Table 1) had to be more than 66% for an incision to be conform gold standard. Also the distal part of an incision could not be located more than 5 mm superior to landmark three. Thus, a surgeon could make four aberrations per incision line (based on ratio 1-3 and the 5mm rule). An incision was marked as "accurate" if no aberrations were made.

CASAM: Incisions reshaped with CASAM were assessed equally. Two new areas of spreading were computed, one representing all accurate incisions and one representing all incisions with at least one aberration when compared to the gold standard.

Statistics: The median number of aberrations per surgical specialty and per J-or L-shaped incisions was calculated and the comparison was tested. The

Table 1, Measurements	Nr. (fig2)	Measurement from	Measurement to	Mean (mm)	Range from	Range to
defining the shape of each ankle (fig. 2, yellow)	(1)	landmark 2	achilles tendon	35.54	24.55	48.19
	(2)	landmark 1	achilles tendon	41.39	29.65	54.85
	(3)	landmark 1	sole of foot	65.08	49.89	82.49
	(4)	landmark 3	sole of foot	15.96	8.48	25.78
Proximal and distal endpoint of incision line (fig. 2, green)	(5)	proximal end of incision	the level of landmark 2	14.90 *	0.00	40.18
	(6)	proximal end of incision	the level of landmark 1	26.67 **	1.43	29.21
	(7)	distal end of incision	landmark 3	14.35 ***	0.00	43.71
Incision location (fig. 2, green)	(8)	landmark 2	incision (proximal)	23.97 *	12.35	41.17
	(9)	landmark 1	incision (proximal)	25.54 **	13.1	14.8
	(10)	landmark 1	incision (distal)	37.90	22.1	58.77
	(11)	incision (distal)	sole of foot	22.76	10.57	44.31
	Ratio	**Description**		**Mean (%)**	from	to
Relative location incision	ratio 1	(8) as a ratio of (1)		66 **	43	93
	ratio 2	(9) as a ratio of (2)		61 *	39	77
	ratio 3	(10) as a ratio of (3)		58	36	75
	ratio 4	(11) as a ratio of (3)		35	17	75
Intra surgeon variation	ratio 1	incision 1 - incision 2		9	2	20
	ratio 2	incision 1 - incision 2		8	0	23
	ratio 3	incision 1 - incision 2		4	0	9
	ratio 4	incision 1 - incision 2		6	0	18

Table 1.
* N=40. In one of the cases the incision was not extended proximal of the tip of the lateral malleolus, this case was excluded from the above calculation. The incision ended 4.5 mm distal of the tip of the lateral malleolus.
** N=22. In 19 cases where the incision was not extended proximally past the top of the malleolus, the average deficit was 15.97 mm (N=19, range 1.43-29.21 mm).
*** N=15 In cases where the incision was not extended distally past the tuberosity, the average deficit was 10.67 mm (N=26, range 1.59-34.79 mm).

correlation coefficient between the average number of aberrations a surgeon made and his experience was calculated. Finally correlation coefficients between the mean number of aberrations and intra-surgeon variation in both incision location and incision angle were calculated.

The incision in relation to the sural nerve

The sural nerves of ten additional specimens were dissected and photographed. Photographed specimens were reshaped with CASAM to match the computed average ankle. Thereby the incisions could be compared to the computed location of ten sural nerves.

Also, an ELA incision was drawn exactly according to the gold standard and it was compared to the location of the sural nerves.

RESULTS

Of 46 drawn incisions, five were discarded due to insufficient visibility of the incision or landmarks. Of 23 participating surgeons five were orthopaedic-, 12 trauma- and six were general surgeons. On average they had 13 years of experience (range 0-27) and performed 5 calcaneal surgeries per year (range 0-20). There was a strong correlation between the years of experience a surgeon had in ELA and the number of calcaneal surgeries performed per year. (Pearson`s $\rho=0.621$, $p=0.002$, N=22, one outlier removed[32]). Correlation coefficients of either one of these variables were therefore corrected for the latter and tested for multicollinearity[33].

Inter-surgeon variation

Of 41 incision lines drawn, 56% (N=23) incisions were J-shaped and 44% (N=18) incisions were L-shaped. Measurements regarding the location of the incision lines drawn are shown in Table 1. The proximal part of 22 incisions extended proximal of the lateral malleolus top at a mean distance of 14.9 mm, 19 incisions extended proximal of the lateral malleolus tip but not the lateral malleolus top and one was not extended beyond the lateral malleolus tip.

The distal part of 15 incisions extended beyond the tuberosity of the fifth metatarsal bone at a mean distance of 14.4 mm. In 26 cases the incisions stopped at a mean distance of 10.7 mm proximal to the tuberosity of the fifth metatarsal bone.

The average distance in height between the tuberosity of the fifth metatarsal bone and the incision was 6.1 mm (range -7.2 – 25.8 mm).

The relative location of the proximal part of incision lines was located at 66% (range 43 – 93%) of measurement one and at 61% (range 39 – 77%) of measurement two. The distal part of incision lines was located at 58% (range 36 – 75%) of measurement three. The distal end of incision lines was located at a level of 35% (range 17 – 75%) of measurement three.

CASAM: The drawn incisions demonstrated a wide variety in both location and shape. The computed area of spreading almost covered the entire lateral side of the foot (Figure 3).

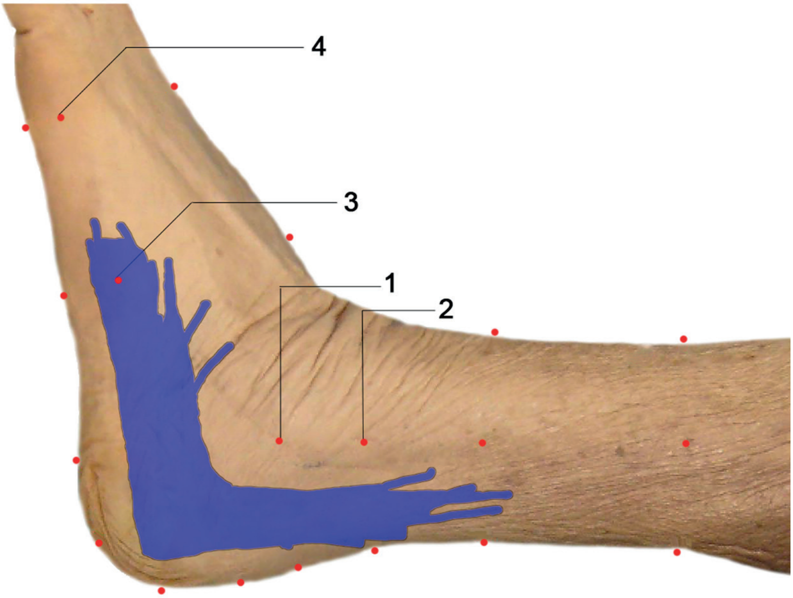

Figure 3. Spreading of all incision lines
With CASAM generated image depicting an average ankle in which all incision lines were warped.
Red dots: used landmarks.
Blue area: spreading of all drawn incision lines (n=41)

Statistics: Surgeons who drew a J-shaped incision on average had 13.5 years of experience (range 0-25) and performed 4.4 lateral calcaneal surgeries last year (range 0-10). Surgeons who drew a L-shaped incision on average had 12 years of experience (range 2 – 23) and performed 2.8 lateral calcaneal procedures last year (range 1.5 - 5). There was no statistical difference between J- and L-shaped incisions when related to years of experience (p=0.706, Mann-Whitney) or ELA`s performed per year (p=0.782, Mann-Whitney).

The mean angle of incision differed significantly ($p=0.015$, Mann-Whitney) between J-shaped (91.2° ± 12.1°) and L-shaped (99.3° ± 6.6°) incisions.

Intra-surgeon variation

The relative location (Table 1, ratio 1- 4) of both incisions drawn by the same surgeon varied.

Proximally the difference was 9% (range 2 - 20%) over ratio 1 and 8% (range 0 - 23%) over ratio 2. Distally the difference was 4% (range 0 – 9%) over ratio 3 and 6% (range 0 – 18%) over ratio 4. The average intra-surgeon variation over all four ratios was 6.3% (range 1.0 – 11.0%). Thus the intra-surgeon variation in incision line placement was on average 6.3% of the corresponding shape defining measurements (Figure 2, ratio 1- 4).

The mean intra-surgeon variation of the angle between the proximal and distal part of the incisions was 7.4° degrees (range 0.6°-17.6°).

Statistics: The mean intra-surgeon variation between two drawn incisions did not differ ($p= 0.171$ Mann-Whitney) between J-shaped (7.2% ± 2.1%) and L-shaped (5.4% ± 3.0%) incisions. The mean difference in incision line angle did not differ ($p=0.216$ Mann-Whitney) between J-shaped (8.7° ± 5.9°) and L-shaped (5.4° ± 3.9°). Intra-surgeon variation was not correlated to the number of ELA`s a surgeon performed per year ($p=0.109$, Pearson) or the years of experience a surgeon had in ELA surgeries ($p=0.736$, Pearson). Intra-surgeon variation in incision location was significantly correlated to the mean difference in angle between both incisions (Pearson $\rho=0.596$, $p=0.012$). Correlation coefficients of either one of these variables were therefore corrected for the latter and tested for multicollinearity.

Comparison to the gold standard

When the relative location of an incision and the height of an incision relative to landmark 3 were compared to values of the gold standard only nine incisions (22%) were considered “accurate”. The other 32 incisions (78%) were aberrant on one or more of the four criteria for an incision conform the gold standard (based on ratio 1 - 3 and the 5mm rule). Nine incisions demonstrated one aberration (22 %), ten incisions demonstrated two (24 %), eight incisions demonstrated three (20 %) and five incisions demonstrated four aberrations (12 %).

CASAM: Results computed with CASAM were identical; nine “accurate” and 32 “aberrant” incisions (Figure 4). Most aberrations were located on the proximal side of the incision, as incisions were drawn too close to the lateral malleolus.

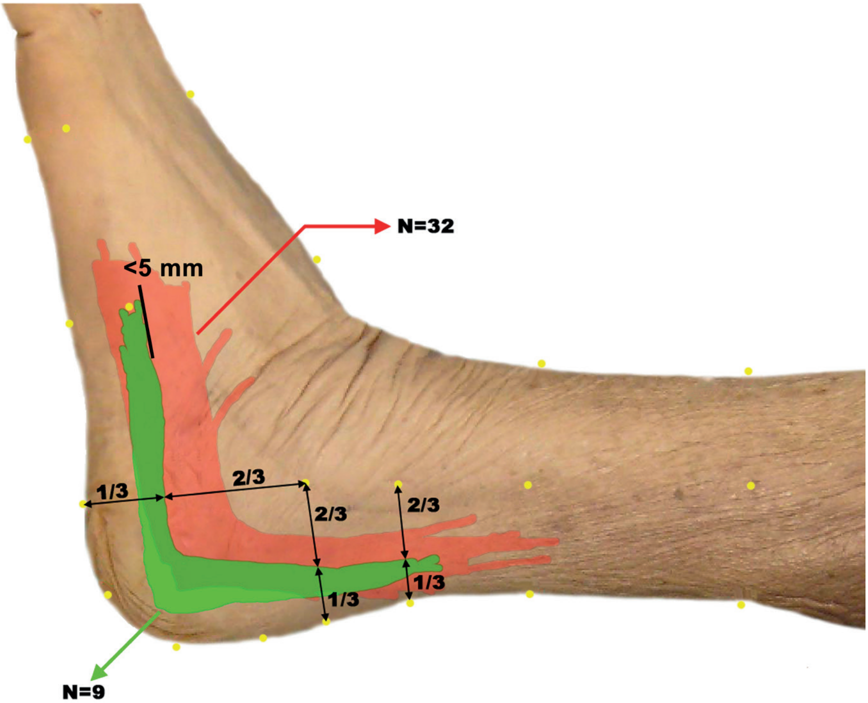

Figure 4. Comparison to the gold standard
With CASAM generated image, depicting an average leg in which all incision lines were warped
Yellow dots: Landmarks used
Red area: spreading of all incision lines with one or more aberrations (N=32)
Green area: spreading of all incision lines in accordance with the gold standard (N=9)

Statistics: The median number of aberrations was one (IQR=2) for orthopaedic surgeons, two (IQR=2) for trauma surgeons and two (IQR=3) for general surgeons (p=0.181, Kruskal-Wallis). There was a significant difference (p=0.018, linear chi-square34) in the number of aberrations in L-shaped incisions (median=1, IQR=2) and J-shaped incisions (median=2, IQR=2). In comparison to L-shaped incisions, J-shaped incision were 4.3 times more likely to have 3 or 4 aberrations instead of 0-2 aberrations (p=0.13 chi-square). The mean number of aberrations a surgeon made in both incisions was not correlated to the number of ELAs a surgeon performed per year (p=0.139, Pearson) or to the years of experience a surgeon had in ELA (p=0.148, Pearson). The mean number of aberrations per surgeon was not correlated to intra-surgeon variation in incision location (p=0.407 Pearson), but was correlated to the mean difference in angle between both incisions (Pearson`s ρ=0.661, p=0.005).

Comparison to the sural nerve

The distribution on the location of the main branch of the dissected sural nerves was small. Of 41 drawn incisions, 35 incisions (85 %) overlapped at least one main branch of the ten sural nerves. Six incision lines had no overlap with any main branch (Figure 5).

An incision line drawn exactly conform the gold standard would have damaged the main branch of one (10%) of the ten dissected sural nerves (Figure 6).

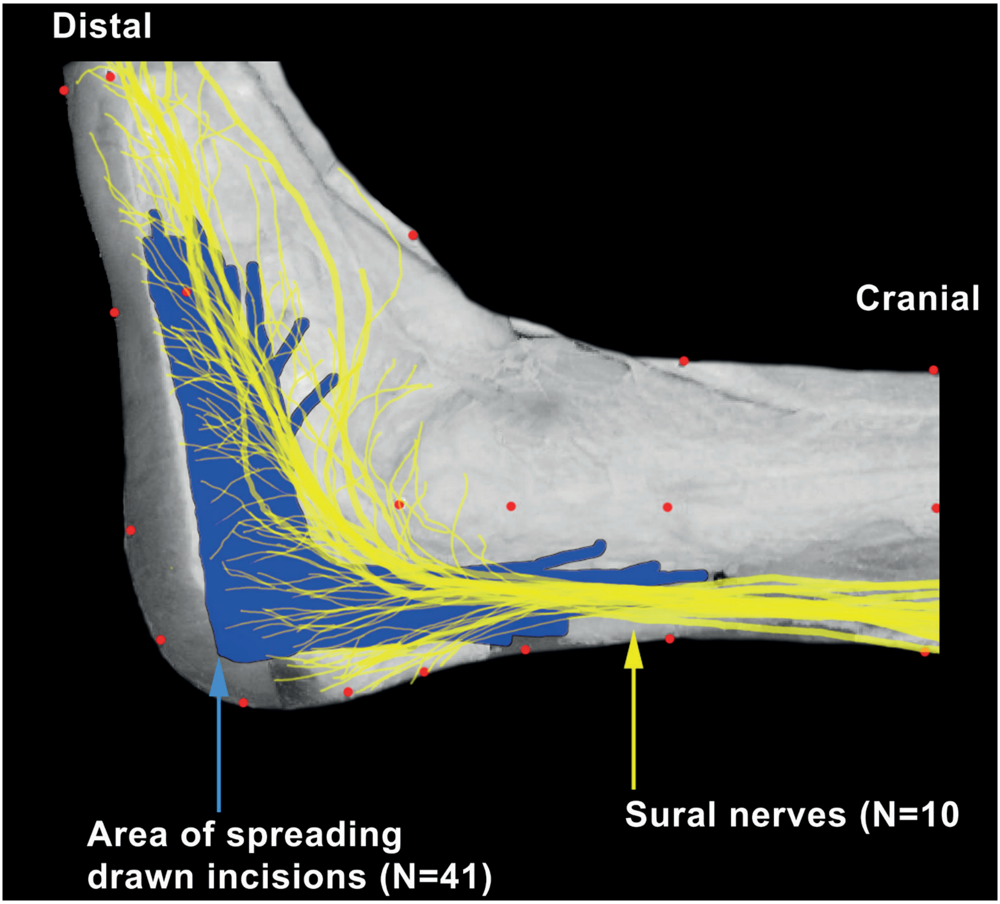

Figure 5. Spreading of incision lines and sural nerves

Lateral view of ten dissected sural nerves. With CASAM the original pictures were warped to match the average ankle size and renditions were made to depict the ten dissected sural nerves in one image
blue area: area of spreading of incision lines (N=41).
yellow lines: Sural nerves (N=10).

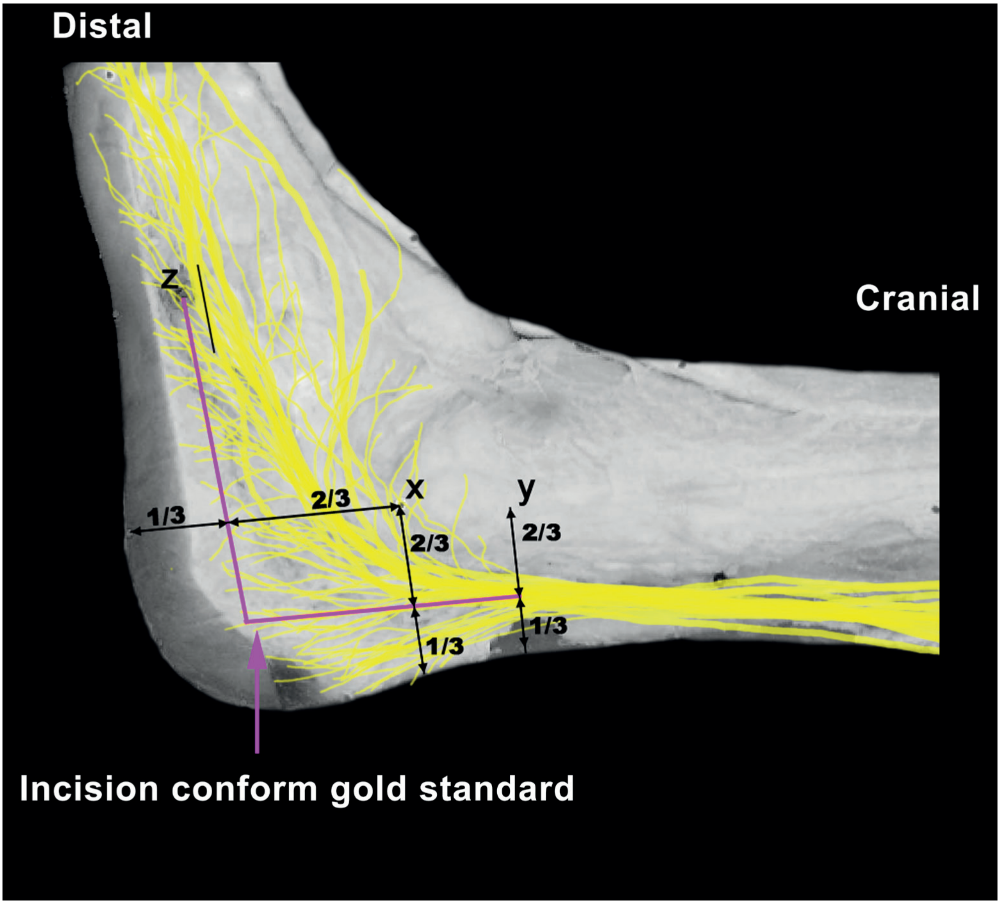

Figure 6. Incision line conform gold standard compared to the sural nerves

Purple line: proposed incision line exactly in accordance with the gold standard
yellow lines: Sural nerves (N=10).

DISCUSSION

Fractures of the calcaneus predominantly occur in young active men and are known for their varying clinical outcome and complications. Still no consensus has been reached on the best method of treatment nor on the optimal surgical treatment regarding the right approach and technique.

Inter-surgeon variation

There was a strong correlation between the years of experience a surgeon had in ELA surgery and the number of ELA surgeries he performs per year. As calcaneal surgery is considered to be technically demanding and it is possible that these surgical procedures are performed by surgeons with many years of experience. Sanders et al. already stated that calcaneal surgery has a substantial learning curve, mainly due to the complicated fracture management[17].

This study demonstrated a wide variety in the location and shape of ELA incisions. The surgeon's personal preference determined the location, shape and length of the incision. In some cases the proximal incision started superior to the lateral malleolus and was extended past the base of the fifth metatarsal, in other cases the incision was much shorter.

Half of the surgeons had drawn an L-shaped incision. The shape of the incision (J or L) was not correlated to the years of experience a surgeon had, nor how many ELA procedures he performed per year. The mean angle of all L-shaped incisions was wider when compared to J-shaped incisions. This either implies that surgeons that have been taught to make an L-shaped incision have also been taught to make a bigger angle or that it is easier to judge the incision angle when a L-shaped incision is made.

Intra-surgeon variation

The mean difference in ratios between the two drawn incision lines by each surgeon is a measure for intra-surgeon variation. The mean intra-surgeon variation for all four incision locating measurements was 6.3%. This means that the difference between the first and second incision drawn by the same surgeon on average is 6.3% of the related shape defining measurements (Figure 2, ratio 1-4), such as the distance between the lateral malleolus and the Achilles tendon. Surprisingly, the intra surgeon variation was not correlated to the surgeon`s years of experience or the number of ELA surgeries he performed per year. This implies that surgical consistency in incision placement is not based on experience, but might be teacher-based.

Comparison to the gold standard

Of 41 incision lines only nine were according to the gold standard. This implies that the gold standard for ELA is not applied by the majority of Dutch surgeons. This finding is amplified by the fact that only two surgeons drew both their incision lines conform gold standard, meaning that the other five "accurate" incisions were drawn by surgeons that were not consequent in their incision placement.

As with intra-surgeon variation, no significant correlation was found between a surgeon`s personal experience (years of experience in ELA surgery and ELA procedures performed per year) and the number of aberrations when incisions were compared to the gold standard. Therefore, incision-related complications such as sural nerve damage and wound or tissue necrosis might not be related to the experience of a surgeon but more related to persisting in the method learned from a supervisor. This in contrast to complications such as subtalar arthrodesis and wound infection which are inversely correlated to the number of calcaneus fractures a surgeon operates per year[14]. Interestingly, surgeons that were consistent in incision line angle made fewer aberrations when compared to the gold standard. Also, L-shaped incisions demonstrated fewer aberrations than J-shaped incisions, most likely because surgeons are more able to determine the angle of incision lines.

Comparison to the sural nerve

Not only were most incisions aberrant when compared to the theoretical gold standard but they also demonstrated much overlap to the highly clinically relevant computed location of the dissected sural nerves. The main branch of at least one of the ten sural nerves would have been at risk for transection in 35 of 41 drawn incision lines.

This is amplified by the fact that when an incision is drawn exactly conform the gold standard the sural nerve would still be at risk of transection in 10% of the specimen. An incision line, as described by Eastwood et al[19], can reduce such iatrogenic sural nerve damage[20].

CONCLUSION

- ELA surgery is mainly performed by surgeons with many years of experience.

- This study shows that there is a large inter- surgeon variation in incision line placement for an ELA and a substantial intra-surgeon variation.

- The location of drawn incision lines is not correlated to a surgeon`s years of experience or the number of ELA surgeries he/she performs per year. This indicates that the incision placement is teacher-based rather than experience-based.

- The dissected sural nerves would have been at risk for transection in almost all drawn incision lines.

- The sural nerve is still at risk in an incision line exactly conform gold standard.

These conclusions suggest that there is a need for an anatomy based teaching model aimed at both novice and expert surgeons. A web-based version of CASAM might be beneficial in two ways;

1) Pre-operative planning using CASAM, can assist the surgeon in determining a ‘tailor made’ safe zone in each patient.
2) For educational purposes CASAM is able to compare a surgeon`s incision with the gold standard or the computed location of nerve and arteries, thus providing personal feedback.

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