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Can we recreate intraoperative weight bearing in hallux valgus surgery? A radiographic study using a reproducible technique of load bearing to simulate weight bearing

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Introduction: Correction of the hallux valgus angle, intermetatarsal angle and sesamoid subluxation in hallux valgus surgery is key to restoring normal joint biomechanics. This is difficult to judge accurately intraoperatively as the foot is not weight bearing. We examine the reproducibility of a simulated weight-bearing test on intraoperative images.

Methods: This is a prospective study of 20 patients undergoing a scarf osteotomy for hallux valgus. All patients were operated by one fellowship trained surgeon and were excluded if they had inflammatory arthropathy. At the time of surgery, two intraoperative images were taken after surgical correction. A standard positional anterior posterior (AP) image was taken followed by a reproducible simulated weight bearing view (i.e. load bearing view). A retrospective review of 6 week and 4-6 month weight bearing images was conducted to assess any measurable differences in a separate group of patients.

Results: The mean preoperative HVA was 30.7, IMA was 14.5, sesamoid position was 5.6. On completion of surgical correction the HVA was 6.6, IMA was 7.2 and sesamoid position was 1.8. On simulated weight bearing with an average of 131.2N (range 98.9-163.5N), the HVA was 8.9, IMA was 10.7 and sesamoid position was 2; this was a closer approximation to the 6-week weight bearing view in all indices recorded. No observed difference was noted between 6 week and 3-6 month weight bearing images.

Conclusions: We have found that our standardized simulated load bearing intraoperative view will yield reproducibility and is a good surrogate marker for the 6-week weight-bearing radiograph. We believe locking the ankle joint will avoid rotation of the foot and allow for an accurate evaluation of final correction (HVA, IMA, and sesamoid position) and aid meaningful evaluation of surgical technique. However, it does not represent a final united position therefore we could not recommend its use in isolation.

Keywords: hallux valgus, scarf osteotomy, basilar osteotomy, radiography, sesamoid

Hallux valgus is one of the most common chronic foot complaints [1]. Surgical correction involves a soft tissue release and reconstruction combined with an osteotomy.

The scarf osteotomy is a complex procedure and has many important steps with a learning curve. As a consequence the time taken to master the nuances of surgical technique may prove lengthy with the potential for difficulties and complications along the way [2]. Technical success is defined by correction of hallux valgus angle (HVA), intermetatarsal angle (IMA) and sesamoid position and patient satisfaction.

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Figure 1 and 2 This positional image taken with the foot pressed flat on the image intensifier housing of the C-arm for both positional (Figure 1 - top) and maximal ankle dorsiflexion views (Figure 2 - bottom).

Only one paper has evaluated the use of intraoperative radiography [3]; it highlighted the difficulty in obtaining standardized images. We have observed that non-weight bearing post-operative images show the position of implanted metal work and may provide a guide to correction but do not show absolute mechanical alignment.

Figure 3 An illustration of how the load-bearing image was taken with the foot placed on the scale and then placed in to a talar neutral and ankle dorsiflexed. To assess actual force we placed a weight scale to record the crude reaction force produced on maximal dorsflexion of the foot pre- operatively.

We therefore hypothesize that a standardized intraoperative load bearing view could provide a better approximation to the final weight bearing correction. If this hypothesis were to be correct then one would expect this view to be an improvement on a non-weight bearing early intraoperative and postoperative image.

The purpose of this study was to compare the effects of an intraoperative simulated load bearing view to that of a simple foot positioning AP view to assess correction. Both images were then reviewed in comparison to the final weight-bearing image at 6 weeks. An assessment was made as to which of the two views better approximated the final weight-bearing image. A further assessment of adequacy of the 6-week view was made in comparison to 3 – 6 month weight bearing views.

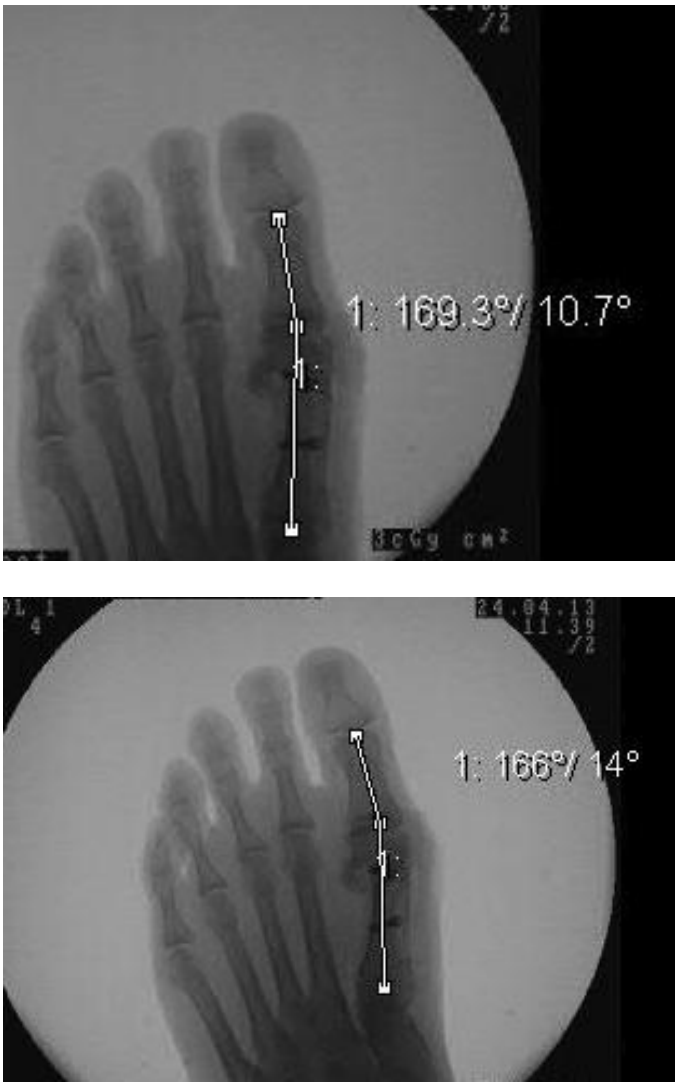

Figure 4 Example of positional (4a) vs. load bearing (4b) images taken in theatre where the soft tissue repair was revised to ensure adequate hallux valgus correction.

Materials and Methods

After internal ethical approval and appropriate consent; consecutive patients operated for hallux valgus were included, conducted by the fellowship-training surgeon (RSA). The operation performed in all cases was a scarf osteotomy plus or minus an Akin osteotomy. The patients were reviewed at 2 weeks postoperatively for a dressing change and wound check. They were seen again at 6 weeks for final weight bearing radiographs.

Intraoperative Radiographic Technique

Images were taken after fixation of the scarf osteotomy and medial capsular repair. All patients had a positional AP intraoperative image as per Elliot et al [3] standard technique. This positional image was taken with the foot placed flat on the image intensifier housing of the C-arm (Figure 1). To produce simulated weight bearing the foot was held in talar-neutral and the image intensifier was raised until maximal ankle dorsiflexion was achieved (Figure 2). In doing this, the simulated pressure was being maximally taken up by the forefoot.

To make an assessment of the force applied when the foot was in this position we placed a single weighing scale to record a maximal amount of reaction force produced on maximal dorsiflexion of the foot preoperatively (Figure 3). The force was calculated in Newtons. A surgeon not involved in the care of the patients made radiographic measurements of the radiographs (C.E.). The images were examined on our PACS system and the intermetatarsal angle (IMA), the hallux valgus angle (HVA), medial sesamoid position was recorded, using the 7 degrees of displacement described by Hardy and Clapham (positions 1–3 normal) [4].

A further retrospective analysis was undertaken by C.E. of 6-week weight bearing radiographs from our hallux valgus data base of patients whom had further radiographs taken at 12 – 24 weeks post-surgery. This additional analysis was done in order to assess the adequacy and validity of 6-week weight bearing radiographs as a surrogate marker for final radiographic outcome.

Statistical Analysis

To determine the accuracy of the fluoroscopy films we compared the two intraoperative images with each other and then finally with the 6-week postoperative radiographs. Further analysis of 6-week weight bearing radiographs and 12-24 week radiographs was undertaken separately. Statistical analysis was achieved with a paired t-test to evaluate the difference between measurement and a Shapiro-Wilk test to evaluate the distribution of measurements with p values less than 0.05 defined as significant.

	HVA	IMA	Sesa. Position	Load
Preoperative	30.7° (26.2-33.7°)	14.5° (13.3-15.4°)	5.6 (3-6)	Body weight
Positional	6.6° (5.2-7.9°)	7.2°* (6.3-8.2°)	1.8* (1-2)	0N
Load Bearing	8.9°* (7.3-10.4°)	8.4°* (7.5-9.2°)	2°* (1-3)	131.2N (98.9-163.5)
Postoperative	10.9°* (10.1-11.6°)	8.8°* (7.9-9.7°)	2°* (1-3)	Body weight

Table 1 Measurement of angles from images taken from time of surgery to follow up and the load applied at the time of imaging. Ranges are given as 95% confidence intervals around the mean for angles and force measurements, and for sesamoid position given as actual values. *Statistical analysis suggested no significant difference was found between these values at $p<0.04$, and $p<0.03$, respectively.

Results

Twenty-two consecutive scarf osteotomies were undertaken for hallux valgus in 20 patients; 2 required an Akin osteotomy, all were included in final analysis. There were 18 females (2 bilateral cases) and 2 males with an average age of 56.2 years.

For the first 10 cases we measured the weight as surrogate for the reaction force produced on maximal dorsiflexion of the foot. We found that the mean pressure generated was 131.2N (range 98.9-163.5N; Table 1). Intraoperative images were taken on completion of surgical correction and on two separate occasions intraoperative images led the surgeon to make an alteration in the soft tissue tensioning to ensure sesamoid correction.

The preoperative radiographs showed the mean HVA was 30.7 (26.2-33.7), IMA was 14.5 (13.3-15.4) sesamoid position was 5.6 (mode 5; range 3-6). On completion of surgical correction the positional view showed the corrected HVA was 6.6 (5.2-7.9), IMA was 7.2 (6.3-8.2) and sesamoid position was 1.8 (mode 2; range 1-2). Our simulated load bearing with an average of 131.2N (98.9-163.5N) demonstrated an increase in the HVA to 8.9 (7.3-10.4), the IMA was 8.4 (7.5-9.2) and sesamoid position was 2 (mode 2; range 1-3) (see figure 4).

	HVA	IMA	Sesamoid Position
6-week weight bearing view	7.5° (6.2-9.9°)	9.6° (7.2-11.9°)	2 (1-3)
3-6 month weight bearing view	7.9° (5.9-10.4°)	9.3° (7.1-12.6°)	2 (1-3)

Table 2 Measurement of angles from 14 patients taken from 6-week and 12-24 week weight bearing radiographs after surgery.

Postoperative radiographs showed the mean HVA increased to 10.9 (10.1-11.6), IMA was 8.8 (7.9-9.7), and median sesamoid position 2 (mode 2; range 1-3) (Table 1). We observed that the simulated weight bearing views were a closer approximation to the 6-week weight bearing view in all indices recorded ($p<0.05$). They showed an improvement in the HVA angle and each individual angle measured. The sesamoid position was found to follow a normal distribution ($p<0.05$) for each image.

Our surgical database identified 14 patients whom underwent sequential bilateral foot surgery and consequently had 3 – 6 month post-operative weight bearing images of their original correction. The results showed an observed difference in HVA and IMA but no change in sesamoid position, from the 6- week weight-bearing image (Table 2). Ranges are given as 95% confidence intervals around the mean for angles.

We found that all populations fitted a normal distribution and there was no difference between HVA ($p<0.03$), IMA ($p<0.05$), and sesamoid position ($p<0.02$) in the radiographic views. Our results also bear out the fact that a positional view does not give a reliable measure of the final HVA as the null hypothesis could not be rejected. The observed difference in HVA and IMA were not significant.

Discussion

In the original paper by Elliot et al in 2011 [3] non-loading intraoperative radiographs were thought to be reliable and reproducible. However, there was a statistically significant increase in post-operative weight bearing HVA compared with the measurements made intraoperatively. This is

important, as hallux valgus correction requires accurate assessment of the HVA angle. Whilst in their series the mean HVA was within normal limits the actual difference between intraoperative and post-operative image was 8.9 degrees and post-operative HVA measurements ranged from 4.5-13.6. This is of significance when it is taken into account that normal HVA is less than 15-20 degrees [1].

Our results show that simulated load bearing on the forefoot whilst the ankle is held in talar-neutral will give a closer approximation to the 6 week weight bearing view in all measurable indices - particularly the HVA than simple placement as suggested by Elliot et al [5].

Our standardized load bearing images require the patient to be able to flex the knee to 60 degrees, and require the hip to flex to 60 degrees and depend on the surgeons ability hold the foot at the ankle and the radiographer's skill to simulate weight bearing. This achieved the constant end point of the patient's maximal ankle dorsiflexion, which is a reliable and reproducible end point allowing the surgeon to lock the foot and preventing rotation leading to a semi oblique view. Our results suggest measurement pressures are highly variable (90-180N) unlike the constant end point of maximal ankle dorsiflexion that is dependent on patient ankle mobility. Loading of the forefoot soft tissues in this manor produced an average of 131.2N once the ankle is fully dorsiflexed. This is not anyway near the forces generated on weight bearing and would account for the measurable differences in angle measurements between the different image time points.

We infer that simulated weight bearing seems to allow loading of the medial capsular repair but not with the high pressures one would expect in a weight bearing view. However, our belief is that the range of motion in the ankle may well be the limiting factor in achieving more force but it may avoid rotation of the foot and getting a semi-oblique image during surgery when trying to simulate true weight bearing. Thus, leading to a more reproducible and accurate measure of HVA.

Further studies would be required to assess where the additional force generated on weight bearing may be taken up e.g. by the elastic nature of the tissues such as the intermetatarsal ligaments and dynamic forces acting on the first metatarsal conform to Hooke's Law to prevent excessive separation of the first and second rays.

Our experience using intraoperative fluoroscopy revealed two separate occasions where the intraoperative images led the surgeon to make an alteration in the orientation or degree of sesamoid correction performed through improved soft tissue release and medial capsular reefing (sesamoid position 5 to 3). In the second case the osteotomy required a further lateral shift to correct the HVA (14.8 to 11.6).

The mean corrections in this study for HVA were within 1-3 degrees (HVA 9.7 vs. 9.9 and IMA 8.8 vs. 6.4) of previously published results from one senior author (M.S.H.) [6]. Thus, we would recommend intra-operative fluoroscopy as a useful aid in the early stages of learning the scarf osteotomy and the many steps to refine this technique [7]. Thus avoiding common procedural problems such as under correction, mal-rotation, metatarsal fracture, and troughing as well as a better appreciation of potential interphalangeus deformity [1,2,5].

Our unit has found that adequate surgical exposure leads to a satisfactory view of the sesamoids and the osteotomy site; providing adequate assessment of correction obtained from the osteotomy and soft tissue release and would not routinely use intraoperative imaging once the surgeon was appropriately skilled in the procedure.

We are aware that some surgeons do not request postoperative radiographs routinely after scarf osteotomy but instead rely on clinical indices [1,8,9]. Even though our results support the use of a reproducible simulated load bearing intraoperative image as a close approximation of actual hallux valgus correction, we could not recommend them as a surrogate for a final united position, and they should not be used in isolation.

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