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Original research

Hemispherical and minimally invasive total hip reamers: a biomechanical analysis of use and design

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ABSTRACT

Background: The purpose of this study was to determine the accuracy of used and new reamer systems for both hemispherical and minimally invasive (MIS) acetabular reamers.
Methods: New and used hemispherical and MIS acetabular reamers were tested on a computer numerical control machine to ream holes in special machinable wax blocks. Each reamer was tested 3 times in sizes 48 mm through 55 mm.
Results: The used reamers significantly underreamed by an average of 1.33 vs 0.28 mm compared to new reamers. Hemispherical reamers underreamed significantly more than MIS reamers, with a mean difference of 0.99 vs 0.63 mm, respectively. Used hemispherical reamers showed an average ream undersize of 1.61 vs 0.37 mm, compared to new hemispherical reamers. Used MIS reamers showed an average ream undersize of 1.06 vs 0.20 mm for the new MIS reamers.
Conclusions: For a manufacturer-specified reamer size, both hemispherical and MIS reamers underream. Newer reamers cut truer to expected values than used ones. MIS reamers performed more accurately than hemispherical reamers. Used acetabular reamer systems may negatively affect the sizing of prepared acetabular beds; therefore, awareness of this potential inaccuracy should be considered when performing total hip arthroplasty.

Introduction

Total hip arthroplasty is one of the most commonly performed orthopaedic procedures worldwide. Modern cementless implantation techniques rely on the accurate press fit of components to obtain initial stability and to allow for bony ingrowth. Cementless acetabular components are typically implanted with 1-3 mm of press fit [1,2]. The diametrical mismatch between the reamed acetabulum and a relatively oversized prosthetic component allow for the tight, initial screw-less fixation known as a "press fit." Any unexpected alteration in the size of reamed acetabulum can compromise the surgeon's intended press fit and lead to poor results [3,4]. Underreaming can lead to loosening, as the implant fails to seat properly or in extreme circumstances may create an acetabular fracture [3,4]. Overreaming can lead to acetabular loosening via excessive micromotion and failure to obtain bony ingrowth.

Accurate press fit requires the manufacturer's stated reamer size to correlate closely with the actual size of the hole reamed [5], thereby allowing the surgeon to make the correct intraoperative decisions regarding implant size to obtain the desired press fit. Manufacturing tolerances of the reamers, the quality and wear of instruments, acetabular bone stock, and surgical technique all impact the degree of press fit obtainable at surgery. Previous studies have attempted to address these factors using cadaver pelves, but variability of bone quality using these specimens adds inconsistency to accurate measurements of acetabular reamers. In addition, the use of factory new reamers in many of these studies fails to reproduce the intraoperative experience that surgeons can expect. Various methods of measurements

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have included sophisticated 3-dimensional digitizing systems, computed tomography scans, mold and cast methods with no clear standardized measurement tool [6-9]. Thus, many variables may affect press fit, and no single study has yet been conducted to elucidate the role of the reamer itself in a standardized fashion.

Acetabular reamer systems typically consist of a modular hemispherical cutting shell and a compatible extension handle that can be attached to a power drill. Recently, reamers with smaller volume hemispherical shells have been developed to enable reaming through a smaller hole, so called minimally invasive (MIS) reamers. The purpose of this study was to answer 3 questions:

1. Is there a difference between the hemispherical and MIS reamers in terms of accuracy and the quality of the reamed surface?
2. What is the difference between new and used reamers in terms of accuracy and quality of the reamed surface?
3. Does the reamed cavity match the manufacturer's stated size and sphericity?

We hypothesized that multiple uses of used, off-the-shelf reamers would cause them to ream a hole smaller than the expected size compared to new reamers. We did not expect a difference in ream accuracy due to head design between the standard fully hemispherical and cutout MIS reamers.

Material and methods

Used acetabular reamers were studied and compared to their brand new counterparts. We compared 2 separate reamer head designs: partially hemispherical MIS surgery sets, and fully hemispherical "conventional" (standard) sets (Fig. 1). The MIS sets were manufactured by Precimed (MPS Precimed, Switzerland). The conventional sets were manufactured by Symmetry Medical (acquired by Tecomet, Warsaw, IN). Both reamer sets were distributed by Zimmer (Warsaw, IN). We compared the accuracy of all used and new reamers to both each other and to the manufacturer's specified size. All used sets tested were taken from our current hospital inventory. The surgeries in which these reamers were used were reviewed. The used hemispherical and MIS reamers had been in service for differing amounts of time. Based on our hospital records, hemispherical reamers were in service for approximately 2 years and were processed about 48 times. The MIS reamers had been in service for about 1 year and were processed about 40 times.

We tested reamers sized from 48 mm through 55 mm in 1-mm increments, as these were the most commonly used sizes at our institution. The reamer test consisted of using an industrial-grade Cincinnati Milacron computer numerical control machine (Cincinnati Machines, Cincinnati, OH) to drill a hemispherical hole into a machinable wax block (Freeman Manufacturing and Supply Company, Avon, OH). Machinable wax blocks were selected, as they allowed for a reproducible test substrate. The blocks are a constant size and density, quick to machine, require no coolant to use, are easy on tooling, and are recyclable. The material allows for excellent detail and resolution.

The machinable wax blocks were sequentially placed into a machinist vice. The computer numerical control machine was programmed to perform the trial ream at a preselected rotational rate of 350 rpm and a Z-axis advancement rate of 7 inches per minute. The terminal depth was selected to ensure the ream depth exceeded the proximal lip of the reamer. The trial was performed 3 times for each reamer (Fig. 2).

After all the blocks were reamed, they were inspected and measured. All reamed holes were assessed for edge quality and surface finish. The researcher was blinded to actual reamer size during all measurements. All reamer cavities were blindly measured using a Brown & Sharpe MicroVal PFx (Hexagon Manufacturing Intelligence, North Kingstown, RI) coordinate measuring machine with an accuracy exceeding ± 0.005 mm. The measurement depth was fixed at 0.5 mm below the surface of the block. A minimum of 8 data points were collected for each reamed hole by manually touching the data probe in sequential locations around the perimeter (Fig. 3). The coordinate measuring machine has a pressure-sensitive stylus that electronically triggers the machine to record the data point in 3-dimensional space when the probe contacts the wax block. The built-in computerized software was used to calculate the "best-fit" circle diameter. The diameter and sphericity of each reamed hole were recorded.

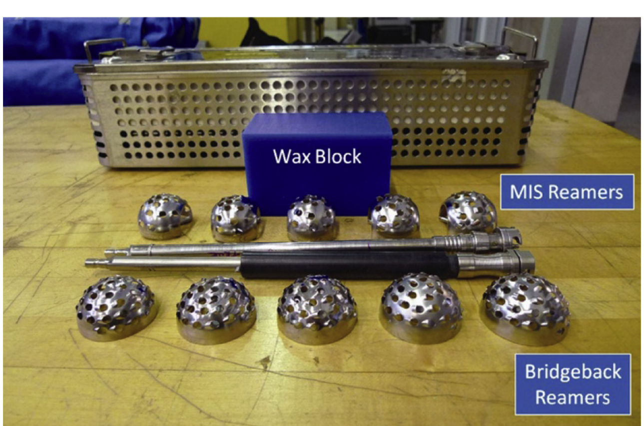

Figure 1. MIS and conventional hemispherical Bridgeback acetabular reamers. The conventional reamers in the foreground have a hemispherical shell. The minimally invasive (MIS) reamers in the background are not full hemispheres.

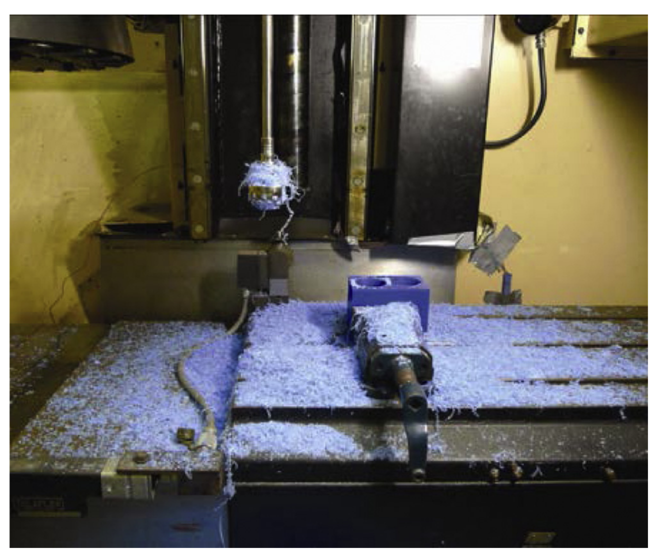

Figure 2. Cincinnati Milacron computer numerical control machine testing setup. The computer numerical control machine holds the handle which is attached to the tested reamer. The reamed cavity in the wax block is shown as well. All trials are performed in this automated manner.

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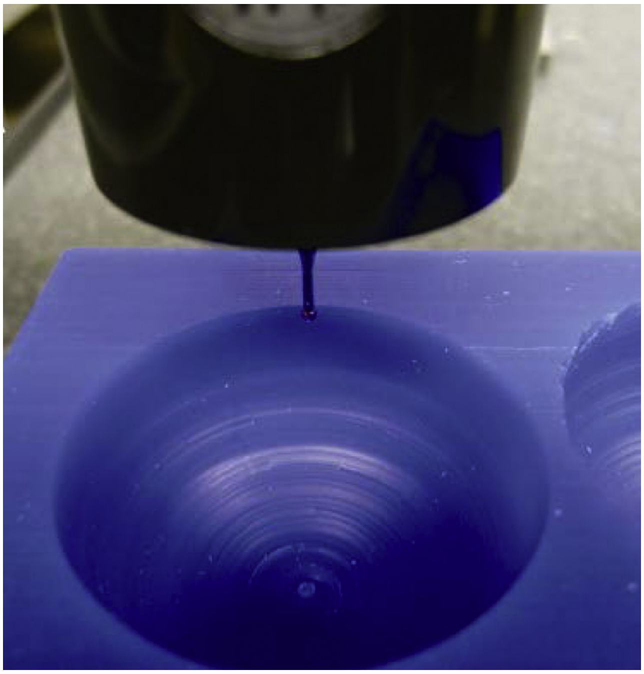

Figure 3. Brown and Sharpe computerized measuring machine measuring reamed cavity. The measurement of the diameter was performed at the aperture of the hole created by the reamer.

Data analysis

All data are described using adjusted means and standard errors. Three sets of measurements were performed on each combination of new/used and hemispherical/MIS reamer, and each trial was repeated 3 times. Two repeated-measures mixed models were built with the difference between actual and expected size and sphericity as the dependent variable of each respective model; while new/used status, type (hemispherical or MIS) along with the interaction between the 2 were the independent terms. An additional 2 repeated-measures mixed models were constructed to examine the effect of size (48 through 55 mm) on the difference between actual and expected size and sphericity. Statistical significance was set at $P < .05$. All analyses are performed using SAS 9.4 (SAS Institute Inc., Cary, NC).

Results

The adjusted mean of the difference between actual and expected ream sizes and sphericity measurements were calculated for each type of reamer (new, used, hemispherical, and MIS, as well as the interaction between them). Tables 1 and 2 demonstrate these results. There was a significant difference between reamed sizes in the new vs used reamers with the used reamers underreaming by an average of 1.33 vs 0.28 mm in the new reamers ($P < .001$). Additionally, the hemispherical reamers underreamed significantly more than the MIS reamers, with a mean difference of 0.99 vs 0.63 mm, respectively ($P < .001$). Finally, the interaction between the reamers showed a significant difference with the used/hemispherical reamers underreaming by a greater degree than the new/MIS reamers (1.61 vs 0.20 mm, $P < .001$). When comparing all categories of reamers, the results show that the largest difference in adjusted mean size exists in the used/hemispherical trials, while the smallest exists in the new/MIS trials (Fig. 4).

Table 1
Adjusted mean difference by reamer category—size.

Reamer category	Reamer	Adjusted mean (SE)	*P* value
New vs used	New	0.28 (0.05)	**<.001**
	Used	1.33 (0.05)	
Hemispherical vs MIS	Hemispherical	0.99 (0.05)	**<.001**
	MIS	0.63 (0.05)	
Interaction of new/used and type	New/hemispherical	0.37 (0.06)	**<.001**
	New/MIS	0.20 (0.06)	
	Used/hemispherical	1.61 (0.06)	
	Used/MIS	1.06 (0.06)	

The table shows the adjusted mean difference of various reamers based on the size of the reamer. There was a significant difference between new vs used, hemispherical vs MIS, and in the interaction category. The most accurate reamers in each category were the new reamers, the MIS reamers, and the new/MIS reamers.
The bold values represent the items that reached statistical significance.
SE, standard error.

The results for sphericity show that the used reamers produced a larger adjusted mean difference than the new reamers (0.96 vs 0.43 mm, $P = .108$) (Table 2). Additionally, the MIS reamers produce less spherical reams than the hemispherical ones (0.98 vs 0.42 mm, $P = .086$). Despite these differences, neither of these categories shows any significance. The used/MIS reamers had the least spherical reams compared to the used/hemispherical reamers, which had the most spherical reams (1.64 vs 0.29 mm, $P = .017$). When comparing all reamers, the largest difference in sphericity was identified as the used/MIS category and the smallest difference was identified as the used/hemispherical category (Fig. 5).

Table 3 illustrates the effect of reamer size on the difference between actual and expected size, while Table 4 shows the effect of sphericity. These tables show that size 48 mm has the largest adjusted mean difference in size, while size 55 mm has the smallest. Sphericity of 25.5 mm has the largest difference, and sphericity of 27.5 mm has the smallest. When comparing the differences by size, the adjusted mean differences have a trend toward less underreaming as the reamer size increases (Fig. 6).

Discussion

The ability to achieve a satisfactory press fit relies on cup geometry, thickness, material properties of the implant, proper surgical technique, and the viscoelastic properties of the pelvis to accept an oversized acetabular implant [10-15]. The amount of press fit necessary to achieve optimal mechanical stability without dome gaps has been studied and varies from 1 to 4 mm, with most authors agreeing that 1-2 mm of underreaming as being ideal [10-12]. The purpose of this study was to answer 3 primary questions: (1) is there a difference between the hemispherical and MIS reamers, (2) what is the difference between new and used reamers,

Table 2
Adjusted mean difference by reamer category—sphericity.

Reamer category	Reamer	Adjusted mean (SE)	*P* value
New vs used	New	0.43 (0.33)	.108
	Used	0.96 (0.33)	
Hemispherical vs MIS	Hemispherical	0.42 (0.33)	.086
	MIS	0.98 (0.33)	
Interaction of new/used and type	New/hemispherical	0.55 (0.41)	**.017**
	New/MIS	0.32 (0.41)	
	Used/hemispherical	0.29 (0.41)	
	Used/MIS	1.64 (0.41)	

The table shows the adjusted mean difference of various reamers based on cavity sphericity. There was no significant difference between new vs used or hemispherical vs MIS in terms of sphericity. The interaction category did show significant differences. The most spherical reamers used/hemispherical reamers.
The bold value represents the item that reached statistical significance.
SE, standard error.

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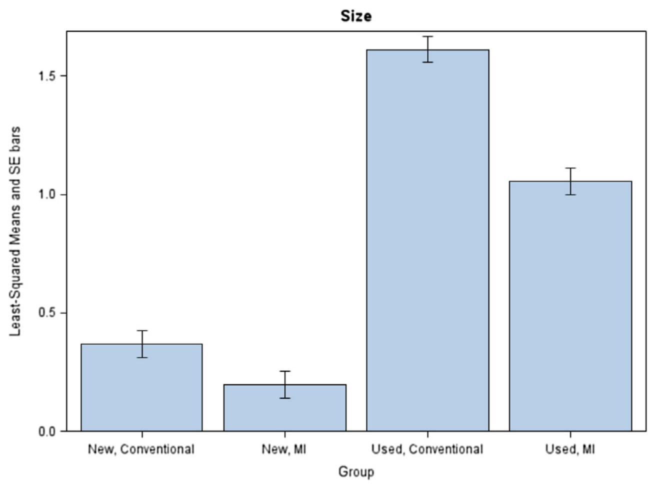

Figure 4. Mean differences with standard errors (SE) of different reamers based on reamer size. The new minimally invasive (MIS) reamers show the smallest differences in expected vs actual cavity sizes while the used/hemispherical reamers showed the greatest differences.

and (3) does the actual reamed cavity match the manufacturer's stated size and sphericity?

Reports in the literature lack consensus regarding the accuracy of both reamers and technique. MacKenzie et al evaluated new reamers, comparing a handheld technique to a vertical drill press technique and found no significant difference between the 2 in cadaver specimens. Their reamers were new and were verified to be true to size and sphericity using a 10× optical comparator prior to proceeding with their study [9]. They found minimal enlargement of the reamed surface compared with the reamer used (average of 0.5 mm). In contrast, Vaughan et al. [16] tested 5 different hip systems (78 reamers in total) and found that 64 of 78 were inaccurate, with 2 systems consistently producing cavities at least 1 mm smaller than intended. White et al [5] looked at the tolerance of 4 different acetabular reamers and implants and reported a variability of 1.5 mm on implant tolerances. Our study showed an average underreaming of 1.33 mm and 0.282 mm for used and new reamers, respectively. Moreover, the smaller sized reamers showed more inaccurate reamings than the larger reamers. This correlates with how often these are used in vivo. Smaller reamers are traditionally used initially to ream increasingly larger cavity sizes, while the larger reamers may not be used in every case. We feel that the cause for the variability in reamer size may be due to repeated use and normal wear, seen with any cutting instrument.

Given the concerns with potential inaccuracy of acetabular reaming for any reason, Kwong et al [8] recommended using bipolar sizers to check the actual diameter of the reamed socket prior to implanting the cementless device. These machined aluminum sizers have radially oriented slots to actually visualize the dome and areas of peripheral contact. Another option would be to replace the reamers on a regular basis. There is no clear data suggesting the amount of use necessary to cause decline in reamer accuracy. Since much of the existing literature tests new reamers, the results may not be generalizable to clinical practice [6-9]. One other option would be to sharpen the reamers, but the manufacturers no longer recommend this option.

Upon review of our hospital records regarding the reamers used for this study, we found a difference in the amount of time that the 2 sets of used reamers had been in circulation. The MIS reamers were used for approximately 1 year, while the hemispherical reamers had been in use for about 2 years. The MIS reamers were processed about 40 times over that year, while the hemispherical reamers were processed about 48 times over 2 years. Again, no reamer was sharpened during this period per manufacturer's recommendations. Additionally, the reamers used for this study were tested only at the end of their lifetime; therefore, conclusions about the used reamers must be made reflecting these differences in processing and time in circulation.

Comparing the differences between MIS and conventional hemispherical reamers has been previously reported as well. Davidson et al. [6] compared cadaveric hips using MIS and standard

Table 3
Adjusted mean difference of actual vs expected values by reamer size.

Expected size	Adjusted mean (SE)	*P* value
48 mm	1.04 (0.10)	**.0391**
49 mm	1.02 (0.10)	
50 mm	0.84 (0.10)	
51 mm	0.78 (0.10)	
52 mm	0.72 (0.10)	
53 mm	0.70 (0.10)	
54 mm	0.73 (0.10)	
55 mm	0.64 (0.10)	

There is a significant difference in reamer accuracy between the smallest and largest reamers. The larger reamers showed less difference in their actual reamed cavity size.
The bold value represents the item that reached statistical significance.
SE, standard error.

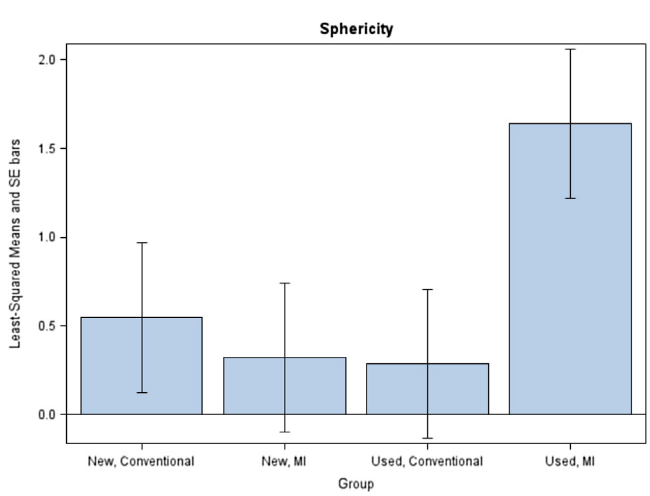

Figure 5. Mean differences with standard errors (SE) of different reamers based on reamer sphericity. The used hemispherical reamers show the smallest differences in expected vs actual cavity sphericity while the used/minimally invasive (MIS) reamers showed the greatest differences.

Table 4
Adjusted mean difference of actual vs expected values by reamer sphericity.

Expected size	Adjusted mean (SE)	*P* value
24 mm	0.56 (0.47)	**.0012**
24.5 mm	0.52 (0.47)	
25 mm	0.35 (0.47)	
25.5 mm	2.84 (0.47)	
26 mm	0.31 (0.47)	
26.5 mm	0.55 (0.47)	
27 mm	0.27 (0.47)	
27.5 mm	0.19 (0.47)	

There is a significant difference in reamer accuracy for various sphericities tested. The 25.5-mm sphericity showed the greatest inaccuracy.
The bold value represents the item that reached statistical significance.
SE, standard error.

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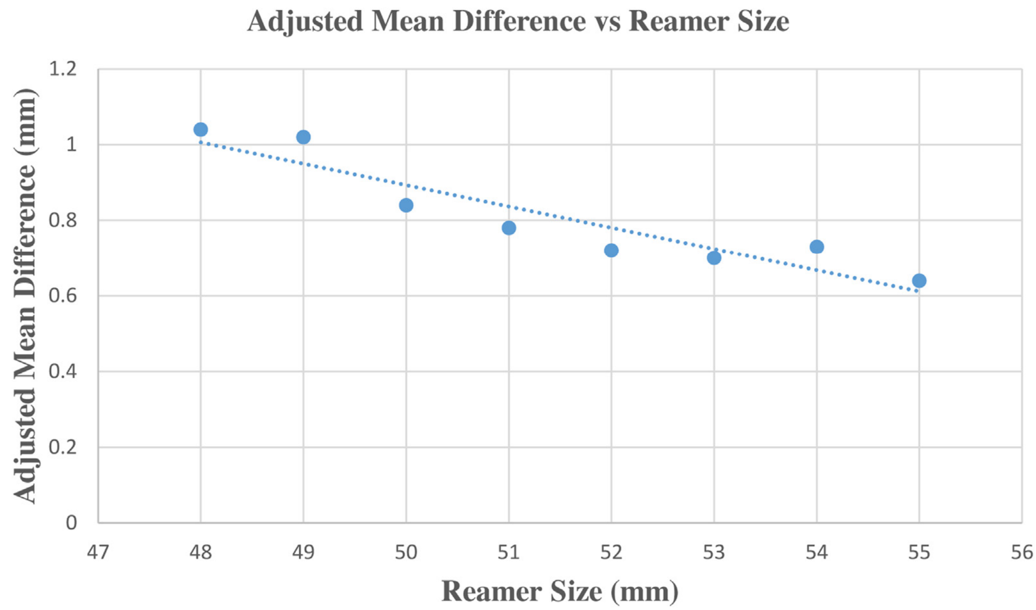

Figure 6. Relationship between adjusted mean difference and reamer size. As the reamer size increases, the mean difference decreases as well.

acetabular reamers with computed tomography–based 3-dimensional geometry to determine the true dimension of the reamed hole. Seventy percent of MIS reamers were within the manufacturer's specification, compared to 81% for the hemispherical reamers. The authors attributed this decrease in accuracy of MIS reamers to a tendency of the MIS reamers to wobble during use. It is difficult to interpret their results, given that they used new MIS reamers and used hemispherical reamers. Baad-Hansen et al. [7] also compared new hemispherical and MIS reamers using 9 pairs of cadaver acetabuli using optical 3-dimensional systems for measurement of the cavity shapes. The mean difference between the reamer domes and the measured values showed an impressive discrepancy of 2.2 mm in the MIS group and 2.8 mm in the hemispherical group. They found no statistically significant difference in comparing the MIS and hemispherical reamer groups in evaluation of the best-fit sphere.

The aforementioned studies compared the same reamer systems we used in our study (Zimmer Inc.), albeit with different results. We found MIS reamers underreamed significantly less than the hemispherical reamers with a mean difference of 0.63 vs 0.99 mm, respectively, suggesting a 64% improvement. Additionally, the MIS reamers produce less spherical reams than the hemispherical ones. Despite these differences in sphericity, neither of these categories shows any significance. Macdonald et al. [17] studied hemispherical reamer design and an experimental cutting design with better cutting flutes on 12 cadaveric acetabuli using dental alginate impressions of actual human acetabulae. They found that diametrical errors of hemispherically reamed cavities averaged 2.1% with the experimental reamers reducing the error rate to only 0.5% ($P < .005$). Their conclusion was that current reamer designs are imperfect and create an uneven cavity shape that may compromise an ideal fit.

The clinical implications of inaccurate acetabular reaming are significant. Not knowing the actual diameter of the acetabulum may lead surgeons to undersize or even oversize the implant. Ries and Harbaugh [13] used a finite element model to look at strains produced by oversized components. They found that bone strain and implant stability were increased when underreaming by 2 mm, as compared to 1 mm, although this was associated with an increased risk of fracture. They recommended 1-mm underreaming for cups less than 52 mm in diameter, 2 mm of underreaming for cups 53-76 mm in diameter, and 3-mm underreaming for cups larger than 76 mm. Other authors have noted that the risk of acetabular fracture increases significantly when the press fit is greater than 2 mm [3]. Furthermore, relative oversizing of the acetabular component decreases polar-dome contact, which can deter bony ingrowth at the bone-prosthesis interface [9]. Thus, accurate sizing of the acetabulum matters greatly to ensure a proper press fit and ultimately avoid fractures and premature loosening.

Previous studies have used various methods for measurement of cavities to assess reamed accuracy. Casting techniques, plaster of paris, 3-dimensional laser studies, and optical 3-dimensional scanning equipment have been reported; however, no measurement method has been the standard in orthopaedic research [6,7,9,16,17]. The use of fresh-frozen and embalmed cadaver pelves presents another confounding variable when assessing reamer accuracy. Frequently, the bone is osteoporotic and is of a heterogeneous density that could affect reamer tracking. Macdonald et al. [17] found that sclerotic areas in the acetabulum impose unbalanced forces on the reamer, thus causing it to wobble and create a less-accurate cavity. Additionally, the use of hand reaming adds another variable that may also change the shape of the experimental reamer bed. It is difficult to hold the reamer in exactly the same position consistently without a change in orientation. Each surgeon develops a "feel" for his or her own reaming technique. Since our primary goal was to assess the accuracy of the reamer itself, we attempted to isolate this variable by keeping as many of the other confounders constant. Hence, we chose a computer numerical control machine to replicate the same reaming motion and used a machinable wax block substrate commonly used in manufacturing and dentistry that would not alter the sharpness of our reamers with repeated uses.

There are several limitations to this study. While we believe the experimental setup was ideal to independently evaluate our 3 primary study questions and isolate only the effects of the reamers themselves, we acknowledge that this setup is not representative of what occurs in vivo during total hip surgery. For example, the use of a computer numerical control machine was not representative of

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the handheld technique surgeons use in vivo. Also, the wax block model in no way replicates human bone. Again, this setup was meant to create a reproducible environment so as to only measure the variation of the reamers. The measurement of the reamed cavity was only in 1 plane and did not constitute a best-fit sphere. Three-dimensional rendering software would potentially provide enhanced evaluation. We were able to estimate an approximate number of uses for our off-the-shelf reamers. More thorough documentation might have allowed an exact number of uses for each reamer system. A reasonable next step would be to perform repeat evaluation of reamers at different time points or processing times to determine the number of cycles necessary to result in clinically relevant decreases in accuracy.

Conclusions

For a specified reamer size, the modular cutting shell tends to undersize the hole created for both hemispherical and MIS systems. Predictably, newer reamers cut truer to expected values than used. MIS reamers performed more accurately than hemispherical reamers. Larger sized reamers were more accurate than smaller sizes. Used acetabular reamer systems may negatively affect the sizing of prepared acetabular beds; therefore, awareness of this potential inaccuracy should be considered when performing total hip arthroplasty.

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