ABSTRACT
Circulating coins represent an inexpensive and ubiquitously available source of radiographic size templating markers. This study was developed to validate the use of the Australian twenty-cent coin as a size marker for the purposes of pre-operative radiographic templating in orthopaedic surgery.

500 Australian twenty-cent coins obtained from general circulation underwent standardized measurement across two diameters (1000 observations) under controlled environmental conditions.

The average coin diameter measurement was 28.456mm. A high degree of size consistency between coin diameter measurements was observed (standard deviation 0.045mm).

The results of this study indicate that size variation due manufacturing tolerance and wear of the Australian twenty-cent coin are insufficient to impact upon the selection of prosthetic implant size when used as a radiographic scale marker. For the purposes of digital templating in clinical practice, we recommend the diameter of the Australian 20-cent coin be approximated to 28.5mm.

KEYWORDS
Radiography, Templating, Joint Replacement, Scale Marker, Australia, Coin

INTRODUCTION
Radiographic templating is a common practice in the pre-operative planning for orthopaedic procedures. For joint arthroplasty, templating allows the Surgeon to pre-operatively evaluate the accurate restoration of joint biomechanics and leg length by prediction of osteotomy levels, selection of implants and determination of optimal prosthetic orientation. Accurate radiographic templating therefore serves as a method to help improve the consistency of joint reconstruction and enhance patient safety. Radiographic templating, including linear size evaluation, is particularly important in situations of unusual patient anatomy or alternatively where the post-surgical outcome is significantly influenced by implant size, as is observed with hip resurfacing arthroplasty. \[1,2\]

Radiographic templating can be conducted by traditional methods using printed images and acetate onlay sheets or by...
the use of prosthesis specific digital templating software. In either situation, as templating requires the appreciation of geometric size, a “fit for purpose” diagnostic quality image must enable the end user to accurately and reproducibly perform linear length measurements. [3] Ideally this is facilitated by the use of a standardized radiographic scale marker placed within the imaging field. [4]

Particularly since the widespread use of digital imaging technology, Orthopaedic Surgeons have experienced increasing difficulty in reliably obtaining radiographs to enable pre-operative arthroplasty templating. As digital processing allows the arbitrary re-sizing of the displayed image after it has been acquired, measurement estimates may be critically compromised. [3] This applies not only to images viewed on digital hardware, but also to printed images reproduced after acquisition by digital methods. Surgeons now routinely face uncertainty relating to potential digital manipulation of image size due to inadequate standardization of radiographic practice and ambiguity of nomenclature. [3,5] While digital imaging does potentially enable accurate templating by use of implant specific software applications, the validity of the process is often undermined in the absence of evidence to confirm size measurement accuracy. [6] On a practical level, digital radiology technology has unfortunately resulted in many Surgeons performing pre-operative templating less frequently or alternatively abandoning the practice of routine templating altogether.

Commercial radiographic scale markers have been available for many years. It is our experience however that scale markers are very infrequently used unless specifically requested. Radiographer inexperience, unavailability of size markers within radiology departments, the extra time required to perform the imaging and a lack of standardized protocols for the use of commercial scale markers are contributing factors that limit their widespread practical application, particularly in private practice.

Circulating coins represent an inexpensive and ubiquitously available source of radiographic size templating markers. Coins are simple and versatile for practical use within clinical practice (Figures 1-4). [7-9] The validity of this method does however rely on the assumption that all coins within community circulation are of a standardized size. In principle, the size of a coin may be affected by many factors, including manufacturing tolerances, damage, counterfeit production or the accumulation of wear (Figures 5-7). This study was developed to validate the use of the Australian twenty-cent coin as a radiographic size template marker. Our working hypothesis was that Australian twenty-cent coins within circulation are of consistent diameter, such that any size discrepancies are of insufficient magnitude to influence implant selection when used as radiographic template marker.

**METHODS**

500 Australian twenty-cent coins within general circulation as legal tender were obtained for the conduct of this study. 4 coins, being used in error as Australian legal tender on the basis of having a macroscopically similar shape and size as the...
Australian twenty-cent coin, were excluded from the study (3 New Zealand twenty-cent coins, 1 Jordanian ten-piastres coin).

All coins were sequentially numbered to enable individual identification. The diameter of each coin was then measured in two standardized planes, defined by the apex of the letter “A” at the start and end of the nationality stamp “Australia” on the obverse side of the coin (Figure 8).

All measurements of coin diameter were conducted by the same evaluator using a Digital Vernier Caliper with a resolution of 0.01mm (Kinchrome Model K11100, Kinchrome Australia, Scoresby Victoria Australia). The caliper was calibrated prior to testing and rated to 0.01mm accuracy at multiple measuring points within the working range and atmospheric conditions selected for this study. The caliper was zeroed after every ten coins measured.

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Figure 4 - Patient radiographs from Figure 3 demonstrating traditional radiographic templating methods for hip replacement surgery using magnification adjusted onlay acetates and printed films. A coin has been placed over projected image of the size marker (arrow) to confirm “true magnification” of the printed film. This is currently our preferred technique.

Figure 5 - Post manufacturing edge wear reducing the coin diameter.

Figures 6 a-c - Examples of Australian twenty-cent coins currently within circulation demonstrating accumulated damage, corrosion and surface wear.

Figure 7 (up) - Australian twenty-cent coin demonstrating a variance in manufacturing (note asymmetry of stamp). Such variation raises the possibility of counterfeit production.

Figure 8 (right) - Measurement of coins using across two diameters using a digital Vernier caliper. Position of the measurements was standardized by reference to the apex of the letter “A” at the start and finish of coin marking “Australia” on the obverse side as demonstrated.
To minimize the effect of linear or volumetric thermal expansion on coin diameter, all testing was conducted within controlled temperature and humidity conditions representative of an average office environment (23.5 +/- 0.5°C, humidity below 80%). Ambient temperature and humidity was monitored using a calibrated Kestrel 4250 Weather Tracker (accuracy 0.5°C and 3% relative humidity respectively; Nielsen-Kellerman, Pennsylvania USA).

In addition to the measurement of two standardized diameters, data recorded for every coin included the year of manufacture and any unique features such as significant markings, damage, wear or corrosion.

Fifty coins underwent repeat measurement of both dimensions (100 observations) to validate reproducibility of the measurement technique.

RESULTS

Manufacturing age distribution of the twenty-cent coins used within this study is presented in Table 1. The diameter measurements of the Australian twenty-cent coins used within this study were found to be highly consistent. Of the 1000 measurements recorded, the mean average coin diameter was 28.456 mm. A high degree of size consistency was observed, with the standard deviation for all observations being 0.045mm.

Table 1: Age distribution of coins within study

<table>
<thead>
<tr>
<th>Manufacturing decade</th>
<th>Number of coins</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st Decade (1966 – 1975)</td>
<td>67</td>
</tr>
<tr>
<td>2nd Decade (1976 – 1985)</td>
<td>70</td>
</tr>
<tr>
<td>3rd Decade (1986 – 1995)</td>
<td>2</td>
</tr>
<tr>
<td>4th Decade (1996 – 2005)</td>
<td>137</td>
</tr>
<tr>
<td>5th Decade (2006 – 2014)</td>
<td>224</td>
</tr>
<tr>
<td>Total</td>
<td>500</td>
</tr>
</tbody>
</table>

Table: All coin diameter observations fell between the range of 28.27mm (smallest) and 28.57mm (largest). In consideration of these extremes of measurement (0.3mm), the maximum variation in any observed diameter across all coins was 1%. Comparison of the two diameter measurements taken on each coin demonstrated a high degree of correlation (p<0.001). The average variation between the two measurements of each coin was 0.013mm (0.04%).

Due to wear of the milled edge, older coins had the tendency to demonstrate smaller diameter measurements, however size the differences observed in relation to coin age were not statistically significant. This included the 20 coins manufactured in 1966. Repeated diameter measurements taken to assess reproducibility of the testing method demonstrated very high correlation (R=0.9512; p<0.001).

DISCUSSION

The Australian twenty-cent coin was first introduced with decimalization of the Australian currency in 1966. The Royal Australian Mint has manufactured the coin since 1967, however quantities have also been struck by the Royal Mint Llantrasant (Wales), Royal Mint (London, England) and the Royal Canadian Mint. The coin is circular in shape with a milled edge; the most common design displays an impression of a platypus on the reverse side. On the obverse side, the twenty-cent coin carries one of four portraits of Her Majesty Queen Elizabeth the Second, facing the right by convention. The twenty-cent coin is manufactured from an alloy of copper (75%) and nickel (25%) and is 11.3 grams in weight according to official nominal specification. [10] The use of non-circular coins as radiographic size markers may potentially introduce measurement error if the face is not projected exactly parallel to the radiograph plate.

The findings of this study demonstrate that variation in coin diameters does exist; however the magnitudes of size differences observed are not of clinical significance. The standard deviation of all coin diameters measured was 0.045mm, representing 0.16% of the average coin diameter. Even if the very largest coin measurement (28.57mm) was compared to the very smallest coin measurement (28.27mm), the difference still only represents a maximum of 1% variation – still acceptable for practical clinical application. By way of example, most acetabular arthroplasty implants in modern practice increase in size by 2mm increments. A 2mm size change for a 50mm implant represents a 4% size increment. Given the reproducibility and distribution of coin diameter measurements observed within this study, coin size variation would not impact meaningfully on the clinical selection of implant size when used as a radiographic scale marker.

Of interest, we also note slight variations in the published nominal diameters of the twenty-cent coin. The Royal Australian Mint publishes the nominal diameter of the twenty-
cent coin as being 28.65mm, [10] however the twenty-cent proof coin held at Museum Victoria is slightly smaller, at 28.5mm diameter and 11.02 grams in weight. [11] This study demonstrated an average coin diameter of 28.456mm, representative of coins circulating throughout the general community and accounting for variations in diameter due to both manufacturing tolerances and accumulated wear. For purposes of digital templating in clinical practice, we recommend the diameter of the Australian twenty-cent coin be approximated to 28.5mm.

The Royal Australian Mint maintains policies for the removal of damaged, worn or mutilated coins from circulation, thereby improving the consistency of coin sizes within the community. In this respect we note a number of the coins used within this study (and currently in circulation) were dated 1966, being the first year of manufacture of the coin. The observation that these coins were not associated with a statistically significant reduction in diameter due to wear is a demonstration of the durability of the materials used and the effectiveness of processes employed for the identification and disposal of defective coins.

As technology available to counterfeit currency becomes more sophisticated and readily available, the quality of counterfeit coins improves, making them harder to detect. [1] The UK £ 1 Counterfeit Coin Study 2014 demonstrated 3.03% coins in circulation (an estimated total of 45 million pieces) were counterfeit, with a rapid rise in the proportion of counterfeit coins detected by annual surveillance between 2004 and 2010. [12] While the Australian twenty-cent coin is of lower value and therefore somewhat of a less attractive target for counterfeiting activities, the possibility of counterfeit twenty-cent coins with less stringent manufacturing tolerances and resultant variations in diameter should be considered.

A potential limitation of this study relates to the application of the findings in relation to currencies outside of Australia. However assuming that wear resistance, durability and precise manufacturing are common requirements for all modern currencies, the results of this study would reasonably be expected to apply to other countries. [13] Formal testing of other currency denominations however would be required to confirm this assumption. We recommend for any given currency that the largest available circular coin be selected for use as a radiographic scale marker.

The advantages of the use of circulating currency as a radiographic size templating system relate primarily to the ease of use. Circulating currency is readily available to all clinicians at time and point of requirement. Coin templating can accommodate Surgeon preferences with respect to placement of the marker and methods of implant templating. In addition, minimal capital expenditure is required to acquire the templating device (twenty-cents!).

CONCLUSION

The results of this study indicate that size variation due manufacturing tolerance and wear of the Australian twenty-cent coin are insufficient to impact upon the clinical selection of implant size when used as a radiographic scale marker.

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REFERENCES


