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Preoperative sizing of hip hemiarthroplasties to accurately estimate head size from non- standardised pelvic radiographs: Can it be done?

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ABSTRACT

Background: Preoperative sizing of implants for hip fracture patients requiring a hemiarthroplasty is difficult due to non-standardised radiographs, absence of sizing marker, variable patient position and body habitus. We investigated whether a simple tool could help predict femoral head size, allowing surgeons to safely proceed with surgery when implant stocks are limited, and to potentially improve theatre efficiency.

Methods: Three independent reviewers measured the maximum width of the contralateral (intact) femoral head using PACS software in 50 cases of intracapsular hip fracture. This was linearly regressed on actual implant size to calculate the average magnification coefficient. Inter- and intra-rater reliability were evaluated using intraclass correlation coefficients (ICC).

Results: The best fitting magnification constant was 118% (95% confidence interval 16.0–19.7%), which achieved a mean error of 1.7 mm. Prediction accuracy was significantly improved by allowing a constant (intercept) as a second parameter in the regression model ($p = 0.01$), which achieved a mean error of just 1.4 mm from the implant used. The inclusion of the constant reduces errors at the upper and lower extremes of head sizes. ICCs for inter- and intra-rather agreement were 0.94 and 0.98 respectively.

Conclusion(s): We have shown that hip hemiarthroplasty head sizes can be reliably and accurately predicted from non-standardised pre-operative radiographs. We have devised a method which can easily be adopted by other centres and tailored to the characteristics of their radiology department.

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Introduction

Hip fractures are the most common serious injury in older people and cost the NHS and social care £1 billion per year [1]. In 2016, over 65,000 people aged 60 or older presented to 177 hospitals in England, Wales and Northern Ireland [1]. With increasing life expectancy worldwide, the number of elderly individuals is increasing, and it is estimated that the incidence of hip fracture will rise from 1.66 million in 1990 to 6.26 million by 2050 [1]. According to the National Hip Fracture Database in the UK, 60% of hip fractures are intracapsular, which is similar to the Swedish National Hip Fracture with 33% undisplaced and 67% displaced [1,2]. The majority of these patients will have a cemented hemiarthroplasty performed rather than and Total Hip Replacement (THR).

Digital templating is now a recognised and well-established method of predicting component sizes in total hip arthroplasty. Not only does it help to prevent complications, but it also helps to optimise important geometric parameters such as leg length, centre of rotation, and femoro-acetabular offset adjustment by determining component sizes [3]. Digital templating in hip hemiarthroplasty is variable in its use, as some digital templating programmes will not have the relevant templates and often pelvic radiographs obtained after acute hip fracture are of poor quality and variable magnification, due to patient body habitus and position. Despite the benefits of digital templating in THR, its accuracy appears to be inferior when used in hip hemiarthroplasty planning [4]. Being able to predict head size in hemiarthroplasties can allow for preparation of prothesis in the operating theatre, safer operating when prothesis stocks are low and a more robust way of measuring head size in fragmented femoral heads or dysplastic femoral heads.

Our aim was to devise a simple model, specific to the quality and magnification of our hospital's radiographs, to predict hemi-arthroplasty head size preoperatively in our hip fracture patients.

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Methods

We looked at 35 patients' postoperative pelvic radiographs who underwent a cemented hemiarthroplasty in our district general hospital. Radiographs were non-standardised pre-operative films. No markers were used, and measurements were taken from the contralateral intact femoral head. All patients included received the same type of cemented prosthesis.

Two senior associate specialist and one specialist registrar reviewed the preoperative radiographs and measured the widest point of the contralateral intact femoral head using PACS system measuring tool. All clinicians were blinded to the actual sizes of implants used. In addition, each clinician performed repeat measurements on a randomly selected 15 radiographs to generate data for the evaluation of intra-observer reliability. Intraclass correlation coefficients as recommended were used to assess inter and intra-rater reliability. [5] These predicted sizes were then compared with the actual sizes used at the time of surgery and analysed by an independent reviewer.

Based on preliminary discussions with radiology staff in the department, the authors hypothesised average magnification levels of 10% and 15%, which were evaluated because they could be favoured for their simplicity if they provided sufficient predictive accuracy. Two other models were evaluated: a simple linear regression-through-the-origin model (which corresponds to calculating the optimal magnification constant), and a second model with an intercept parameter. Predictive accuracy was evaluated by calculating and plotting the root mean square error for each model from the mean radiographic measurements. 95% confidence intervals were calculated for the parameters of the fitted models. Goodness of fit of the two fitted models was compared using ANOVA.

Statistical analyses were performed in R version 3.4.3. [6]

Results

Head sizes

The range of hemiarthroplasty head sizes used was 38–56 mm.

Demographic variation in hemiarthroplasty head size

Median head sizes were 46 and 52 mm in female and male patients respectively ($p < 0.001$).

(Fig. 1)

Although a significant correlation between age and head size (Pearson's ρ = -0.09; $p = 0.01$), this was not significant after adjusting for sex in linear regression analysis (β = -0.008; $p = 0.5$).

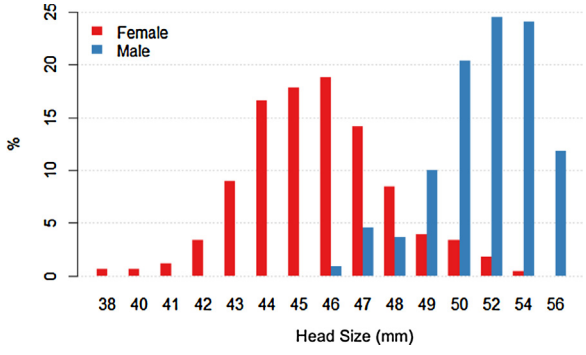

Fig. 1. Demographic variation in hemiarthroplasty head size in female and male patients ($p < 0.01$).

Radiographic prediction of head sizes

Measurement

The intraclass correlation coefficient for intra-rater agreement was 0.98 (95% confidence interval 0.97 – 0.99). The intraclass correlation coefficient for inter-rater agreement was 0.94 (95% CI 0.88 – 0.97).

Predictive models

We evaluated two magnification constants proposed by the authors (10% and 15%), and two fitted models: regression-through-the-origin (Model 1) and model including an intercept parameter (Model 2) (Fig. 2).

The magnification constant fitted in Model 1 was 17.8% (95% confidence interval 16.0–19.7%). The parameters for Model 2 were:

$$\textit{Actual femoral head size size} = 9.7 + 0.68 \times \textit{Radiographic measurement}$$

The 95% confidence intervals were 2.3–17.1 for the intercept and 0.5 – 0.8 for the slope.

Residuals (errors) for each model are summarised below.

Root mean squared errors were 3.3 mm (10% magnification), 1.8 mm (15% magnification), 1.7 mm (Model 1; 17.8% magnification) and 1.4 mm (Model 2). Model 2 produced significantly better goodness-of-fit than Model 1 in ANOVA ($p = 0.01$) (Fig. 3)

Discussion

Preoperative planning in joint arthroplasty is becoming a widely practised method and has shown to improve implant sizing,

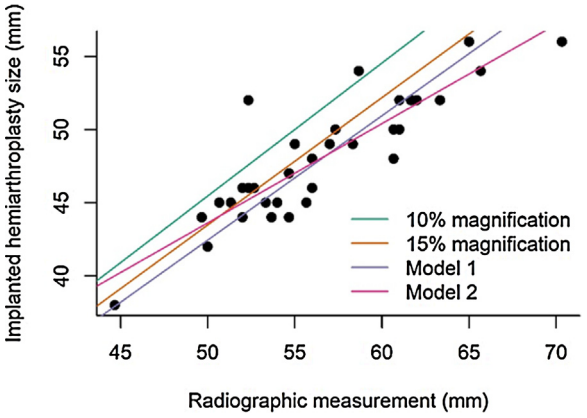

Fig. 2. Four models for prediction of hemiarthroplasty head size. Model accuracy is maximised when the corresponding line passes through the most data points.

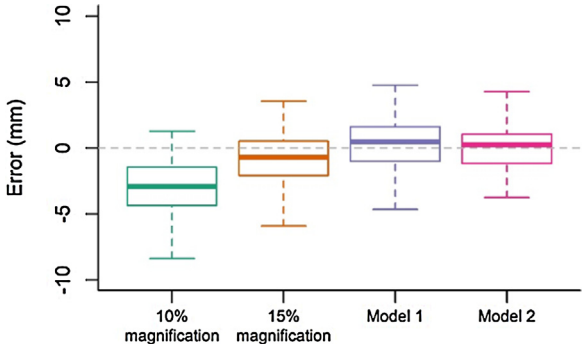

Fig. 3. Errors (residuals) for each model. A model is biased if the median (the bold line in the centre of each box) $\neq 0$. Narrower whiskers correspond to improved predictive accuracy.

offsets and leg lengths [7]. Multiple authors have advocated various methods or pre-op, intra-op and post-op measurement and verification or restoration of leg lengths and offset [8,7,9–15]. Methods used range from a simple ruler measurement, to computer navigation and digital templating. There have only been a few studies in the literature looking at templating in hemiarthroplasties to predict femoral head size to improve the fluency and outcome of surgery.

In 2013, Polishchuk et al retrospectively looked at 136 patients who underwent a hemiarthroplasty for a hip fracture. They found that gender, height, age and race significantly affected femoral head size. Using a regression formula there average predicted was femoral head size was 1.63 ± 1.10 mm of the intra-operative measurements [16]. Cadaveric studies have used femoral head diameter to predict femoral head height (leg length) and have shown that femoral head diameter has a linear correlation with head height [17].

Calculating radiological magnification is key to being able to predict certain dimensions of structures on radiographs. Variability in non-standardised radiographs can lead to inaccuracies. Recent reviews in the literature have shown that surgeons run the risk of up to 11% inaccuracy when assuming a standard 120% magnification [18]. Adjuncts used to help calibrate radiographs have shown that the scaling of PACS AP pelvic radiographs using a caliper is significantly less accurate than when using a coin placed in the plane of interest [19]. The issue presented with hip fractures patients are that radiographs are not taken with markers as is routinely done in our total hip arthroplasty patients. One may argue that we should be using skin markers on our neck of femur fractures. However, at the time of presentation in the A&E X-ray department, it is unknown whether hip fractures are intra or extra capsular and quite often patients are in pain, agitated or confused which makes it difficult for radiology staff to discuss placement of skin markers.

A variable that is important to a successful hip hemiarthroplasty is the correct femoral head size. While the commonest way is to measure the head diameter intra-operatively, this can cause issues with available stock, with the occasional patients having an extra small or extra large femoral head size, requiring either unnecessary conversion to total hip replacement or the use of undersized components that are not correctly matched to patient's acetabular anatomy. We have proposed a method of estimating the femoral head size that would allow appropriate implants to be available within +/- 2 mm to be able to order correct sizes pre-operatively to prevent mismatches as well as to efficiently perform the procedure.

Another advantage to predicting femoral head size during hemiarthroplasty for hip fractures is to be able to have the correct implants available in the operating theatre, thus potentially decreasing operative time and avoiding inventory errors. We use simple data to predict the femoral head size with little dependence on high-quality radiographs. In this way, if extra-small or extra-large components are needed, those can be planned for ahead of time.

Whilst in the United Kingdom we have access to a reasonable amount of prothesis stock, it is the developing countries that will often not have stock on the shelves and have to order components in based on the patients who present to hospital. Often surgical equipment has to be purchased by the patients at an upfront cost. Our method and formulae could be used to aid clinician and patients in ordering the correct prothesis preoperatively, saving patients or hospitals unnecessary costs in countries where financial resources are limited.

Magnification may vary substantially between radiology departments and devices, [20] under which circumstances, the exact parameters of the formulae presented may not apply. We have demonstrated the excellent the intra- and inter-observer reliability of measurements taken from unstandardized radiographs. On this basis, we propose that our methodology may safely be replicated, and site-specific parameters calculated, from as few as 35 extant cases by diverse practitioners and in diverse settings. The calculations required to replicate Model 2 can be easily performed in Microsoft Excel, or freely online (e.g. www.graphpad.com/quickcalcs/linear1/).

Limitations

We accept as authors that our project has limitations. Other papers have used templating programs to measure the widest point on the femoral head, in our project we measured the widest point judged by visual guide. Despite being a potential of inaccuracy, the inter- and intra-rater reliability remained excellent and as such can easily be replicated in other institutes around the world.

Secondly, we used the contralateral (unbroken) femoral head to measure the femoral head diameter. A contralateral hip joint configuration may vary individually and differ from the affected limb. However, previous studies have reported little difference in radiographic geometry between right and left hip joint in East Asians [21]. In fact, our own internal audit showed good co-relation in hemiarthroplasties head size for those patients who went on to fracture both hips.

The confidence intervals for the parameters of the fitted models, while they do not include the null values, are broad, reflecting the small sample size. The reproduction of this methodology with a larger sample would allow more precise reporting of model parameters.

Conclusion

We have created and present a simple but useful tool to help predict hemiarthroplasty head sizes in hip fractures patients. It is an adoptable model which can be easily calibrated and employed in other centers. Although it cannot account for all variation it may allow surgeons to plan for component sizes in stock and increase theatre efficiency in physiologically unstable patients who require timely operations. This model does not require the use of templating programs to which some department may not have access. Considering that most orthopaedic surgeons are less likely to recollect the formula in model 2, and that model 1 (117.8 +-% magnification) gives a very good estimate of actual head size, we propose the use of model 1 and have adopted it in our department.

Declaration of Competing Interest

There were no conflicts of interest in respects to this publication.

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