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The biomechanics of the first metatarsal bone in hallux valgus: A preliminary study utilizing a weight bearing extremity CT

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ABSTRACT

Background: Hallux valgus is a common but aetiologically not perfectly understood condition. Imaging in hallux valgus is based on weight bearing plain radiographs or in exceptional cases on non-weight bearing computerized tomography (CT)-studies.
Methods: A portable extremity CT was used to study the forefoot with focus on first metatarsal bone in ten hallux valgus patients and five asymptomatic controls at rest and at weight bearing. Two-dimensional (2D) or three-dimensional (3D) hallux valgus angles, intermetatarsal angles and various other parameters were measured on CT data and the measurements between study groups were compared. The measured angles were also compared to angles measured on plain radiographs.
Results: 2D or 3D angles from CT data sets can be used to evaluate hallux valgus. In hallux valgus, when compared with normal asymptomatic foot, the first metatarsal bone is medially deviated (intermetatarsal angle is wider), the width of the forefoot is increased and the proximal phalanx pronates. Between the study groups there was a statistically significant difference of the measured 3D hallux valgus angles at weight bearing but not at rest suggesting the importance of weight bearing CT studies when evaluating hallux valgus.
Conclusions: To our knowledge, this is the first time weight bearing CT data is presented when evaluating hallux valgus, offering a true alternative to plain radiographs. The relationships of bones of the forefoot, including rotational changes, can be reliably measured using this imaging method.

1. Introduction

More than one third of population over 65 years of age have hallux valgus [1–3]. Even though hallux valgus is so common, its aetiology remains somewhat unclear [4]. Some aetiological factors have been identified in the past. Risk factors include age [2], female gender [2,3], use of high-heeled shoes [5], genetic factors [6] and a long first metatarsal bone [7,8]. Studies on relation of hallux valgus with body weight and pes planus have shown contradictory results [3,9,10].

Operative treatment of hallux valgus includes a long list of different procedures. In fact, over 100 different operative methods have been described in the literature [11]. This high number can be interpreted to reflect an incomplete understanding of this process. In the aetiological studies the main focus has been in risk factor analyses, cadaver studies or imaging studies based on two-dimensional (2D) plain radiographs. Hallux valgus is a slowly progressing complicated three-dimensional (3D) biomechanical process - therefore it is obvious that neither 2D nor a momentary study can provide researchers and clinicians with full understanding of this condition.

To date, the rotational changes of bones of the foot during weight bearing have been hard to measure [12]. In hallux valgus surgery these rotational changes may play a role [13] because during operative treatment also rotational pathology can be corrected. Previous studies based on plain radiographs and cadaveric studies have shown that the first metatarsal bone pronates in hallux valgus [13–16]. These studies also pointed out that the rotational changes of the metatarsals are difficult to evaluate on plain radiographs.

Weight bearing plain radiographs are today regarded as a basis when imaging hallux valgus [17]. Weight bearing CT is a nascent imaging method and may prove to be valuable in the future. Only few studies utilizing weight bearing during CT have been published until now, and none of these with true weight bearing [18,19]. The aim of this study was to determine whether weight bearing CT can be used to study hallux valgus and the rotational status of the bones of the foot.

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2. Methods

2.1. Patient demographics

Ten patients with symptomatic and radiologically proven bilateral hallux valgus at the Podiatric department of Turku University Hospital enrolled in this study. All hallux valgus patients experienced typical pain associated with bunion, the hallux deviated laterally and the hallux valgus angle on plain radiographs exceeded 20 degrees. Five symptomless healthy women served as a control group. They did not report symptoms at the time of the study and did not have hallux valgus or any other foot disorder at the clinical examination. The average age in the hallux valgus-group was 55.7 years (standard deviation (SD) 13.6) and in the control group 57.4 years (SD 6.4). All subjects were women. Both study groups were examined identically at rest and during weight bearing using an extremity CT. The ethics committee of the Turku University Hospital approved the study and the subjects gave their informed consent. We examined altogether twenty forefeet in the hallux valgus group and ten forefeet in the control group at rest and during weight bearing. One foot in the hallux valgus group was operated and therefore excluded from the study.

2.2. Hardware and radiation dose

The CT studies were done with a prototype of an extremity cone beam CT (CBCT) (Verity®, Planmed Oy, Helsinki, Finland). The scanner utilized cone beam technology and was equipped with a 20×25 cm^2 flat panel detector and a 90 degrees rotating gantry (Fig. 1). The scanner was light weight (350 kg) and portable with built-in wheels. The design of the scanner allowed scanning of the patient at rest (sitting) and in weight bearing (standing) position (Fig. 1) with full weight bearing at one foot. The scanner had an anode voltage up to 96 kV, anode current 1–12 mA, dual filtration 0.5 mm Cu+ 2.5 mm Al and pulsed X-ray radiation. The field of view (FOV) was approximately 11×16 cm^2 and during a scan 300 projection images were acquired over an angle of approximately 210 degrees with a scan time of 18 s and an image reconstruction time of 30–120 s. An anode voltage of 90 kV and a filament current of 10 mA were used in this study. The isotropic voxel size was $0.4 \times 0.4 \times 0.4$ mm^3. In the weight bearing position a tailor made carbon fibre plate with thin copper wiring was used under the sole of the foot as a reference plane for the measurements. The copper metal wiring produced visible faint but acceptable metal artefacts to the CT images. According to the manufacturer, the estimated radiation dose for the patient per single CT study was 0.01–0.03 mSv which corresponds to 1–2 chest radiographs.

2.3. Software

CT data sets were analyzed using image processing software (Osirix v. 3.9.1) [20]. The software allowed the export of 3D coordinates of annotated points to external spreadsheet software (Microsoft Excel).

2.4. Data analysis

For the hallux valgus group weight bearing plain radiographs were available for 16 feet. These radiographs were obtained with the subject standing on both feet. In the hallux valgus group, the hallux valgus angle and the 1–2 intermetatarsal angle were measured on plain radiographs as shown in Fig. 2A. Lines connecting the centre of the distal and proximal articular surfaces of first metatarsal bone and the proximal phalanx were drawn and the intersecting angle was measured (the hallux valgus angle) [21]. Lines connecting the centre of the distal and proximal articular surfaces of the first and second metatarsal bones were drawn and

Fig. 1. The light-weight portable CT with a rotating gantry (A). This device allows imaging of the foot and ankle at rest (B) and at full weight bearing (C and D).