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Improved radiograph measurement inter-observer reliability by use of statistical shape models

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ABSTRACT

Pre- and post-operative radiographs of patients undergoing joint arthroplasty are often examined for a variety of purposes including preoperative planning and patient assessment. This work examines the feasibility of using active shape models (ASM) to semi-automate measurements from post-operative radiographs for the specific case of the Oxford™ Unicompartmental Knee. Measurements of the proximal tibia and the position of the tibial tray were made using the ASM model and manually. Data were obtained by four observers and one observer took four sets of measurements to allow assessment of the inter- and intra-observer reliability, respectively. The parameters measured were the tibial tray angle, the tray overhang, the tray size, the sagittal cut position, the resection level and the tibial width. Results demonstrated improved reliability (average of 27% and 11.2% increase for intra- and inter-reliability, respectively) and equivalent accuracy ($p > 0.05$ for compared data values) for all of the measurements using the ASM model, with the exception of the tray overhang ($p = 0.0001$). Less time (15 s) was required to take measurements using the ASM model compared with manual measurements, which was significant. These encouraging results indicate that semi-automated measurement techniques could improve the reliability of radiographic measurements.

1. Introduction

Throughout the field of orthopaedics, measurements taken from radiographs play an important role in patient assessment. With regards to lower limb arthroplasty, pre-operative measurements are essential to accurately plan the optimal component size and position. Post-operative measurements are often used for surveillance; either to monitor the patient recovery, surgical performance or for research. Clinical decisions are made based upon these measured parameters [1,2] and it is therefore important that these data are correct and reliable.

Radiographic measurements of distances or angles are often made manually; these can be taken using a pencil, or more commonly in recent times with digital image processing software (such as Picture Archiving and Communications System, PACS [3]). With both these methods, anatomic points need to be selected by the user and requires clinical knowledge; this process can be subjective and therefore result in error. Manual measurements can also be time consuming. Another technique often used for pre-operative planning is templating. Often the orthopaedic component manufacturer will provide a series of templates for each size component, these can be overlaid on the radiograph to help decide which size to implant; as components are discrete sizes, this is therefore a discrete measurement method [4].

With the advent of digital radiographs, two main methods have been used to attempt to automate assessments of radiographs. The first is edge detection, where edges are defined by an abrupt change in brightness. This method works well provided it is used for the application it is written; this is not a particularly versatile technique and does not cope well with images of varying content or brightness. Nevertheless, this method has been used successfully to measure knee joint space [5,6]. The second method is statistical shape modelling; this is where an average shape is defined by manually selected landmarks from a collection of standard images. Once the information is gathered, this model can then be applied to numerous new images to search for the shape [7]. This technique

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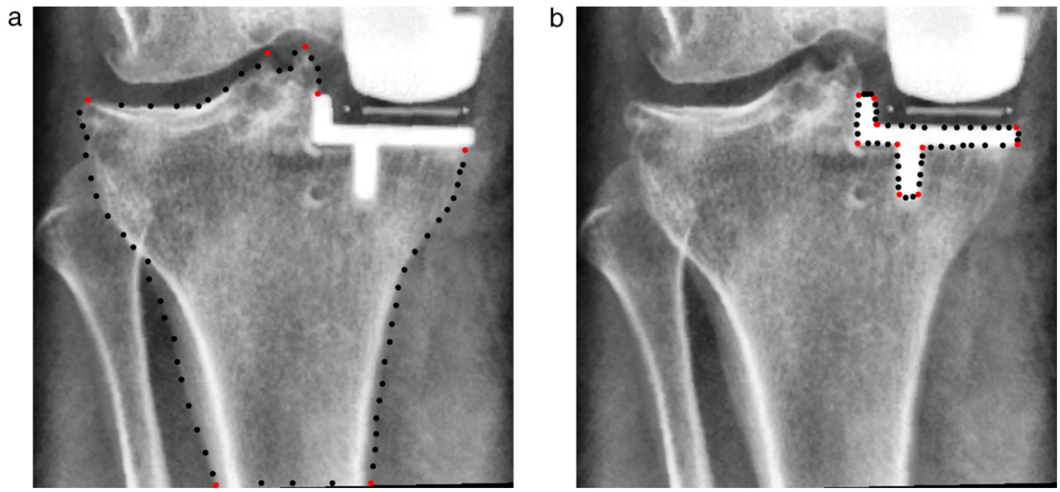

Fig. 1. Position of landmark points selected surrounding the tibia (a) and the tibial tray (b) on proximal post-operative UKA radiographs. Red markers represent fixed anatomical landmarks and black dots represent perimeter points in-between.

has been primarily used as a segmentation tool for medical images or to assess natural variations in anatomical shapes rather than for measurements. However, some studies have successfully used this technique for measurements of both vertebral [8,9] and hip radiographs [10–13], and have shown the measurement reliability to be equivalent to manual measurements [8]. This is referred to as ASM (Active Shape Modelling).

Due to the semi-automatic nature of measurement using ASMs, the subjectivity of the user is minimised and also the necessity for clinical knowledge is removed. The current study investigates the hypothesis that this could result in an improvement in measurement reliability whilst maintaining accuracy and reducing measurement time. The particular case of unicompartmental knee arthroplasty (UKA) was chosen; parameters were measured from the post-operative radiographs using both the ASM and manually, and the intra- and inter-observer reliability was assessed.

The current study investigates the feasibility of the use of active shape models to measure the positioning of implanted components after unicompartmental knee arthroplasty (UKA) from post-operative radiographs. We tested the null hypothesis that there is no difference in the measured values of radiographic parameters using an ASM based measurement compared to manual measurement. Specific parameters were measured using both the ASM and manual measurements, and the intra- and inter-observer reliability was assessed.

2. Materials and methods

The ASM model was created using custom written routines within MATLAB (Version 7.10, MathWorks Inc., MA, USA); the model was based upon the technique reported by Cootes et al. [7]. First, the ASM model was trained using a set of 36 standard anterior–posterior (AP) radiographs. The model was then applied to a different set of 19 radiographs, which ranged in quality (from 9.5 to 0.9 pixels per mm), to find the shape and location of the proximal tibia and the implanted tibial tray within the images. Finally, calculations were performed on the recorded shapes to provide the measured parameters and these data were compared with manual measurements.

2.1. Training the model

Thirty-six post-operative radiographs of patients who had undergone UKA were chosen to train the model. Each radiograph was flipped or inverted if necessary, to ensure that the image represented a right knee, with the implanted component appearing white. Sixty-four points surrounding the tibia were manually selected in landmark locations (Fig. 1a); 20 points were interpolated between each of the landmarks to give a total of 1198 co-ordinates. The same process was performed for the tibial tray shape model using 53 landmark points (Fig. 1b), which were interpolated to give a total of 989 co-ordinates. The shapes were aligned using the Procrustes method [14]; translation was removed by positioning the shape so that the centroid was at the origin, rotation was removed using the mean angle to the centroid as reference; scaling was removed by normalising using the width of the tibia; due to varied length of the tibial radiographs, the overall shape could not be scaled.

$$Translation = \frac{1}{N}\sum_{i=1}^{N} x_i \tag{1}$$

where x is the list of co-ordinates for a certain axis and N is the number of co-ordinates.

$$Rotation = \frac{1}{N}\sum_{i=1}^{N} \tan^{-1}\frac{y_i}{x_i} \tag{2}$$

where x and y are the co-ordinates and N is the number of points.

$$Scale = \frac{1}{Tibial \quad width} \tag{3}$$

Principal component analysis (PCA) was then performed on the 36 sets of co-ordinates, and the pixel profiles perpendicular to each point (12 pixels long) and greyscale differences in the pixel profiles (normalised by the average profile).

2.2. Application of the model

The individual assessing the radiograph positioned the average shape (from the training data of either tibia or tibial tray) over the image and if necessary the average shape could stretched in x- or y-directions or rotated to enable a rough fit. Once satisfied, a starting position was chosen for the model to run. Both the proximal tibia and tibial tray ASMs performed 40 iterations to find the final shape. At each iteration, the current pixel profiles were calculated and the points moved to a location which minimised the Mahalanobis distance (maximum movement of 6 pixels). The Mahalanobis distance is a way of describing how far a parameter is away from the desired