The Foot 38 (2019) 34–38

Contents lists available at ScienceDirect

The Foot

journal homepage: www.elsevier.com/locate/foot

Original Article

Learning anatomy of the foot and ankle using sagittal plastinates: A prospective randomized educational trial

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ARTICLE INFO

Keywords:
Surgical education
Anatomy teaching
Sagittal anatomy
Plastination
Orthopaedic

ABSTRACT

Background: Foot and ankle anatomy is highly complex and presents a considerable educational challenge for the medical student or junior doctor. The successful interpretation of cross-sectional radiological images requires a detailed knowledge of anatomy and spatial relationships. Plastic-impregnated cadaveric prosection slices, known as 'sagittal plastinated slices', or 'SPS', are becoming popular as an adjunct to traditional anatomical teaching methods.

Objectives: To compare the impact of SPS versus conventional anatomy teaching resources (dry bones and whole cadaveric feet) on learners' ability to correctly identify structures of the foot and ankle on sagittal MRI images.

Methods: Randomized educational study using sequential exploratory mixed-methods.

Results: The intervention group anatomy test scores were a mean of 1.2 higher after the educational intervention, compared to 0.7 for the control group (scores out of 14), but this was not statistically significant ($p = 0.41$). Learners reported that the SPS intervention was most useful to augment and refine their knowledge after a teaching session using conventional resources.

Conclusion: The qualitative results showed that SPS provide a valuable adjunct to traditional teaching methods in both anatomy and radiology of the foot and ankle, which should be used after teaching with traditional methods.

1. Introduction

A detailed knowledge of three-dimensional (3-D) applied gross anatomy is required for the practice of foot and ankle surgery, the application of clinical skills, and the interpretation of diagnostic images. A sound knowledge of foot and ankle anatomy is relevant across many clinical disciplines including; orthopaedic surgery, rheumatology, radiology, general practice, physiotherapy and podiatry. In recent years there has been an interest in teaching anatomy at both undergraduate and postgraduate levels in a clinically relevant fashion, to match an integrated and problem-based approach to learning rather than as "pure" knowledge [1,2]. The integration of diagnostic 3-D images in the anatomy curriculum is becoming commonplace as medical schools are modernizing their curricula [3,4]. Tools used in the teaching of cross sectional anatomy are wide-ranging and include; cadaveric dissection, anatomical models and cross sections (including plastinated models), atlases of photographs, radiological images and more recently, 3-D computer models. With regard to the acquisition of spatial relationships in anatomy, studies have been undertaken to determine the best method for teaching and enhancing the spatial ability of medical students and doctors, including surgeons and radiologists [5–7].

Plastination of cadaveric material is a preservation technique whereby body water and fats are replaced by various plastics. This gives the specimen strength, preserves longevity, and removes any odours. The specimens retain their original structure and many of their original tissue properties, and can be handled safely. Plastinates present a unique teaching aid in the understanding of complex areas of anatomy and can be made into sagittal, coronal or axial cross sections of varying degrees of thickness [8,9]. Different preservation techniques are employed for large prosections as compared to thin body slices, the latter of which are typically produced using the P40 polyester technique [10] or E12 ultrathin technique [8]. These cross-sectional specimens can then be correlated to radiological images as an adjunct to standard teaching methods including traditional didactic sessions and cadaveric dissection [11,12]. These techniques enable preservation of fine anatomical structures, such as nerves, vessels and joint capsules, which are essential for the understanding of complex areas of anatomy such as the

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https://doi.org/10.1016/j.foot.2018.11.004
Received 19 September 2018; Received in revised form 14 November 2018; Accepted 25 November 2018

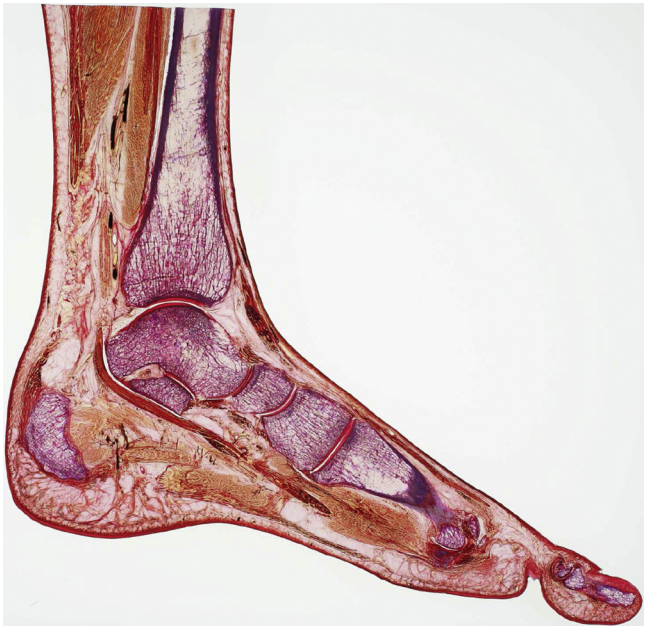

Fig. 1. Sagittal plastinate cross section – medial slice of hindfoot and foot at the level of the first metatarsal.

foot and ankle. Axial cadaveric abdominal sections have been shown to improve the ability of learners to identity anatomical structures on abdominal CT scan images [13].

The hypothesis considered in the present study postulates that the use of sagittal plastinated slices (SPS) of cadaveric tissue of the foot and ankle (Figs. 1–3) is enhance the learning of 3-D anatomy and the interpretation of sagittal Magnetic Resonance Imaging (MRI) images of the foot and ankle by medical students and junior doctors. The SPS are 1 mm thick, show the structures on both medial and lateral sides and can be handled, flipped and rotated by the learner. These sections provide the learner with true 2-D images, which show the detailed anatomical structures as they are seen in cross-sectional radiological images, and in life. Multiple sequential SPS can then be used by the

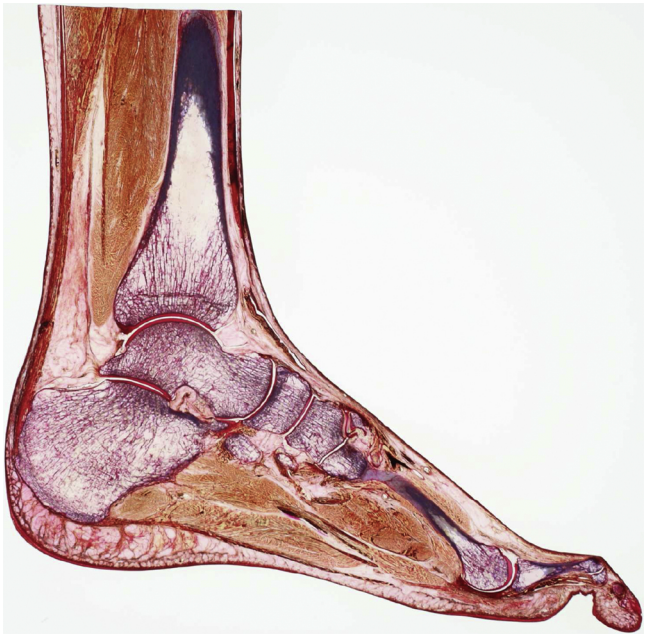

Fig. 2. Sagittal plastinate cross section – mid – section slice of hindfoot and foot at the level of the second metatarsal.

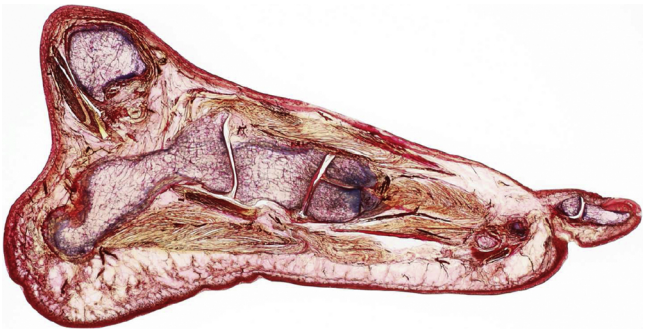

Fig. 3. Sagittal plastinate cross section – lateral slice of hindfoot and foot at the level of the fourth and fifth metatarsal.

learner to build a 3-D image in their mind and consolidate their understanding of spatial relationships. The aim of this study was to determine, using principally qualitative methods, whether the students found the SPS useful as a learning tool and to determine how best to use them as part of an anatomical and radiological teaching session. The students were also objectively assessed on their knowledge to determine the impact of the SPS teaching on their ability to correctly identify structures of the foot and ankle on MRI sagittal imaging.

2. Methods and materials

2.1. Plastinated cross-sections

The SPS that were used in this study are part of the West Midlands Surgical Training Centre (WMSTC) collection designed by the senior author and were dissected and plastinated at the Plastinarium, Gubin, Germany. The funding for this complete collection was from the West Midlands Strategic Health Authority (SHA).

2.2. Participants

53 participants responded to an advertisement circulated to the local medical school and university hospital inviting participation in the study. All respondents were recruited to the study. Participants were randomized by administrative staff at registration for the study by means of selecting a sealed opaque envelope containing questionnaire packs and group allocation.

Group A (n = 25) was the control group and Group B (n = 28) was the intervention group. Participants were blinded as to whether they were part of the control group or the intervention group. At the start of the study baseline data were collected from the participants including age, gender, stage of training and future career intention. Study group demographics are presented in Table 1.

2.3. Intervention

All participants were asked to complete focused pre-reading of 2–3 h duration from standard recommended textbooks before attending the session, covering the bones and joints of the foot and ankle, major neurovascular structures and major tendinous insertions of the foot. The amount of pre-reading completed by each participant was recorded on arrival, by self-reporting.

On arrival, and before commencing the teaching sessions, the study participants completed a qualitative questionnaire requiring them to rate their agreement with a series of statements on a 10-point Likert scale, with a high score relating to strong agreement and a low score to strong disagreement. Participants' views were sought on a range of pertinent issues including perceived difficulty in interpretation of sagittal MRI images of the foot and ankle and the importance of a good understanding of sagittal anatomy in clinical practice. Information was

Table 1
Characteristics of the study participants, by intervention group.

		Group A (n = 25)	Group B (n = 28)
Gender	Male	14	14
	Female	10	14
	Not disclosed	1	0
Age group	20–25	14	16
	36–30	9	11
	31–35	1	0
	Over 35	1	1
Career	Radiology	2	1
	Orthopaedic surgery	2	2
	Surgery specialities	5	5
	General practice	4	2
	Medical specialities	4	10
	Other	2	2
	Undecided	6	6
Experience	Third year student (S3)	17	18
	Fourth year student (S4)	6	8
	Professional (other)	2	2

also collected on the participants' previous anatomy education, including whether they had access to plastinated prosections and whether participants found them useful. At an introductory lecture on basic foot and ankle anatomy, it was explained to the participants that they were taking part in a study on how best to teach radiological anatomy of the foot and ankle and verbal consent was given to participate. Ethical approval was previously sought but deemed not required. Anonymity was guaranteed.

The teaching session started with a 40-min didactic lecture for both groups on basic foot and ankle anatomy and radiology by a consultant trauma and orthopaedic surgeon. The following teaching interventions were structured as two parallel 'round-robin' circuits of three 20 min stations (i.e. 6 stations in total) covering the bones and joints of the foot (station 1), neurovascular and soft-tissue structures (station 2) and tendons and muscles (station 3). Each station was manned by at least 2 experienced demonstrators and each of the circuits of 3 stations had a senior faculty member present. The circuits were hosted in adjacent soundproofed rooms to minimize cross-contamination between groups. The demonstrators were unblinded to group allocation.

The intervention group (group B, circuit B) received teaching using SPS, sagittal radiographic images and photographic anatomy atlases. The control group (group A, circuit A) received teaching using 'conventional resources'; dry articulated bones, sagittal radiographic images, plastinated prosections and photographic anatomy atlases.

The aims and learning objectives of each of the parallel circuits were identical; the only difference was the materials available for teaching. Prior to the start of the study all teaching faculty in both circuits received an identical briefing.

2.4. Assessment of educational impact

At the start of the study, immediately prior to commencement of the teaching session, participants were subjected to a formal written pre-test whereby two normal sagittal MRI images of the foot and ankle were displayed on a projector and the participants completed a test paper asking them to identify the structures marked with numbered arrows. Each image had 7 structures to identify; therefore the total test score was out of 14 with one mark for each correct answer. All participants sat the same test regardless of group allocation. The test was held under examination conditions with no conferring permitted between participants. The purpose of this pre-test was to assess baseline knowledge of sagittal foot & ankle anatomy and permit comparison with post-intervention performance.

On completion of the circuit of 3 stations (total 60 min teaching time), participants were re-convened and re-tested using the same methods, using two different sagittal MRI images of the foot & ankle. Pre and post-test question papers were scrutinized by senior faculty members in the design stages of the study to ensure they were of equal difficulty and therefore that the scores would be comparable.

Table 2
Mean and standard deviations of the unadjusted pre and post-intervention test scores by group.

Score	Group A (n = 25)	Group B (n = 28)
Pre course	7.3 (1.70)	8.0 (1.88)
Post course	8.1 (1.69)	9.2 (1.33)
Improvement	0.7 (2.44)	1.2 (2.07)

After the second written test and a short refreshment break the groups were crossed over to the opposite circuit i.e. Group A (control group) received teaching using the SPS resources (circuit B) and Group B (intervention group) received teaching using 'standard' resources (circuit A). In total all participants rotated through 2 circuits of 3 stations of 20 min receiving 120 min of teaching.

At the end of the study participants completed a further qualitative questionnaire assessing change in confidence in interpreting MRI images of the foot & ankle, perceived usefulness of the SPS as a teaching resource for foot & ankle and for learning sagittal anatomy in general. Participants were also asked to state in which order they preferred to receive the teaching, i.e. SPS or conventional resources first.

3. Statistical analysis

Analysis was carried out by a medical statistician using R version 2.12.1. Non-parametric paired data was analyzed using a t-test. Adjusted data was analyzed using a simple linear regression model to examine the influence of pre-reading and seniority on test scores.

4. Results

53 participants were randomized. All participants completed the pre-test qualitative questionnaire and MRI interpretation written test. One participant dropped out of the study after the first circuit but before the second written test. Complete test data is available on 52 participants.

4.1. Qualitative results

The pre-course qualitative questionnaire consisted of 8 items on a 10-point Likert scale. Results of the questionnaire are presented in Tables 3a.

Before the teaching interventions, participants reported low confidence in identifying normal anatomical structures of the foot and ankle on sagittal images (mean = 3.6), and placed high importance on this as a skill for their future careers (mean = 8.0). They reported interest in the use of new tools for learning sagittal anatomy (mean = 8.8).

After cross-over when both groups had received both interventions, the participants reported they were more confident in interpreting sagittal images of the foot and ankle (mean = 8.0), and found the SPS teaching very useful (mean = 7.6). The majority of participants stated that they would like to see SPS incorporated into standard anatomical teaching in all areas of the body (mean = 7.6)

The participants preferred to receive teaching using conventional resources first and then the SPS to augment their knowledge (mean = 7.8) rather than using the SPS first and then conventional resources (mean = 4.3) (Table 3b).

Table 3a
Qualitative pre-course assessment of trainees; participant agreement with statements using a 20-point Likert scale.

Question	Mean value (standard deviation)
I have been taught sagittal anatomy (in general) at medical school	5.2 (1.77)
I feel I have an adequate knowledge of sagittal anatomy in general	4.7 (1.67)
I find it difficult to interpret sagittal anatomy of cross-sectional images (CT or MRI)	7.0 (2.16)
I find it difficult to build a 3D picture in my mind of normal anatomical structures	5.8 (2.21)
I think a good understanding of sagittal anatomy (in general) is important for later in my career	8.0 (1.79)
I am confident at interpreting normal anatomy on cross-sectional scans of the foot and ankle (MRI or CT)	3.6 (1.83)
I think that being taught anatomy using normal methods is a good way to learn cross sectional anatomy	6.4 (1.90)
I would be interested in using other teaching tools to enhance learning of sagittal anatomy	8.8 (0.99)

Table 3b
Qualitative post-course assessment of trainees.

Question	Mean value (standard deviation)
I am more confident at interpreting normal anatomy on cross sectional scans (MRI or CT) of the foot and ankle after attending the course	8.0 (1.41)
After attending the course, I think that sagittal plastinated slices (SPS) are a useful tool in learning sagittal anatomy	7.6 (1.85)
The SPS helped me to build a 3D picture of the relevant anatomical structures in my mind for when I look at scans	7.2 (1.96)
I think that SPS may be useful in other areas of anatomy education	8.2 (1.54)
I think it is better to learn the cross sectional anatomy firstly using conventional resources and then to use SPS as an extra resource to learn how to interpret images	7.8 (2.24)
I think it is better to be taught using SPS first, to enhance my understanding of 3D anatomy, than to have teaching using conventional resources alone	4.3 (2.33)
I would like to see SPS incorporated into standard anatomical teaching in all areas of the body, to help build a 3D picture and to help interpret cross sectional (CT or MRI) images.	7.6 (1.87)

4.2. Written-test scores

The mean and standard deviations of the unadjusted pre and post-intervention test scores are presented in Table 2. Group A (control group) showed a mean improvement in test score of 0.7 points following the teaching intervention and Group B (intervention group) improved by 1.2 points. Improvement was calculated by subtracting the pre- from the post-intervention test scores. There was a wide range in test score improvement as demonstrated by the boxplot in Fig. 4. Using a t-test the difference between the mean improvements in scores for the two groups was not found to be statistically significant ($p = 0.413$)

It was hypothesized that the amount of pre-course reading and that the clinical experience of the participants may also affect test performance. Hence, a linear regression model was constructed to test this hypothesis. The dependent variable was the improvement in scores and the independent variables were the intervention group (A or B), the number of minutes of pre-course reading completed (0–240 min) and the professional level (third year student, fourth year student or professional). No variables were found to be significant. There was no statistical significance in test scores between male and female participants.

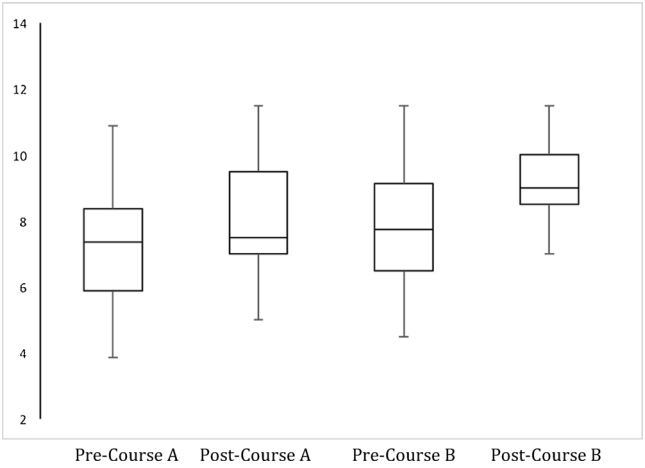

Fig. 4. Boxplot showing pre and posttest scores by group (A = control group, B = intervention group); median and IQR are shown.

5. Discussion

Plastinated techniques were first introduced in the late 1970s [14], and although expensive, plastinated prosection models are gaining popularity as an anatomical teaching tool due to their practicality and robust nature. Preservation methods allow students to study the specimens repeatedly with minimal wear and tear, whilst maintaining the detail that standard plastic models lack, and therefore offer a practical solution without sacrificing detail. They also permit realistic visualization of anatomical concepts that are too difficult to describe [4].

In a study examining the use of plastinated cross sections as a learning tool for veterinary students learning cross-sectional imaging of the tarsus of a horse, Latorre et al. [15] found that plastinated cross sections could be used to produce body sections for comparison with MR images and that a combined use of transparent and thick slices from the same specimen allowed an accurate evaluation of many anatomic structures in the MR images. Furthermore, student satisfaction with plastinated models was high [15]. As well as being perceived to be a useful educational tool, plastinated cross sections are valuable in the research setting to describe and investigate complex anatomical interactions such as in the foot and ankle [16,17], and in ultra-thin form to validate radiological research [18].

The present study results indicate that students value knowledge of cross-sectional anatomy and think that it is a necessary skill to acquire for their future careers, although they report that they do not feel they have adequate knowledge and are not confident to identify anatomical structures on cross sectional images. They are, however, interested in new tools that may help their understanding and reported that the SPS helped them to build a mental 3-D picture when looking at sagittal scans. They also indicated that it would be useful to have SPS for learning other conceptually challenging anatomical structures such as the head and neck.

Learning spatial relationships appears to require both perception (derivation of information about pattern and form) and imagery (reconstructing the perception in ones' own mind) and requires time for

both reconstruction and validation [19]. Miller [20] identified that learning spatial relationships in anatomy is difficult and that the difficulty varies greatly between students. This ability is apparently quite independent of students' general intelligence and may even influence future career choice, suggesting it may at least, in part, be innate to the individual [21]. The results of this study indicate that the students preferred to use the SPS after being taught by traditional methods. This is also in line with constructivist principles, namely that students can construct their own understanding and knowledge through experiences. They can then reflect on those experiences and build on the knowledge that they already possess. The SPS provide an invaluable bridge between true cadaveric tissues and radiological images and the use of serial images allows the student to work independently and sequentially through the SPS and radiological images to build spatial relationships at their own pace.

When considering how the SPS may provide assistance to learners, Garg et al. [22] described how three dimensional (3-D) objects can be studied from multiple views (MVs) or from only certain key views (KV) and gave the example of a human skull in an anatomical atlas where the skull can be viewed from 5 key viewpoints (anterior, posterior, lateral, superior and inferior) whereas a computer model may be able to rotate the skull through a 360° sphere allowing up to 614 different viewpoints (MV). Although there has been recent evidence that 3-D images can improve understanding of spatial and functional anatomy [23,24], the effect was found to be greater in male participants than female participants [24]. Traditionally, it has been found that spatial anatomy may be remembered as viewpoint specific 2-D mental images, which the mind then rotates; hence there has been controversy over whether 3-D images provide a true educational advantage over standard 2-D images [22,25,26]. Interestingly, when provided with an entire range of images, students chose to spend the majority of their time examining the KVs [27].

In a study examining how medical students learn spatial anatomy using KVs and MVs of the carpal bones [23], it was found both that the inherent high spatial ability of the student and self-directed examination of a object from multiple perspectives improves spatial learning. The authors suggest that the use of student-controlled multiple-view models such as dissected samples, skeletons, and plastic and computer models are an effective method of improving spatial learning and suggest that when designing new instructional materials it is prudent to consider the inherent characteristics of these materials and how they will benefit the learners. The qualitative results of our study have confirmed that the students value new educational tools to assist with their learning of spatial anatomy and we suggest that the 2-D nature of the SPS will help the learners to remember KVs and will appeal to all learners, regardless of ability or sex. SPS may also be used either for didactic teaching purposes or as self-directed learning aids.

The intervention group scored 1.2 points higher in the post-intervention test, and the control group scored 0.7 points higher. This difference did not achieve statistical significance, and there was a wide range of test improvement scores. This may have been due to a number of factors, including small sample size and confounding variables including the amount of preparation for the session and prior knowledge, although the teaching sessions were designed to standardize knowledge between the two groups. Also, for ease of testing, students were given stand alone sagittal MRI images, and the inability to orientate themselves by using multiple images may have influenced test scores. There were some methodological weaknesses to our study, there was no systematic matching done at randomization (which may have had value given the professionally heterogenous nature of our study participants), the questionnaires were not previously validated and we did not employ reverse scoring for the Likert items. Despite these weaknesses, we feel that the qualitative data obtained provides valuable information about the educational intervention.

In conclusion, the acquisition of spatial relationships in foot and ankle anatomy is challenging to teach and to learn. Ideally, students should be presented with a variety of educational and clinical tools to assist their learning to accommodate for differences in inherent ability and gender. The learners in this study found the SPS to be a useful educational tool and preferred their use after traditional teaching methods. We therefore conclude that SPS are a valuable educational tool in both anatomy and radiology teaching.

Conflict of interest

The authors have no conflicts of interest to declare.

Funding

None has received funding for this study.

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