Can radiographs of hip fractures predict subsequent hip fractures? A shape modelling analysis

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ABSTRACT

Introduction: The geometrical shape of the proximal femur has previously been shown to predict primary hip fractures. Hip fractures are routinely diagnosed on plain radiographs of the pelvis, and these have both hips viewable. We have investigated if statistical shape modelling of the uninvolved hip on plain radiographs, at the time of the first hip fracture episode, could predict a subsequent 'second fracture' on that (uninvolved) side.

Materials and methods: 60 radiographs taken at the time of the index hip fracture were blinded and separated into two arms; patients sustaining one hip fracture only ($n = 30$), and those who went on to sustain a second fracture ($n = 30$), over the three-year follow-up period. Two separate shape models were used for these groups and compared using t-tests or Mann–Whitney U-tests, along with Cohen's d to measure the effect size of each measure.

Results: We found no statistically significant difference in the shape of the femur between the first fracture and second fracture group ($p > 0.05$) and no results reached a "medium" effect size (Cohen's $d < 0.5$).

Conclusions: Shape modelling is feasible and can be applied in the routine clinical setting. However, we were unable to elucidate any predictive value in this relatively small sample. A reliable radiograph-based method of identifying patients at risk of second fracture would be of value in planning prevention, service provision, and cost analysis. Further work is required and a study with more patients might exclude the type 2 error in our work.

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Introduction

'Second', 'subsequent', 'contralateral' hip fractures occur on the other side of an acutely fractured hip (OTA 31-A, 31-B, 32-A1.1) but separated in time [1,2]. Their incidence has been reported variably, due to poor survival over prolonged follow up. Most studies quote a 5-year incidence ranging from 8% to 24% [3,4]. Mortality from a second hip fracture is universally regarded as high, with a 5-year mortality of 64% for men and 58% for women after second hip fracture [5]. A higher proportion of second fracture patients require transfer to institutionalised care, than patients presenting with their first hip fracture [1]. This translates into higher service and care costs. Successful preventative measures are predicated upon accurate prediction of second fracture. This prediction has proven challenging to date.

The aetiology of second fractures is likely to be multifactorial, as there are hardly any identifiable risk factors that can be classed as exclusive to second fractures. Previous biomechanical work has confirmed that the shape of the proximal femur is significantly related to the risk of first hip fracture [6,7]. Neck length, in particular, is biomechanically important for the risk of both extracapsular and intracapsular fractures and an increased neck shaft angle has been often associated with both male and female hip fracture groups [8]. Recent research suggests the contralateral hip weakens in the first year following a hip fracture [9].

The shape of the proximal femur can be quantified in several different ways. Example of techniques include geometrical

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measures and advanced hip analysis (AHA), or more comprehensively by statistical shape modelling (SSM). We used an active shape model (ASM) to build the SSM for this study. Statistical shape models quantify the shape of an object, each model is unique to the shape imaged and the cohort on which it is based. SSM uses landmark points to outline the shape of an object, which can be applied to subsequent objects to identify differences between these objects or in the same object over time. It lends itself to orthopaedic application as anatomical skeletal landmarks have long been established. SSM has been successfully used to quantify the change in shape of the hip joint with progression and prediction of osteoarthritis [10,11], and has also confirmed the shape of the proximal femur to predict the first hip fracture [12–14].

We wished to investigate whether there was additional stratification of risk for a further second fracture based upon hip geometry using validated methods of analysis. Hip fractures are routinely identified from pelvis anteroposterior radiographs on presentation to hospital. We questioned whether there would be a difference for anteroposterior visualised geometry of those who subsequently went on to suffer a second contralateral hip fracture compared to a control group of patients who did not suffer further hip injury during the study period.

Materials and methods

The authors have previously published a study evaluating outcomes after first and second hip fractures treated at their trauma unit at Newcastle upon Tyne from December 2008 to May 2011 [1]. This study reported on 672 patient episodes; 610 patients suffered one fracture only during this period, 52 patients had previously had one side fractured and now presented with a contralateral fracture, while ten patients presented with fractures of both hips separated in time but still within the same study period.

These patient identifiers were used to download all pelvis radiographs performed on these patients from the digital picture archiving and communicating system (PACS) (Kodak Carestream, Eastman Kodak Company, New York, US). These included radiographs: (1) at presentation to the Emergency department with an injury, (2) performed subsequently during the study period, and (3) performed in the past for suspected injuries or osteoarthritis. The standard protocol includes anteroposterior (AP) films of the pelvis (including both left and right hips), and cross-table lateral projections of the affected hip. Two authors (SK and DD) reviewed these radiographs, noting the fracture patterns and implants used to treat them. The patient episodes were then randomised and two groups constituted, each with sample size $n = 30$. Group 1 included patients who only had one fracture throughout, whilst Group 2 comprised patients who had two sets of radiographs showing both hips fractured at different times.

Radiographs were cropped to remove the fractured hip, leaving the contralateral uninjured hip viewable. These were then anonymised and blinded to the operator (DN) who had a repeatability of 1.2 mm mean point to point error on a training set of 50 proximal femur images, unrelated to the present study, completed twice and 30 days apart. Using a pre-existing SSM of the proximal femur from a previously published study, points were placed using the active shape modelling toolkit (Visual Automotive Limited, Manchester, UK), and statistical models were built in Shape software (University of Aberdeen). Twenty-nine landmark points on the proximal femur were marked by the operator on each image (Fig. 1). Each landmark represents a key anatomical feature visible across all varying shapes of proximal femur. During data collection, the SSM automatically identified the outline of the femur analysed, and the operator checked and
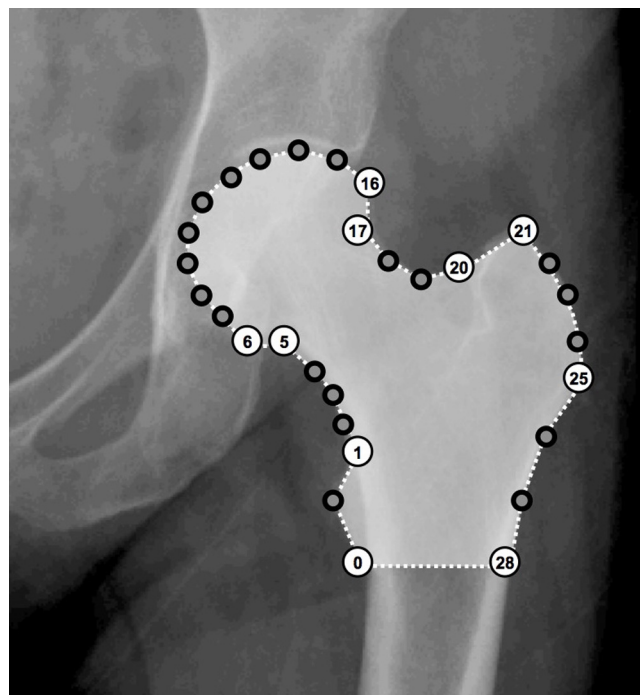
Fig. 1. Twenty-nine landmark points on the proximal femur marked by the operator on each image.

fine-tuned the location of the landmark points to ensure accuracy. In order to compare the differences between shapes, they first have to be aligned as closely as possible without distortion. This is done by adjusting the scale, rotation and translation of each proximal femur using Procrustes Analysis, allowing the shape of the average femur to be calculated. The point-to-point error compared the landmarks placed by the operator on separate occasions.

Principal components analysis was used to describe the dataset in a series of "modes of variation", output variables which describe the characteristic ways the femurs vary from the average shape. Mode scores have a mean of 0 (representing the average femur) and are expressed in standard deviations from this mean. Each mode of variation is orthogonal and so linearly independent of all the other modes. Modes are ordered in the amount of variance they describe from the dataset, with mode 1 describing the most. This allows the major features of the dataset to be characterised using just a few variables, whilst the rest are discarded as noise by examining the proportion of variance explained and visual assessment of the shape change described.

Two SSMs were used to test for differences between the first and second fracture groups. SSM-1 was built from the radiographs in this study; SSM-2 was built from a previous study that found significant differences in hip shape in women who had either no hip fracture or a unilateral hip fracture [15]. SSM-2 was rebuilt in Shape software and re-analysed. The rebuilt model classified the fracture and control groups with the same accuracy as the previous model (area under Receiver Operating Curve = 0.8) using a combination of three modes which was saved as a single predictor variable, PShape, however the mode numbers included were different to the previous model (3, 4, 6 and 7). Groups were compared using t-tests (normally distributed), or the Mann–Whitney U-tests (not normally distributed), along with Cohen's d to measure the effect size of each measure (SPSS V22. IBM Software). Differences in gender distribution were measured using Fisher's exact test, and differences in American Society of Anaesthesiologists (ASA) grades [a measure of general health