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Digital magnification error when templating total hip replacement?

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Abstract

Background: Digital templating has become an accepted method of pre-operative planning for total hip replacement (THR). Templating software permits digital templating in a complete digital environment. Accurate templating requires knowledge of the true magnification of the radiograph. **Aims and objectives:** The aim of this study was to compare the measured magnification factor from using an external calibration marker (ECM) in a standardized radiology protocol, to the true magnification derived from using a prosthetic femoral head of known diameter. **Materials and Methods:** All patients awaiting staged bilateral THR between 2012 and 2017 were identified. Their radiographs were reviewed, and included in the study if an ECM was present with THR prosthesis in situ. The radiographs were assessed for scaling using two methods, a built-in software method using the ECM, and a manual method, using the implanted femoral head. Magnification factor derived from both methods were compared. **Statistics:** Statistical analysis was performed using paired Student's t-test for matched samples. **Results:** A total of 64 radiographs were included. The two methods of scaling produced consistently different magnification factors. Using the ECM, the mean measured magnification was 113.9% (SD 5.4%). The mean true magnification using the implanted femoral head was 119.6% (SD 2.1%). The mean difference was 6.9% (SD 5.7%, range of -18% to 17.1%, $p<0.05$). **Conclusion:** In conclusion, a single external calibration marker will have significant error. In clinical practice, the ECM consistently underestimated the magnification of templating radiographs. In patients with an implanted hip replacement, we recommend using the femoral head prosthesis for radiograph scaling.

Keywords: Templating, Total hip replacement, Arthroplasty, Radiographs, Magnification.

INTRODUCTION

Precise pre-operative templating is of paramount importance in planning for total hip replacement (THR). Templating potentiates accurate sizing and placement of implants to create the requisite biomechanics of the hip. Furthermore, templating can predict intra-operative challenges, help manage theatre inventory, improve team communication and facilitate training [1, 2].

Traditionally, templating involved the use of implant-specific acetates with built-in fixed magnification laid over hard-copy x-rays [3]. There is potential for x-rays to be rescaled to fit radiographic paper when printed which may result in a magnification different from the acetate overlay [4]. Modern digital templating software allow on-screen templating in a complete digital environment with the theoretical advantage of avoiding magnification errors, as template overlays can be scaled to the known magnification of the radiograph. This is reflected in multiple studies which report excellent predictive accuracy of digital templating in THR [4-6].

However, accuracy of digital templating is still dependent on magnification being calculated by using an external calibration marker (ECM) at bone level when the x-ray is taken [7]. There are many methods available, including using a coin or ball of known diameter placed at the level of the femur, either beside the greater trochanter or between the patients' thighs [8, 9]. These methods are not always convenient or feasible for radiographers to reproduce accurately [7, 10]. The weight of the patient also directly correlates with the magnification of templating radiographs [11].

Radiological magnification depends on the vertical and horizontal distance of the ECM from the X-ray source. When the marker is not at the exact vertical level of the hip, or horizontally near the region of interest (ROI) magnification error will be introduced, and subsequent templating will less accurate [10, 12, 13].

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The use of an internal calibration marker (ICM), such as the prosthetic femoral head, is a potentially more accurate technique to assess magnification of radiographs. This technique has been previously described in the literature [11, 14]. The femoral head is equivalent to the true magnification of the ROI given it is in the same vertical and horizontal plane [12]. However, this can only be done post-operatively.

The aim of this study is to analyse the magnification error of digital templating using an ECM with previously described radiography technique, compared to magnification measurements using the implanted prosthetic femoral head in patients awaiting their second operation in staged bilateral THR.

METHOD

Ethics

Ethical approval was not required by the local institutional review board.

Study sample:

All patients awaiting bilateral staged THRs for primary osteoarthritis between 2012 and 2017 at our institution were identified and their imaging reviewed on Carestream PACS (Rochester, NY, USA). We included all patients who had antero-posterior (AP) pelvis radiographs featuring both their prosthetic hip, and the external calibration marker. The component sizes were recorded from theatre records. Patient identification was anonymised.

Radiology assessment:

Radiographs were acquired using a Phillips DigitalDiagnost (Philips GmbH, Hamburg, Germany) and converted to digital images using Carestream Radiography (Rochester, NY, USA).

AP pelvic radiographs were obtained in a standardised way: the gantry was positioned 120cm above the film plate for all patients with the beam centred on the pubic symphysis. The external calibration marker is a 10mm ball bearing on a handle. Radiographers were trained to place the ECM in between patients' legs close to the groin, at the level of the greater trochanter. The leg was internally rotated by 15 degrees if possible (Figure 1).

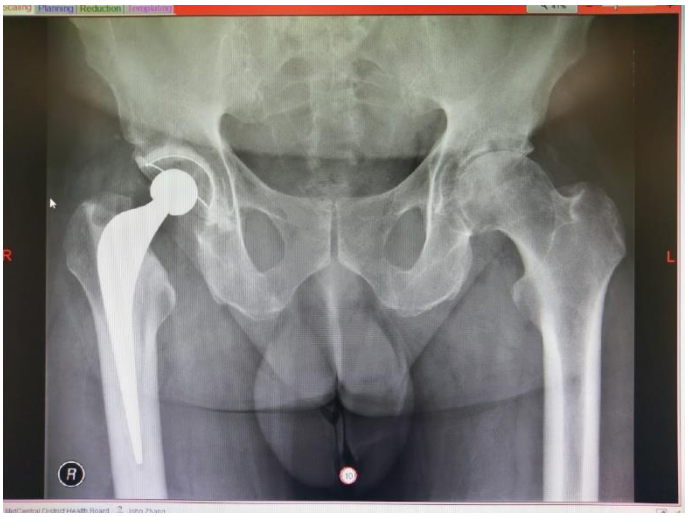

Figure 1: Example antero-posterior templating radiograph with external calibration marker

Radiographs were viewed and analysed using Orthoview software (Meridian Technique Limited, Southampton, UK). X-rays were first scaled using the 10mm external calibration sphere which Orthoview detects automatically, and the size of the 10mm ECM is entered manually and confirmed (Figure 2).

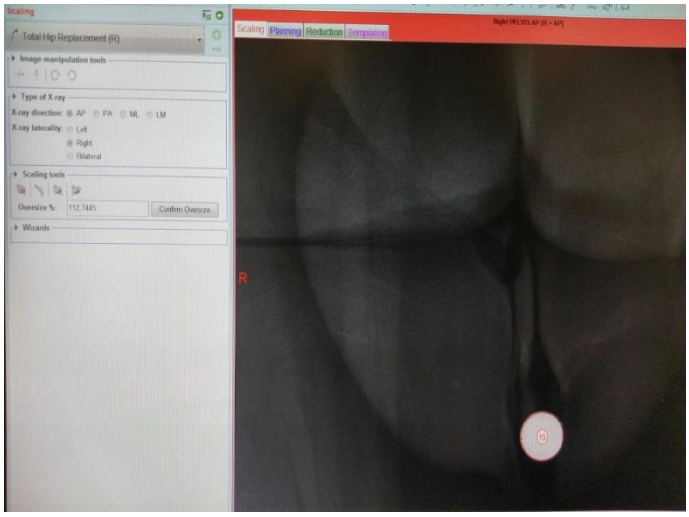

Figure 2: Figure 2 Scaling using ECM (10mm ball bearing)

The radiographs were rescaled manually by drawing a sphere around prosthetic head (Figure 3). The femoral head was enlarged first to maximum size to increase accuracy, and a circle was interpolated from three points selected on the margin of the head using the cursor.

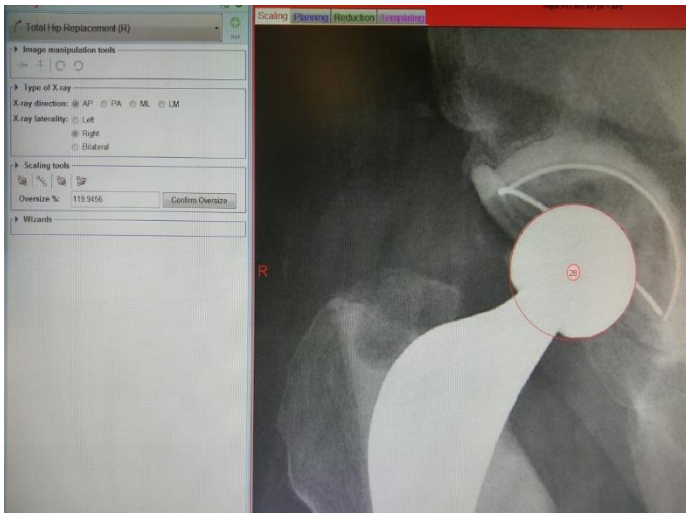

Figure 3: Scaling using prosthetic femoral head

The magnification of both methods was recorded.

Statistics:

Statistical analysis was performed using paired Student's *t*-test for matched samples.

RESULTS

A total of 107 radiographs were reviewed and 64 radiographs were included in the study. Patient demographics of the included patients showed a female majority (n=40, 62%) with a mean age of 66.6 years (range 49-90). The excluded radiographs did not feature an ECM.

The majority of femoral heads implanted were 28mm (n=60, 92%), there were three 32mm and two 36mm heads.

The two methods produced different magnification factors for all radiographs. Using the ECM, the mean magnification was 113.9% (SD 5.4%, range 106.4%-133.3%). The mean magnification using the ICM was 119.6% (SD 2.1%, range 108.7%-123.6%). The ICM also produced less spread of magnification, indicated by the smaller standard deviation result.

In 58 x-rays, the ECM underestimated the magnification factor (90.6%) (Figure 4). The mean absolute difference in the two magnification methods was 6.9%, (SD 5.7%, range of -18% to 17.1%) which was statistically significant ($p<0.05$).

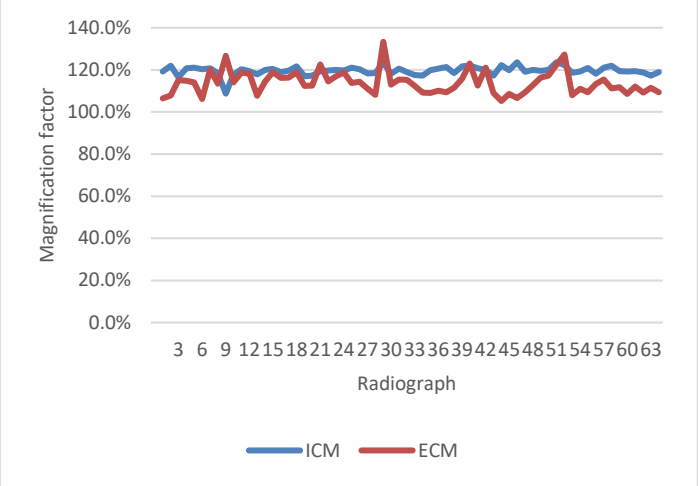

Figure 4: Comparing individual magnification factor for each radiograph

DISCUSSION

This study shows that there is a statistically significant difference of 6.9% in the measured magnification using a standard external calibration technique compared to the true magnification from an implanted femoral head ($p<0.05$). The difference in magnification between the two methods can be as high as 17.1%. The ECM technique underestimated the magnification of x-rays in 90% of radiographs.

A magnification error of 6% is sufficient to translate to an error of 1 acetabular cup sizing [15]. In our study, an error of 6.9% when templating a 52mm acetabulum cup translates to a potential error of ± 3.5mm. This error is outside of the accepted standard of templating accurately to within one size of a component [4-6].

When the ECM underestimates the magnification of the radiograph, this leads to overestimation of the required component during templating. For cement-less femoral stems, there is a risk of an intra-operative femoral fracture between 3-24% if an oversized femoral component is inserted [16]. In cemented femoral components, this can potentially decrease the cement mantle size, increasing risk of cement mantle fracture [17]. In the worst-case scenario, an error of 17.1% translates to ±8.8mm for a 52mm cup.

This suggests even with a standardized protocol for taking AP pelvis x-rays, the ECM is not always placed in the plane of the ROI. Placing the ECM between the patients' thighs is difficult to reproduce accurately as there are no clear anatomical landmarks. The proximity to the patients' groin also can make this task uncomfortable for staff and patients [7, 14].

The accuracy of the spherical ECM placed between the patient's thighs compared to an internal calibration marker has been studied previously. Franken *et al.* showed a mean error of 2.04%, with a maximum difference of 6.46%. The *et al.* showed an error of magnification of only 1.5% whilst Wimsey et al. were even more accurate in their study, with an average magnification difference of only 1.1% [9, 18]. However, two other similar studies using the implanted femoral head have both shown magnification error to consistently near 6%, which suggests despite a standardized radiological protocol, scaling using an ECM has inherent consistent magnification error of 6% [13, 19]. Magnification error can also differ between different radiological departments which use the same standardized protocol [20].

Our study confirms, that in everyday use, the precision of the marker placed between the patients' thighs is poorer than that reported in the literature and is extremely operator dependent. The strength of this study is that our results demonstrate how inaccurate external calibration may be in the 'real world' of clinical practice, removing potential participant bias from the radiographers.

During templating, surgeons must be aware of potential pitfalls of digital templating and need to be aware of erroneous magnification. Whilst pre-operative templating is useful as part of radiograph assessment and THR planning, inconsistent calibration marker placement introduces unacceptable levels of error into the process, even in the modern environment of digital templating. It is obvious that templating cannot be solely relied to assess and judge final componentry sizing or there will be significant intra-operative complications.

One potential source of error in this study is the manual scaling of radiographs using the femoral head. This required drawing a sphere around the implanted femoral head, error was minimised by increasing the zoom on the radiograph. However, there will remain a small non-quantifiable discrepancy in this method of scaling.

There are other methods to reduce but not completely eliminate magnification error. It can be minimized by using a double-calibration device that avoids the essential step of having the calibration marker in the precise horizontal plane of the ROI. King *et al.* showed when using this method, there was only a median difference of 1.1% between the measured magnification and the true magnification [2]. Digital radiographs can also be scaled to the built-in magnification of acetate templates using the method developed and described by Brew et al, which obliviates the need for a marker [21].

CONCLUSION

In conclusion, a single external calibration marker will have inherent error. In real world clinical practice, this can underestimate the magnification of x-rays significantly. Surgeons should be aware of potential templating pitfalls and use templating as a guide and not a target. When possible, radiographs should be scaled using the implanted contralateral prosthetic femoral head.

Conflicts of Interest

The authors declare that there are no conflicts of interest.

Authors' Contribution

JZ was responsible for conducting the study, collecting results, performing the statistical analysis and writing and editing the manuscript. MW was responsible for editing the manuscript and final approval. GA was responsible for the study design, editing the manuscript and final approval.

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