Journal of Orthopaedics 15 (2018) 787–791

Contents lists available at ScienceDirect

Journal of Orthopaedics

journal homepage: www.elsevier.com/locate/jor

Original Article

The 3-dot circle: A reliable method for safe and efficient digital templating of the acetabular component

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ARTICLE INFO

Keywords:
Hip replacement
Preoperative templating
Preoperative planning
THR

ABSTRACT

Background: Templating for preoperative planning of joint arthroplasty has followed the evolution of digital templating software.

Objective: This study aims to provide a safe, reliable and reproducible method for prediction of acetabular component size based on measurement of the radiographic femoral head diameter, with the aid of templating software.

Methods: A defined methodology for femoral head measurement was applied to 97 consecutive, calibrated digital pelvic radiographs. Based on radiographic femoral head diameter, the minimum acetabular shell diameter was calculated and then compared to the size of the implanted acetabular shells.

Results: This method predicted safe minimum acetabular component size with an accuracy of 95.9% with a high inter-observer reliability of 97.6%.

Conclusions: This study presents a simple, reproducible and accurate method for templating of the minimum safest acetabular component diameter.

1. Introduction

Hip templating refers to a structured process of predicting hip arthroplasty implant size and position.

There are four main reasons to template:

1 To aid the selection of the most favourable implant size, to restore anatomy & biomechanics, improve function and improve joint stability, e.g. to reproduce femoral offset.
2 To facilitate operating room preparation, to assure availability of an appropriate implant size selection and optimize procedure duration.[13]
3 To estimate the position and insertion depth of both components[12] and thus restore the centre of hip rotation
4 To predict potential complications and detect anatomic anomalies,[12] e.g. to detect protrusion and the need for bone graft. And to reduce risk of periprosthetic fractures from oversized implants.

This process can be difficult and inaccurate as radiographs are two-dimensional projections of a three-dimensional structure. Therefore, preoperative surgical planning has traditionally been performed by means of conventional analogue (printed film) radiography with a consistent radiographic magnification (assumed to be 15%) which allows templating for a selected prosthesis with transparent component overlays.[4] Questions have been raised about the accuracy of non-digital templating.[9] A number of factors can influence the precision of the estimated magnification, such as the patient's body habitus. Accurate preoperative planning requires calibration of the digital radiograph using a quantified tool of known dimensions such as a coin[3] and versatile templating software that can be adapted to accommodate various types and sizes of prostheses. Digital radiography has become readily available in many orthopaedic centres, creating the need for digital templating.

In order to standardize acetabular component size Beverland et al.[1] suggested an acetabular component diameter of 4 mm larger than the intraoperative measurement of the diameter of the femoral head. This guide helps restore acetabular height and offset, minimizing the risk of persistent postoperative pain that can be associated with acetabular component diameter 6 mm larger than the original femoral head, possibly due to iliopsoas impingement.[14]

In this study, we review our experience of preoperative planning for total joint replacement of using a templating software system (TraumaCad®, Brainlab, Germany) that can integrate with and enable the import and export of all "Picture Archiving and Communication System" (PACS) files from local working stations. Early publications on the accuracy of the use of TraumaCad® (Germany, Brainlab)[6] showed

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https://doi.org/10.1016/j.jor.2018.03.027
Received 9 November 2017; Accepted 25 March 2018
Available online 27 March 2018

promising results with the acetabular component falling within ± 1 of the templated size in 89% of the patients; the femoral stem fell within ± 1 of the templated size in 87% of patients. Eggli et al. [2] found similar results; with agreement between planned and used components of 90% on the acetabular and 92% on the femoral side. According to Miashero et al.[7] these results fared better compared to conventional templating based on acetates (acetabulum: 78.6%, femur: 82.2%).

We aimed to develop a simple, reproducible method aiming to compare radiographic femoral head to implanted acetabular shell diameter in order to define conditions that need to be met to estimate the minimum acetabular component size with 100% certainty.

We tested the hypothesis that pre-operative templating using digital radiograph was accurate in predicting a minimum cup size of 3 mm larger than the systematically measured femoral head diameter. A templated safe minimum shell size should then give the surgeon confidence in their choice of shell sizes with patient safety in mind.

2. Methods

All total hip replacements (THRs) using a cementless acetabular component, in a single district general hospital under the care of the senior author between January 2013 and January 2017 from electronic records were identified. All the operations were performed by the senior surgeon or his fellow under the senior surgeon's supervision. The posterior approach was used in all cases.

2.1. Inclusion criteria

All radiographs that had been digitally calibrated preoperatively
Cementless acetabular cups

2.2. Exclusion criteria

Cemented acetabular cups
Radiographs without digital calibration

Preoperative anteroposterior radiographs had been obtained obtained using the KingMark® (Germany, Brainlab) adjustable calibration device (Fig. 1). KingMark® is a double calibration device that uses two separate sets of markers – one behind the pelvis and one in front.

A standing anteroposterior projection of the pelvis for hips was used and the correct alignment of the KingMark® was checked so that the circle representing a calibration sphere lies within the vertical row of transverse radio-opaque lines and that the rod markers lie on the midline of the pelvis to give more accurate prediction. This is derived from the principles set out by the designers that the radio-opaque markers should be placed on the midline.[15] In addition, one of the spheres and one of the rods should align with the femoral head of the hip[2] (Fig. 2).

Fig. 1. KingMark® calibration device.

Templating of the pre-operative radiograph was conducted using our templating software (TraumaCad®, Brainlab, Germany) We utilised a three-dot circle method for radiographic femoral head diameter measurement as follows:

- The healthiest femoral is maginified to allow for maximal precision
- To define the outline of the femoral head based on three dots of the circle (Fig. 3) were placed as follows:
  1 First dot: placed on the outline of the superolateral quadrant between head-neck junction distally and a vertical line through the centre of femoral head proximally. This point had to be proximal to any cam lesion to avoid oversizing.
  2 Second dot: placed in the superomedial quadrant of the femoral head, avoiding the fovea to prevent undersizing.
  3 Third do: placed in the inferomedial quadrant of the femoral head, avoiding any osteophytes to prevent oversizing.

This circle tool then calculated the diameter of the femoral head automatically. All decimal figures over 0.6 were rounded up to the nearest integer. To take into account the presence of femoral and articular cartilage, 3 mm was added to this value to give us the smallest acetabular cup size. Estimated smallest shell diameters were then compared to the implanted sizes, as documented in the electronically saved operative reports.

Radiographs were reviewed by two assessors (named first and second assessor), who were blinded to each other's' results. They each measured the femoral head diameter separately. They were also blinded to the operative records which were reviewed after the measurements were made.

Statistical analysis was conducted using SPSS (IBM, USA) to assess for interobserver reliability using an interclass correlation coefficient (ICC) with $P < 0.05$. Further analysis was conduced using Chi-squared tests (Pearson Chi-square and Fishers test) to compare the difference between the cup size and femoral head and when the radiograph marker was aligned and not aligned.

3. Results

A total of 152 cases were reviewed. 59 cases were excluded: 39 due to lack of KingMark-calibrated radiographs and 20 because the implants were cemented. 97 cases were included and analysed that fulfilled the inclusion criteria. 57.1% patients had Exceed cup (ZimmerBiomet, USA) implanted and 42.9% patients had Trident cup (Stryker, USA) implanted (Fig. 4).

The mean value of the estimated smallest cup size was 52.03 (SD = 4.037, Range: 48–64). The Mean value of the used cup size was 56.00 (SD = 4.301). The results of both first second assessors showed that the difference between cup size and femoral head was 3 mm or larger in all evaluated patients.

The mean femoral head value of the first assessor was 47 (SD = 4.122; range: 40–57). The mean femoral head value of the second assessor evaluated was 47 (SD = 4.291; range: 41–57). Interobserver agreement showed a high degree of concordance between both assessors with ICC showing 97.6% agreement (Table 1).

With regards to calibration device alignment, 71.4% of patients had Kingmark® aligned and 26.5% was misaligned. The results show that there are no statistically significant differences ($p = 0.810$, $p > 0.05$) in measurements taken on aligned and not aligned radiographs (Fig. 5).

4. Discussion

Digital templating is an accurate tool to preoperatively plan total hip arthroplasty and to determine the correct prosthetic size. This study shows that our 'three-dot circle 'protocol of measuring the radiographic femoral head diameter predicted the safe minimum size of the acetabular shell with an accuracy of 95.9% with a high inter-observer

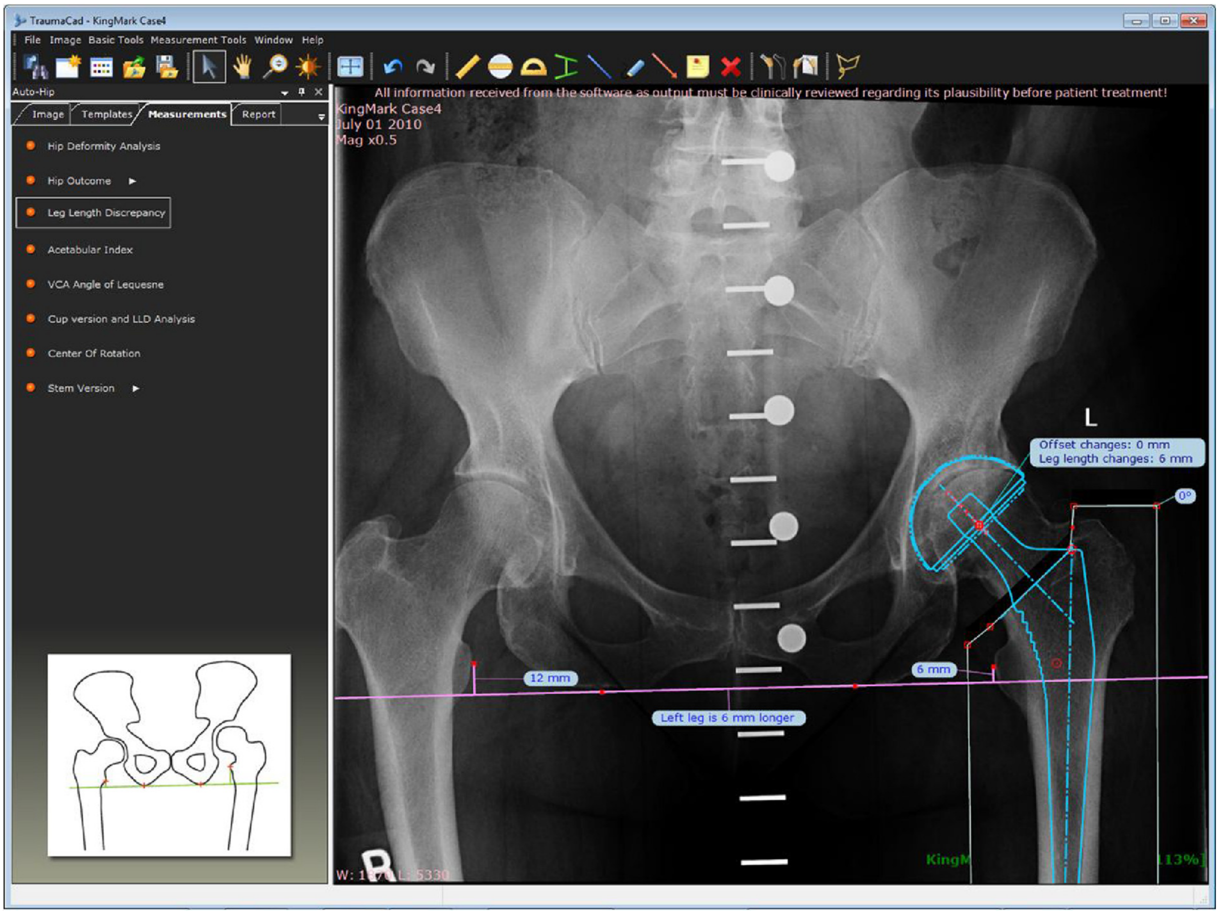

Fig. 2. Anteroposterior pelvic radiograph showing adequately aligned KingMark®.

Fig. 3. Anteroposterior pelvic radiograph demonstrating the 'three-dot circle' technique of femoral head measurement with blue circles pointing to the three-dot allocation.

reliability of 97.6%.

Numerous studies have highlighted the benefit of templating. Film based templating as studied by Knight and Atwater[1] accurately predicted 62% of the acetabular cups, based on the conventional non-digital templating system. They concluded that surgeons need better methods to estimate magnification and bone morphology from preoperative radiographs to improve accuracy.

Digital radiography has become the preferred method for preoperative planning of orthopaedic procedures. One great advantage of modern software and hardware is a filmless working environment and the ability to securely and electronically store patient data including various prostheses, types and sizes, and the ability to retrieve this information when needed. Training for applying the programs is simple, and the system is user friendly and requires only a PC workstation. Widdon et al.[19] compared their results using printed film methods and a computer software method. Their digital method was 11% more accurate for the acetabular component. Della Valle et al.[17] found very good prediction (81%) within one size for the acetabular component, using digital radiographs. Davila et al.[5] used the EndoMap® (Siemens AG, Medical Solutions) software in 36 patients undergoing primary total hip replacement: 86% were accurate within one size of the acetabular component.

Three-dimensional computed tomography (CT) may be superior to the two-dimensional templates particularly in difficult clinical cases.[18] This method, however, exposes the patient to a high level of irradiation and may not be necessary for standard hip replacements. It could, however, be used to plan complex hip arthroplasty.

Nevertheless, pre-operative templating is not without its problems. Inaccurate templating can result in significant complications such as intraoperative acetabular fractures during prosthesis impaction.[8] Furthermore, there is a reluctance to template due to its difficult and time-consuming nature. The accuracy of traditional methods is likely to be user and experience dependent.

Our alternative method for predicting the size of the smallest acetabular shell was based on the following assumptions/criteria:

- "The ball must fit in the socket"
- The average combined cartilage thickness of femoral head and

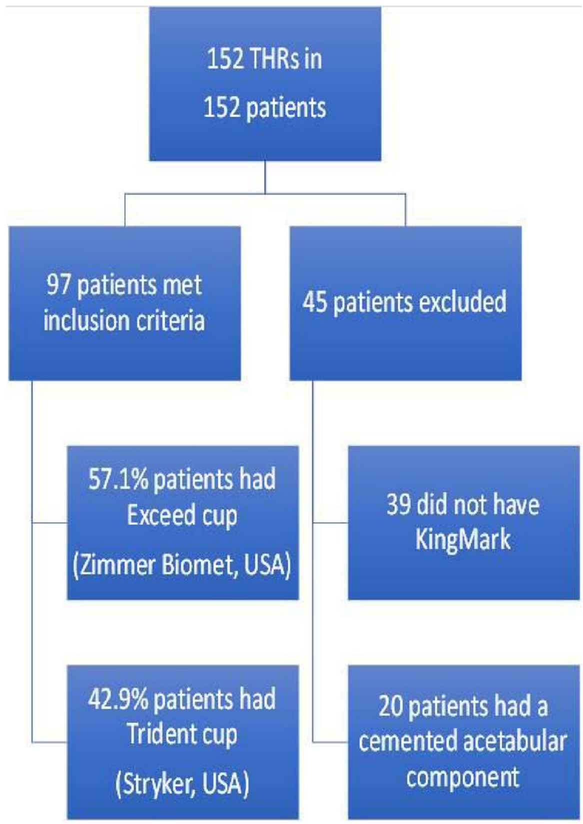

Fig. 4. Flow chart of patients included.

Table 1
ICC for interobserver reliability.

	Intraclass Correlation[b]	95% Confidence Interval	
		Lower Bound	Upper Bound
Average Measures	,976	,964	,984

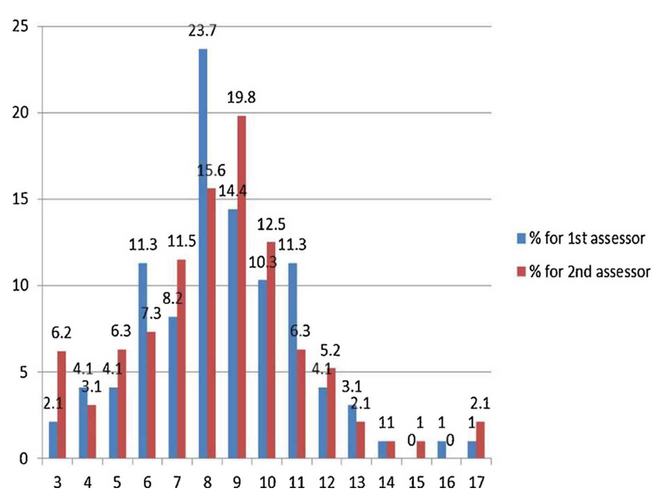

Fig. 5. Results of cup size minus femoral head measurements in the two assessors) C–H: cup minus head measurement.

acetabulum ranges between 2.32 mm to 3.24 mm.[10]

- Our clinical assumption that there is a need to remove a minimum of one to three mm of cortical bone.
- A projection of the above reaming criteria to a minimum safe size of final reamer of 3.32 (2.32 + 1) mm larger than the radiographic femoral head diameter. Therefore, the smallest safest reamer is at least 3 mm larger than the femoral head.

Table 2
Step by step method for predicting smallest acetabular cup size.

	Action
1	Calculation of the diameter of the healthiest bony femoral head radiographically using the "three-dot circle" method
2	addition of 2.32 mm to include the minimum thickness of the combined femoral head and acetabular cartilage
3	Further addition of 1 mm to estimate the safest, minimum acetabular cortical bone that needs to be reamed
4	The cup is then chosen based on the manufacturer's design and surgeon's preference (line to line or press fit)

This method is not intended to replace existing templating methods, but is an alternative for those with a reluctance to template or it may be used to supplement methods already used. Furthermore, it is not designed to aid the decision regarding positioning of the component. This, some feel, is best determined intra-operatively. Instead it gives the surgeon a quick and an accurate method to determine the minimum size of the component required and aid in the decision with which reamer to start with. This would be in keeping with the alternative reaming techniques advocated to maintain acetabular offset and, thereby, the centre of rotation.[11]

The accuracy demonstrated in this study can be reproduced regardless of the templating software chosen. The short learning curve, user-friendly defined methodology (Table 2), and low-cost maintenance make it an attractive alternative or supplement to the hip surgeon. It is also reliable with excellent interobserver reliability and is not reliant upon the radiological marker used being aligned. In addition, it facilitates safe practice in that the knowledge of the "safest shell size" helps avoid pitfalls. One such pitfall may be when the surgeon is faced with small, outlier femoral heads when performing total hip replacement surgery. This reliable preoperative templating practice may also help minimise primary acetabular component theatre stock. It also allows every step of a hip replacement to become more predictable for theatre personnel, such as the choice of the starting reamer. Reliable implant sizing can save priceless operative time and improve theatre efficiency.

Some of the challenges to overcome include obtaining adequate radiographs. Rather than standard pelvic radiographs, which are generally centred on the sacrum, a low AP pelvic radiograph with the x-ray beam centred on the pubis is preferred for hip templating, the symphysis pubis should project on a line through the middle of the sacrum.[16] Furthermore, this method may not be suitable in hips with significant dysplasia.

To our knowledge this study represents the only series in the orthopaedic literature looking at templating the acetabular component size based on calculating the radiographic diameter of the femoral head. This method has a short learning curve and provides the surgeon with a reliable and safe method of preoperatively estimating acetabular shell size. We believe that this systematic standardised preoperative sizing method contributes to hip arthroplasty function and outcome.

Conflicts of interests

There are no competing interests or funding disclosures. No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article

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