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Value of a lower limb immobilization device for SPECT/CT image fusion optimization

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Short running title: Lower limb immobilization SPECT/CT

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Abstract

The foot and the ankle are small structures commonly affected by disorders, and their complex anatomy represent significant diagnostic challenges. SPECT/CT Image fusion can provide missing anatomical and bone structure information to functional imaging, which is particularly useful to increase diagnosis certainty of bone pathology. However, due to SPECT acquisition duration, patient's involuntary movements may lead to misalignment between SPECT and CT images. Patient motion can be reduced using a dedicated patient support. We aimed at designing an ankle and foot immobilizing device and measuring its efficacy at improving image fusion.

Methods: We enrolled 20 patients undergoing distal lower-limb SPECT/CT of the ankle and the foot with and without a foot holder. The misalignment between SPECT and CT images was computed by manually measuring 14 fiducial markers chosen among anatomical landmarks also visible on bone scintigraphy. Analysis of variance was performed for statistical analysis. **Results:** The obtained absolute average difference without and with support was 5.1±5.2 mm (mean±SD) and 3.1±2.7 mm, respectively, which is significant ($p<0.001$).

Conclusion: The introduction of the foot holder significantly decreases misalignment between SPECT and CT images, which may have clinical influence in the precise localization of foot and ankle pathology.

Key words: SPECT/CT, misalignment, lower-limb, patient-motion

Introduction

Single photon emission computed tomography/computed tomography (SPECT/CT) is an imaging technique combining both functional and anatomical information (1-5) in the identification and characterization of different disorders (2), including endocrine and neuroendocrine diseases, infection and inflammation (2,4,6-8), benign and malignant bone diseases (2,4). SPECT/CT is currently on the main focus of growing interest in the assessment of musculoskeletal disorders (5).

The high sensitivity provided by the single photon emission computed tomography (SPECT) combined with the increased specificity provided by the computed tomography (CT) (7,9) can increase diagnostic accuracy and confidence in areas with special diagnostic difficulties, like the foot and the ankle (7,9,10). Indeed, in clinical examination, it can be challenging to find the origin of the pain (10), even for the most experienced clinicians (4), mainly because of the variety of etiologies producing similar patient complaints and clinical abnormalities (8). The foot and the ankle are composed by a complex anatomy of small structures (1,9,10), including bones, ligaments and tendons (11), which can be subject to inflammatory and degenerative diseases producing severe disability (12).

To make specific diagnoses and deliver appropriate treatments, small or focal pathologic changes must be well localized (7). Currently, magnetic resonance imaging (MRI) is the most widely used imaging technique in evaluating chronic foot and ankle pain, although SPECT/CT can play an important role in assessing the origin of pain (4,10) and early stages of the disease (13). On the other hand, in early degenerative changes in the varus and valgus misaligned hind foot, SPECT/CT is useful before conventional scintigraphy and CT scans (14).

Aligning two different modality datasets is not a simple task due to differences in imaging resolutions, patient's alignment (15), as well as differences between the information obtained from each technique (16).

Some authors have shown that imaging misalignment resulting from patients movement (6,17) occurs in the majority of studies and that even 1 pixel misalignment can already be visible on corrected SPECT images (18). Based on the CT information on tissue absorption, SPECT images can be corrected for tissue and bone attenuation. The pixel values must be scaled to match attenuation coefficients appropriate and SPECT images must be precisely aligned and CT-based attenuation correction is sensitive to spatial misalignment between CT and SPECT and can result in artifacts in the attenuation corrected SPECT scan (19). In order to avoid these issues, it is important to have an optimal patient preparation, which includes appropriate and comfortable support, as well as to select established and validated protocols (20,21).

The aim of this study was to manufacture and implement a dedicated foot immobilization support during SPECT/CT acquisitions of foot and ankle to decrease the likelihood of movement between both studies, thus contributing to the improvement of alignment.

Materials and Methods

Patient Population

We evaluated twenty patients (mean 50±15 y, range 18–73 y, 16 men, 4 women) referred for various foot and ankle problems, investigated for persistent pain after post-traumatic injury. Between January and May 2014, they underwent distal lower-limb SPECT/CT imaging at the end of a standard 3-phase bone scintigraphy. According to the Swiss legislation (Art. 2 of the Federal Act on Research Involving Human Beings), the Ethics Commission ruled that the present study on imaging quality did not require approval by a Swiss Ethics Committee on research involving humans and waived the requirement to obtain written informed consent.

Patients were divided into two groups: group G1: 10 patients, in whom the SPECT/CT was performed without the foot holder; and group G2: 10 patients, in whom the SPECT/CT was performed with the foot holder.

Foot Support

The support consists of a 40-cm (L) 22-cm (W) × ×15-cm (H) compact panel composed of synthetic materials (0.8- and 1-cm thickness, 200–300 HU) built for this study to achieve firm, but comfortable immobilization of the foot and the ankle during the examination (Figure 1). The inner parts were padded with soft material (2- to 3-cm thickness, HU –950) in order to reduce patient discomfort. The support was not found to minimally attenuate significantly the gamma radiation at 140 keV energies (about 13–16%) (22). More importantly, the support was entirely in the field of view of the CT, which is important as to not introduce truncation artifacts during attenuation correction (17).

Each patient received instructions to avoid any movements during the procedure. The support was manufactured to resemble the ankle and the foot MRI array coil used by our Radiology Department to ease SPECT/MRI fusion, when needed. When in use with patients, we confirmed that both feet were always securely fixed with the built-in strap to increase the accuracy and to make individuals feel comfortable during image acquisition.

Image acquisition

All patients underwent classical technetium-99m-3,3-diphosphono-1,2- propanedicar-boxylic acid bone scintigraphy after intravenous injection of a mean activity of 840±100 MBq (range, 590–950 MBq), followed by SPECT/CT imaging of both foot and ankle 5.4±0.9 hours (range 3.8–7.8 hours) after tracer injection.

SPECT/CT (GE Discovery NM/CT 670, GE Healthcare, Milwaukee, WI) image acquisition was performed using high-resolution low-energy collimator with auto contour rotation mode (15 seconds/frame, 60 views over 360º, step-and-shoot mode, matrix size 128x128, zoom factor 1.00) and a 15% energy window was centered on 140 keV. Helical CT acquisitions used a voltage of 120 kV, a current of 90 mA, a slice thickness of 0.625 mm and a 512 matrix for reconstruction.

SPECT images were reconstructed using iterative reconstruction (ordered subset expectation maximization), 2 iterations, 10 subsets, using PSF-recovery "Evolution for bone" algorithm" and CT for attenuation correction on a Xeleris 3.0 workstation (GE Healthcare, Milwaukee, WI).

Image analysis

SPECT and CT image datasets were processed using the Integrated Registration tool on an Advantage workstation (GE Healthcare, Milwaukee, WI). The misalignment between SPECT and CT acquisitions was quantified by manually placing 14 fiducial markers chosen among anatomical landmarks (tibia, fibula, medial malleolus, lateral malleolus, insertion of the Achilles tendon, tuberosity of the 5th metatarsal and distal phalanx of great toe of right and left foot/ankle) on each SPECT and CT images (Figure 2). For optimal visualization of the different landmarks, varying the color look-up table of the images was allowed. The fiducial marker placement was processed by a nuclear technologist and subsequently checked by two nuclear physicians.

Statistical Analysis

The results were analyzed using Stata 13.1 (StataCorp, College Station, TX). Mean and standard deviation are presented unless specified otherwise. Box plots were generated to display the absolute difference between patients group. Differences between the 2 datasets according to the presence or absence of support and the fiducial marker number (1–14, 7 for the right foot and 7 for the left one) were assessed using analysis of variance. A p-value of 0.05 was considered as the threshold for significance.

Results

A total of 280 anatomical landmarks were analyzed in twenty patients (as illustrated in Figure 3 for the great toe landmark on SPECT and CT images for a patient with the support and without the support. The absolute difference for patients without and with support was 5.1±5.2 mm vs. 3.1±2.7 mm, respectively. Thus, the alignment between SPECT and CT images was better with support, as reported in Figure 4. When considering a misalignment threshold of 5 mm as a reference for appropriate clinical evaluation, most individuals using the support were found below this empirical value (dotted line) as opposite to patients without the support.

Results of the analysis of variance showed that misalignments in the group using the support were significantly lower than for those without support ($p<0.0001$). Moreover, no dependence of the misalignment on the fiducial marker was observed ($p=0.54$) (Figure 5A).

Discussion

This is the first study that quantitatively evaluates the value of a lower limb immobilization device during SPECT/CT acquisitions. Our results show a significant reduction in misalignment of SPECT/CT images between patients with and without the dedicated foot support, presumably due to a more stable and comfortable patient position using the support. However, a certain degree of misalignment is still present because of uncontrollable movements and the support may need to be adjusted for each patient (*e.g.* the distal extremities of the toes depend on the foot size).

Beyer et al. assessed the effectiveness of different supports to reduce misregistration in the head and the neck during whole-body positron emission tomography/computed tomography studies using anatomical landmarks *(20)*. They observed that the motion likelihood can be reduced and that an improvement in accuracy can be observed during coregistration (the misalignment was reduced to a minimum of 1.4 mm for a head holder fitted with a vacuum-lock bag). However, our study shows larger misalignments even when the support is applied, which could be explained by SPECT's worse spatial resolution and greater partial volume effect. Moreover, head and the neck structures maybe more stable when compared with lower extremities, as the ones addressed in this article.

An important limitation of manual alignment is the focally increased pathological uptake observed in certain patients, which increased uncertainty when assigning anatomical landmarks close to these structures. The simultaneous analysis of CT images increases accuracy when using this approach, emphasizing the previously mentioned limitation. Structures such as malleoli or the one concerning the insertion of the Achilles tendon were particularly difficult to identify but the task seemed to be easier when the support was used. In these conditions, the implementation of the support seems to improve the clinical performance of the test, allowing for better characterization in case of small focal abnormalities. It is worth mentioning that SPECT spatial resolution was worse than CT's leading to difficulties to precisely identify anatomical landmarks; this could therefore mask smaller differences.

Gayed *et al.* reported an increased quality in diagnostic when using SPECT/CT, when compared to SPECT (8). Considering this, misregistration between SPECT and CT would need to be kept to a minimum by using a support like ours. For instance, when considering the horizontal red line in Figure 3, drawn at 5 mm (this represents the size of a SPECT voxel or about half of the spatial FWHM SPECT resolution), 32% (45/140) of the values for the class of patients without support is above it while this number reduces to 12% (17/140), for patients with the support which is significantly different ($p<0.001$).

One limitation of this current support design is a slight increase in the distance between the foot/ankle and the detector due to the intrinsic geometry of the support which was manufactured to look alike a foot ankle MR array coil to allow easy SPECT/MR fusion. This could lead to a slight decrease in spatial resolution. A final limitation of our study would be a relatively small number of patients in each group ($n_{patients}=10$), with a number of anatomical landmarks in each patient ($n_{landmarks}=14$) quite high making a large number of measurements in each group ($n_{measurements}=140$ in total), however. Future research will include comparing the comfort with and without support in the same patient, as well as simultaneously evaluating image quality.

Conclusion

Our study shows that a foot immobilization device can significantly reduce misalignment between SPECT and CT images during hybrid SPECT/CT. This may positively influence localization and clinical diagnosis in areas of complex foot and ankle anatomy.

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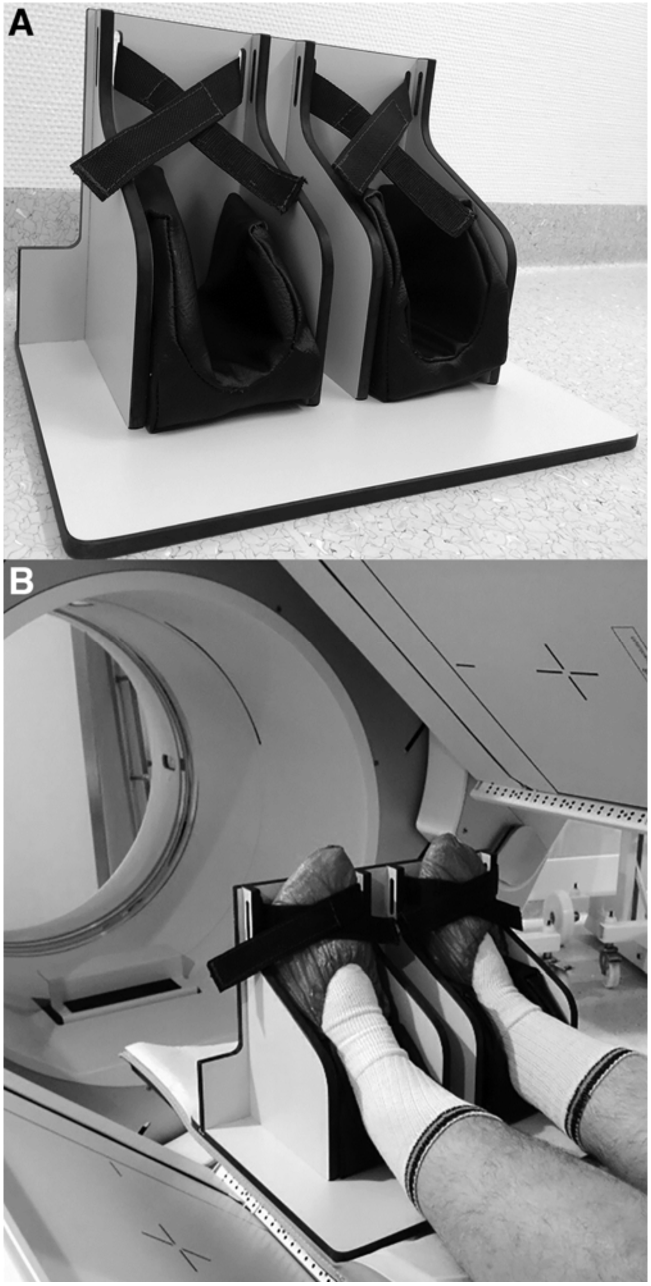

Figure 1. (**A**) Dedicated support for ankle/foot used for SPECT/CT acquisitions. (**B**) The foot is well fixed and retains an aligned position thanks to comfortable cushions.

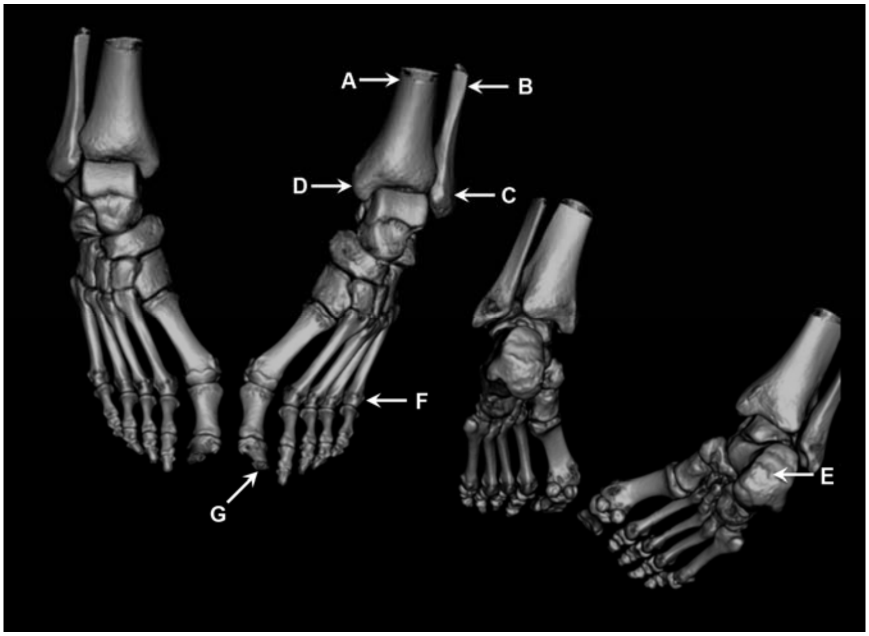

Figure 2. Listing of the 7 anatomical landmarks (**A–E**, see text) used to quantify misalignment between CT and SPECT images.

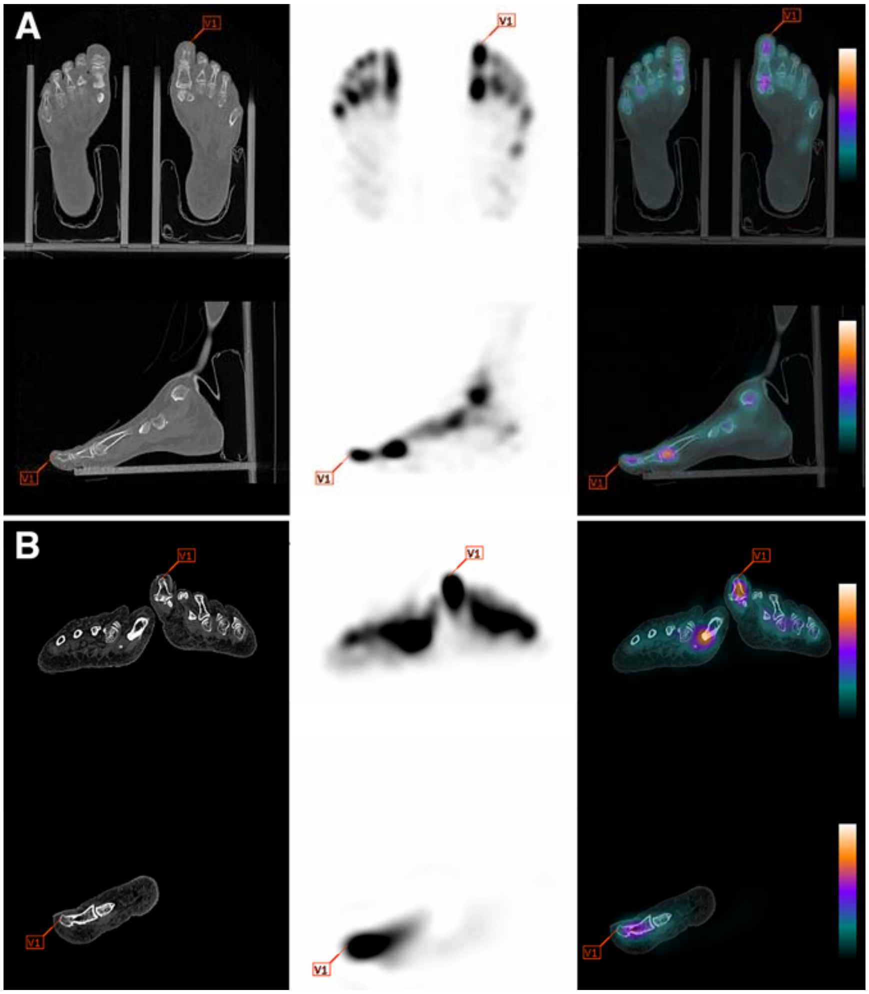

Figure 3. Example of anatomic landmark of the left distal phalanx of the great toe in patients with (**A**) and without the support (**B**). From left to right: CT, SPECT and SPECT/CT fusion images.

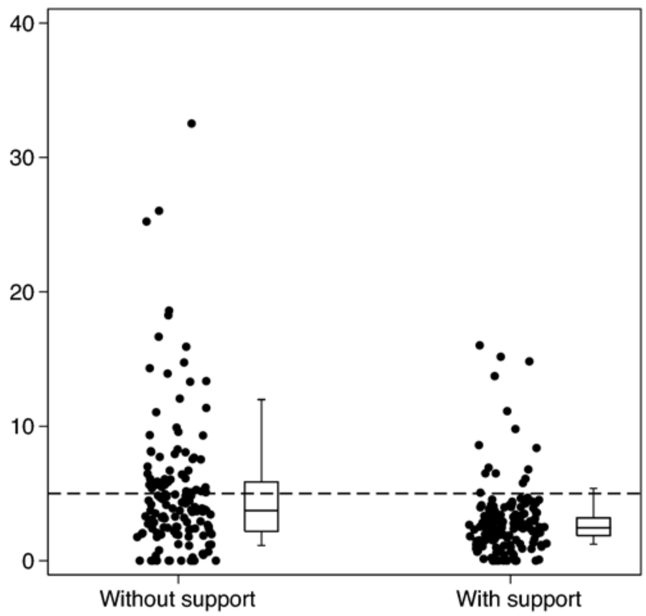

Figure 4. Box plot showing distribution of absolute difference |SPECT–CT| (mm) in the groups of patients without and with the support (the box represents the median and quartiles and the whiskers show the 10th and 90th percentiles). The dotted line is drawn at 5 mm (representing the size of a SPECT voxel), above which 32% (45/140) of the measurements were larger without support and only 12% (17/140) with the support (p<0.001).

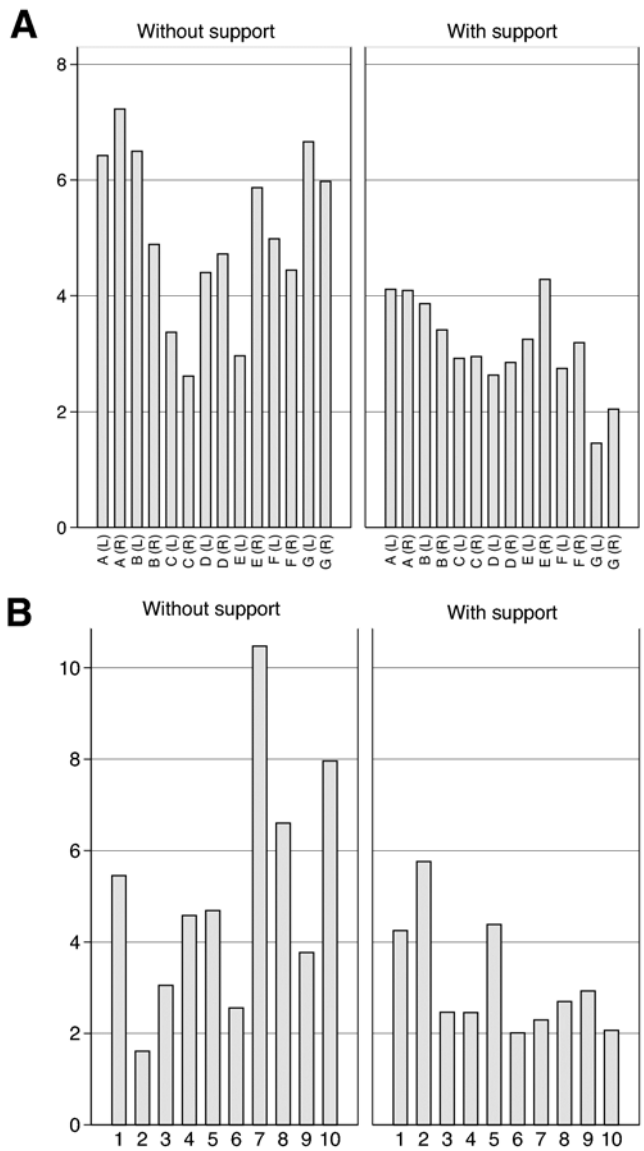

Figure 5. (**A**) Mean absolute difference **|**SPECT–CT**|** (mm) according to the landmark (A–G), each for the left (L) and right (R) foot without and with the support. (**B**) Same mean absolute difference **|**SPECT–CT**|** (mm) for patients #1–#10 without and with the support.