Automated Assessment of Hallux Valgus in Radiographic Images

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Automated Assessment of Hallux Valgus in Radiographic Images

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Abstract. The purpose of the study was to develop an automated method for measurement of the selected angular variables, characterizing foot skeleton based on dorsoplantar projection radiographs. The study was a retrospective analysis of radiographic data. Totally, 50 dorsoplantar projection radiographs of a weight-wearing foot were analyzed (24 left and 26 right feet) of 32 patients (23 female, 9 male). Various quantities were measured to assess the severity of hallux valgus. The measurements were performed manually and with an automated method designed in the study. The automated and manual measurements were correlated. Repeated manual measurements were additionally performed to determine the variability of manual assessment of the hallux valgus. High correlation between manual and automated measurements have been observed. The accuracy of the framework is comparable with the accuracy of manual measurements.

1 Introduction

Hallux valgus (HV) is one of the most common deformities of a foot [1]. It is defined as "lateral (valgus) deviation of the big toe at the metatarsophalangeal joint with concomitant medial (varus) deviation of the first metatarsal" [2]. Functional disabilities are associated with the presence of hallux valgus, primarily due to abnormal gait and pain [3]. These disabilities are progressing when not properly treated. The severity of hallux valgus is clinically assessed based on measurement of various angular indices in dorsoplantar projection radiographs of a weight-bearing foot [3]. The image acquisition process is standardized to reflect the maximum deformity in standing position [4]. The most frequently used indices are the hallux valgus angle (HVA), the first and second intermetatarsal angle (IMA12), and hallux valgus interphalangeal (HVI) angle, (Fig. 1) although many more indices can be defined and used depending on the actual need [5]. At present, there is no specialized software for automated assessment of hallux valgus deformity. Usually, the reference lines defining the angles of interest are drawn manually in digital images on monitors of computers using general-purpose software packages supporting such manual measurements. The purpose of the study was to

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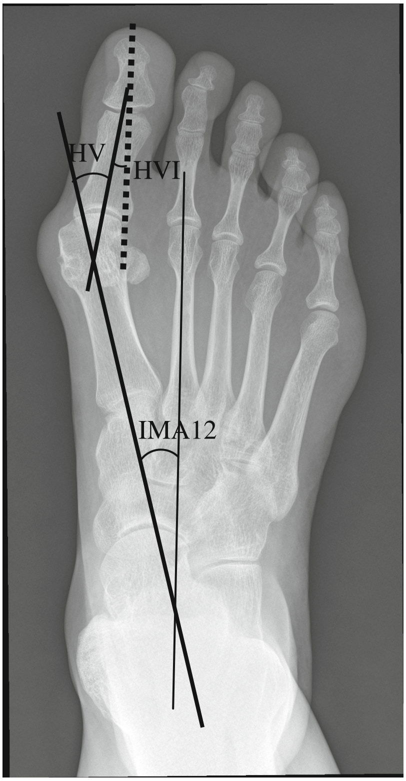

Fig. 1. Definitions of the quantities of interest.

develop an automated method for measurement of the selected angular variables, characterizing foot skeleton based on dorsoplantar projection radiographs.

2 Materials and Methods

The study was a retrospective analysis of radiographic data. Totally, 50 dorsoplantar projection radiographs of a weight-wearing foot were analyzed (24 left and 26 right feet) of 32 patients (23 female, 9 male). The measurements of HVA, IMA12 and HVI were performed manually and with an automated method designed in the study. The images were acquired with a computed radiography system Digital Diagnost (Philips Medical Systems) with built-in 43 cm $\times$ 43 cm flat panel detector. The patients were imaged in standing position. Dorsoplantar projection radiographs of a weight-bearing foot were acquired with peak kilo-voltage from 57 to 60 kVp, exposition from 2.9 to 3.6 mAs and magnification from 0.25 to 0.33. The pixel size of the images was equal to 0.136 mm. The average width of the analyzed images was equal to 950 pixels (minimal 750, maximal 1160, standard deviation 130). The average height of the images was equal to 2060 pixels (minimal 1760 maximal 2460, standard deviation 210). The images were coded with contrast resolution equal to 1 byte.

Following quantities were measured manually and in an automated way (Fig. 1):

1. The hallux valgus angle (HVA) is measured between longitudinal axes of the first metatarsal and the proximal phalanx. Its normal value is below 15° [2].
2. The first and second intermetatarsal angle (IMA12) is measured between longitudinal axes of the first and second metatarsal bones. Its normal value is below 10° [2].
3. Hallux valgus interphalangeal angle (HVI) is measured between longitudinal axes of the proximal and distal phalanges of the toe. Because HVI adds to the total valgus deformity of the hallux it has been recently postulated that HVI should be evaluated besides other angular quantities [6].

The algorithm designed for the automated measurement of the aforementioned quantities consisted of the following stages:

1. Background extraction.
2. Segmentation of the diaphyses of metatarsal bones followed by contour extraction.
3. Detection of the contours of the proximal and distal phalanges of the toe.
4. Determination of the axes of the metatarsal bones and the axes of the proximal and distal phalanges of the toe based on the bone contours.
5. Determination of the angular quantities of interest based on the detected axes.

The automated and manual measurements were correlated.

3 Results

The study cases were analyzed manually three times by the same reader. The Pearson's coefficients of correlation between the average of manual measurements and automated measurements and the differences between the average of manual and automated measurements are presented in Table 1. The correlations between automated and average of manual measurements were significant. Very high correlation (over 96%) between manual and automated measurements of two (HVA, IMA12) out of the three measured angular variables have been observed.

Table 1. Comparison of manual and automated measurements.

Parameter	Coefficient of correlation between automated and average of manual measurements	Maximal difference between the automated and average of manual measurements	p-value
HVA	0.984	5.0	0.23
IMA12	0.969	3.3	0.29
HVI	0.856	10.7	<0.001

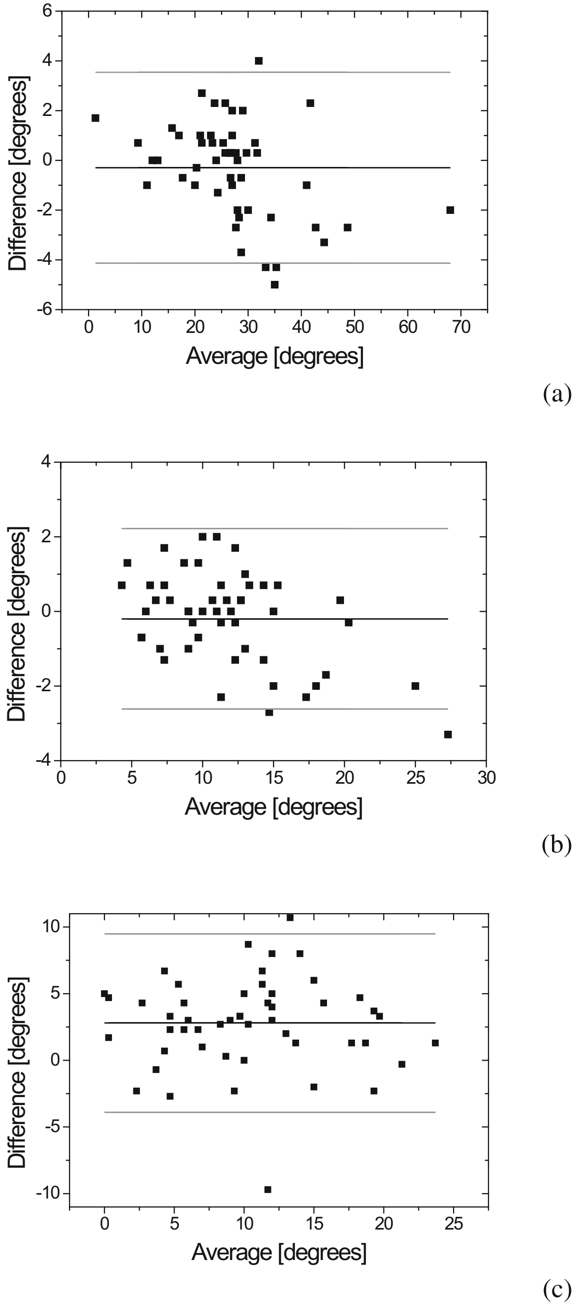

Fig. 2. Bland-Altman plots showing agreement between manual and automated measurements of (a) HVA, (b) IMA12, and (c) HVI.

For the third angular variable (HVI) the correlation was lower and equal to 86%. Except for HVI there are no statistical differences (at 0.1% significance level) between manual and automated measurements (Table 1). There was non-zero bias of the automated measurement related to the manual measurements of HVI. The bias was equal to 2.8°. The agreement between automated and average of manual measurements is demonstrated in Fig. 2. In the plots sown in Fig. 2 the bias (black horizontal line) and the limits of 95% agreement (gray horizontal lines) are also shown. The discrepancies between average manual and automated measurements are, except HVI, almost the same as the discrepancies between repeated manual measurements. The Bland-Altman plots show that such larger discrepancies, exceeding the discrepancies between successive manual measurements are observed for isolated cases.

The computations were run on a Intel® Core™ i5-6300U Processor, 8 GB RAM machine (ThinkPad T460 s) (single core was only used). Typical size of analyzed images was around 2–4 MB (image size around 1000 × 1000 pixels, 1 byte per pixel) and the total processing time for 50 images was about 2600 ms. It gives about 52 ms per one image.

4 Discussion

In the study we have demonstrated a system for assessment of selected angular variables, characterizing foot skeleton. The system analyzes dorsoplantar projection radiographs of a weight-bearing foot in a fully automated manner. We demonstrated a very good agreement between automated and manual measurements. The results of this study suggests that the developed method achieves performance similar to that of manual measurements. The processing speed of a single image (with size of around 10^6 pixels) is very advantageous, as it is less than 0.1 s.

The developed automated method is a processing pipeline which depends on a number of parameters. It consists of algorithms specialized for the problem in hand. This special design was a prerequisite as we assumed that the processing time must be optimized. This goal has been achieved with average processing time equal to around 50 ms and processing consisting of low-level algorithms. High level algorithms (like e.g. image registration followed by appearance models) were intentionally not used as it can be expected that for broad class of anatomical variants of foot skeletons successful application of these methods may require similar level of tuning as the developed method but at a higher time expense. Because the cases of poor performance of the developed automated method are only few, the automated method was not tuned further above the level presented in this study.

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