Arthroplasty Today 7 (2021) 91–97

Contents lists available at ScienceDirect

Arthroplasty Today

journal homepage: http://www.arthroplastytoday.org/

Original Research

Variability of Cutting and Thermal Dynamics Between New and Used Acetabular Reamers During Total Hip Arthroplasty

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ARTICLE INFO

Article history:
Received 6 October 2020
Received in revised form
2 December 2020
Accepted 7 December 2020
Available online xxx

Keywords:
Acetabular reaming
Thermal dynamics
Total hip arthroplasty
Reaming accuracy

ABSTRACT

Background: Aseptic loosening of the acetabular component remains one of the leading causes of early failure of total hip arthroplasty. Poor apposition of bone onto the implant surface can be due to inaccurate reaming and osteonecrosis of the acetabular bone due to the heat generated while reaming.
Methods: New and used acetabular reamers were tested on an MTS system using a clinically relevant force of 87.6 N. A thermal profile and depth achieved by the reamers were analyzed and compared between the 2 cohorts. Heat generated and force required for the community used reamers to achieve the same depth as the new reamers were subsequently analyzed.
Results: The new reamers achieved a depth 3.4 mm deeper than the community reamers ($P < .001$). The new reamers generated 4.1°C less heat than the community reamers ($P = .007$) under the same force and time. When programmed to ream to the average depth of the new reamers, the community reamers generated 16.8°C more heat ($P = .002$) and required forces 95-318% greater than the 87.6 N force used by the new reamers.
Conclusions: Community use of reamers will cause variations in depth of penetration and increased temperatures at a clinically generated force vs new reamers. When community reamers were forced to the same depths the new reamers achieved, a significantly greater amount of heat was generated, and an increased amount of time was needed, both of which are known risk factors for osteonecrosis.

Introduction

Total hip arthroplasty (THA), with a survivorship greater than 90% at 15 years, is regarded as one of the most successful surgical procedures performed [1,2]. With the aging population, the incidence of primary THA is projected to increase 174% by the year 2030 [3,4]. Modern cementless implantation is used in over 93% of THAs performed today [5]. Pressfit acetabular components require a precisely reamed acetabulum and an oversized prosthetic component for a tight fit promoting bone apposition onto the implant via osseointegration [6,7]. Aseptic loosening of the acetabular component remains one of the leading causes of early failure of THA, accounting for 9.5%-30% of all failures [8-11]. Survival of the implant can also be affected by surgical factors such as the accuracy of reaming, acetabular bone coverage, and cup position [7].

The cutting of bone is a dynamic shear failure process which releases thermal energy through the mechanical overwhelming of the intermolecular bonds of the bone [12]. It is well described in the literature that heat produced from high-powered orthopedic instruments can lead to osteonecrosis [13,14]. The extent of osteonecrosis is positively correlated with the amount of heat generated from the orthopedic instrument [15]. Temperatures above 45°C result in coagulation of blood ultimately causing ischemia and infarction of the bone [16]. In addition, the length of heat exposure is also an important variable, with previous studies reporting bone necrosis occurring at 47°C for 5 minutes, 50°C for 1 minute, or 56°C for less than 1-minute duration [13,17]. This osteonecrosis can also result in delayed healing and improper bone-implant incorporation [14,18].

The potential to achieve a stable, intimate fit of an acetabular cup in a reamed acetabulum depends on a multitude of factors

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https://doi.org/10.1016/j.artd.2020.12.002

including bone quality, instrument quality, and surgical technique [6]. When performing THA, surgeons have little data on the sharpness of the acetabular reamer set as they are often turned over such that the quality of the reamers is largely unknown. The lack of knowledge of how dull a reamer is leads to a variable in surgery which forces surgeons to increase or decrease reaming pressure and time of reaming to get to a desired depth and cup position. With reamers that may dull over time, there is concern for increased heat generation during reaming which may not be recognized intraoperatively. Therefore, the aim of this study was to determine what effect community use of an acetabular reamer set has on depth of penetration and heat differential at a force generated by practicing hip surgeons during reaming, compared with a set of new reamers. A secondary aim was to determine the force required and heat generated for the community-used reamers to reach the same depth achieved by the new reamers.

Material and methods

This was a laboratory study using solid polyurethane foam Sawbones blocks (Sawbones; Pacific Research Laboratories, Vashon, WA) with a density of 0.48 g/cm3 chosen as the mean density between cortical bone (0.64 g/cm3) and cancellous bone (0.32 g/cm3) to best represent the cortico-cancellous bone in an acetabulum on a consistent substrate [19-21]. The 2 study groups consisted of unused reamers and reamers which were acquired after being in the community for use at a regional facility with an undefined amount of use but felt to be in need of replacement because of use.

Reamer size and selection

The reamers used in this study consisted of sizes 47 mm through 55 mm reamers in one-millimeter increments and were from the CuttingEdgeTM Acetabular Spherical Reamers series (Stryker Ltd, Kalamazoo, MI).

Development of testing apparatus

Computer-aided design software from SolidWorks (SolidWorks, Waltham, MA) and an Ultimaker 3+ (Ultimaker, Cambridge, MA) 3D printer were used to construct an attachment connecting the surgical reamer to the actuator of the MTS Servohydraulic Test System (MTS Bionix 370; MTS Systems Corporation, Eden Prairie, MN). A second attachment was constructed to secure the Sawbone blocks to the force transducer of the MTS Servohydraulic Test System. Using an Arduino and servomotor, a mechanism was developed to standardize the ream time and reamer speed (Fig. 1). A Dyonics Power drill (Smith & Nephew, Andover, MA) was used in this study, along with the use of the Arduino, and the drill was set to ream at 270 revolutions per minute (RPM). The 270 RPM chosen for this study was based off the RPMs achieved by the Stryker series 8 drill (Stryker Ltd, Kalamazoo, MI) when used on the ream setting. Immediately after each trial, A FLIR One infrared camera (FLIR Systems Inc., Wilsonville, OR) was used to obtain the thermal profile of the reamed surface from a consistent angle and distance.

Acetabular cavity preparation

To prepare the sawbone blocks for reaming, acetabular cavities were preformed with a reamer taken from another set not used elsewhere throughout the experiment. Each cavity was formed with a reamer that was 1 mm larger than the respective experimental reamer for each trial. The prereaming was performed to simulate acetabular conditions and promote circumferential contact seen in clinical settings where all cutting flukes are engaged without adding equatorial stress at the reamer edge where there are no cutting flutes. Each block was allowed to cool down to 28°C before advancing with the study.

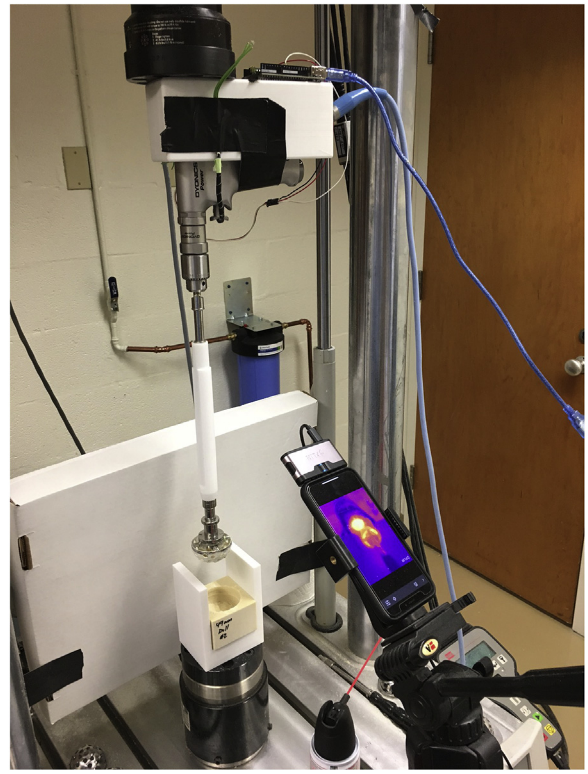

Figure 1. The setup used in the study with the MTS Servohydraulic Test System, drill with Arduino, and infrared camera.

Depth and heat generation disparities with a constant force and time

To best approximate clinically relevant findings, a force transducer was installed into a reamer establishing a reamer simulator. Four fellowship-trained hip surgeons were asked to simulate the length of time and peak force in which they would ream the acetabulum before placing the acetabular implant during surgery which was calculated at 87.6 N. The 4 surgeons were then asked to push as hard as they physically could while maintaining a stance they would use while reaming to capture a mean max effort force of 330.4 N (Table 1). The mean intraoperative peak force of 87.6 N along with a mean ream length of 8 seconds was programmed into the MTS Servohydraulic Test System and executed for one reamer trial. Sawbone blocks were initially put into compression at 43.2 N, and the force was increased at a rate of 4.45 N/s for 10 seconds to reach the determined 87.6 N before the reaming. Servohydraulic test systems tend to exceed the programmed force when incremented at a high rate, hence the need to gradually increase the force to ensure 87.6 N was not surpassed. Once this threshold was

Table 1
Force generated by fellowship trained hip surgeons during reaming simulation.

Surgeon	Trial	Average reaming force (N)	Max effort force (N)
I	Average	95.42	414
II	Average	79.54	310
III	Average	76.67	325.67
IV	Average	93.14	271.83

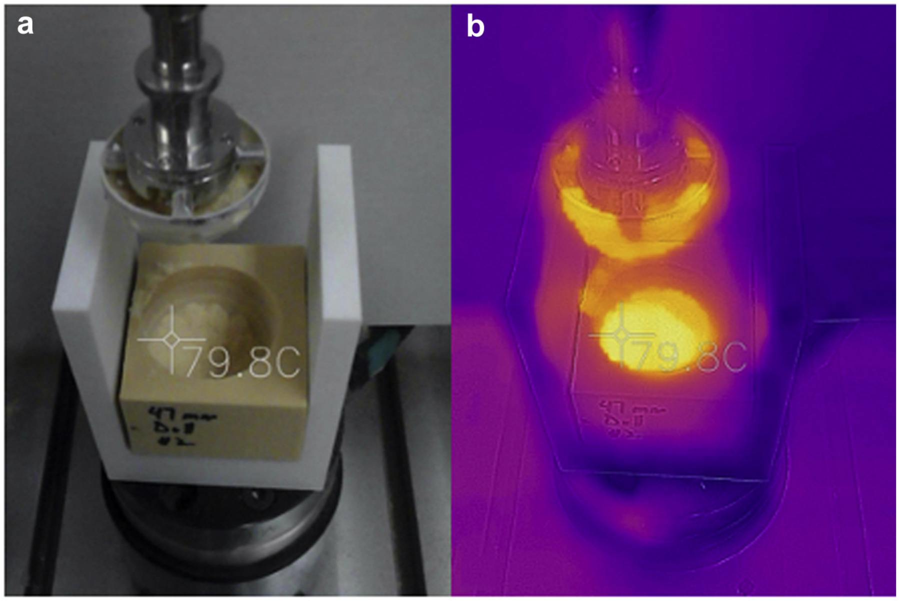

Figure 2. Capturing the thermal profile after reaming the bone substrate with a 47-mm community reamer. (a) Without infrared filter. (b) With infrared filter.

achieved, the MTS Servohydraulic Test System maintained constant force, and reaming was initiated. After 8 seconds of reaming, the drill was deactivated, and the reamer was lifted out of the socket to expose the reamed surface. A thermal profile was then obtained (Fig. 2), and the maximum temperature was recorded. Cutting depth was recorded by the MTS Servohydraulic Test System. Three trials were conducted for each reamer to decrease variability.

Force and heat generation disparities with a constant cutting depth

The second portion of the study used the average depths achieved by each of the new reamers, and these depths were programmed into the MTS Servohydraulic Test System. For example, the new 47-mm reamer achieved a depth of 4.9 mm, so the used 47-mm reamer was programmed to reach this depth. To get a community reamer to the same depth as a new reamer, 2 variables could be changed in this setting and in surgery, which are force and time of reaming. If the time was kept constant and force allowed to change, the forces needed to achieve the same depth were higher than any force a surgeon could provide clinically and also were beyond the torque limitations of the surgical reamer. The decision was made to double the time and allow for a variable force to best simulate surgical conditions. The maximum force and thermal differentials were recorded. If the reamer was unable to descend to the predetermined depth, the MTS Servohydraulic Test System recorded the maximum achieved depth within the time allowed. The methods used to measure the maximum force and temperature for these reamers were the same as those used for the reamers that achieved the correct depth. Three trials were conducted for each community reamer. Based on the ranges reported in prior studies, 50°C was chosen as the osteonecrosis threshold for analysis of the heat differential between the 2 cohorts [13,16,22].

Three trials were performed for each reamer size, with 9 sizes represented in total (47-mm through 55-mm reamers). Statistical analysis was performed using a Welch t test for scale variables and a Levene's F test to compare variances between groups. A P value of <.05 was considered statistically significant. A statistical analysis was completed using SPSS Statistics 24 (IMB, Armonk, NY). A Shapiro-Wilk test was used to test for normality on the main dependent variable heat and depth of penetration and was found to be normally distributed ($P > .05$).

Results

When reamed at a constant force and time, the new reamers penetrated to a greater depth (3.9 mm ± 0.92 mm) than the community reamers (0.5 mm ± 0.2 mm), a statistically significant difference of 3.4 mm ([95% confidence interval (CI), 2.6 mm to 4.1 mm], $P < .001$). There was a statistically significant difference between the depth of penetration of new reamers and community

Table 2
Differences in depth between different reamer sizes at constant force and time.

Reamer size (mm)	Depth (mm) community reamer	STE	Depth (mm) new reamer	STE (N)	Difference	95% CI	P value
47	0.34	0.03	4.95	0.99	4.603	3.02-6.19	.001
48	0.33	0.006	4.57	0.26	4.24	3.83-4.66	<.001
49	0.72	0.18	3.53	0.28	2.81	2.28-3.34	<.001
50	0.90	0.13	2.35	0.51	1.45	0.61-2.29	.008
51	0.32	0.04	2.70	0.41	2.38	1.72-3.04	.001
52	0.28	0.01	4.78	0.54	4.50	3.62-5.37	<.001
53	0.54	0.03	4.60	0.15	4.06	3.81-4.31	<.001
54	0.62	0.17	3.76	0.53	3.14	2.25-4.03	.001
55	0.49	0.03	3.77	0.30	3.27	2.79-3.76	<.001

STE, standard error of the mean.

Table 3
Differences in heat between different reamer sizes at constant force and time.

Size (mm)	Community reamer temperature (°C)	STE	New reamer temperature (°C)	STE (N)	Difference	95% CI	*P* value
47	47.5	0.57	45.8	3.25	1.7	3.59-6.99	.42
48	51.7	1.04	49.1	1.59	2.6	0.45-5.64	.08
49	55.3	0.70	49.9	3.86	5.4	0.887-11.69	.08
50	54.0	2.62	48.2	1.29	5.8	1.12-10.48	.03
51	47.5	1.50	49.4	3.57	−1.8	4.31-8.11	.44
52	52.5	2.59	46.0	0.65	6.5	2.22-10.78	.01
53	51.6	1.20	47.7	0.62	3.9	1.73-6.07	.01
54	52.7	0.40	47.5	1.7	5.2	2.39-8.00	.01
55	58.9	0.49	51.1	1.57	7.8	5.16-10.44	<.001

STE, standard error of the mean.

reamers for every reamer size, with new reamers of size 47 mm to 55 mm achieving greater penetration than community reamers (Table 2).

When reamed at a constant force and time, the new reamers (48.3°C ± 1.76°C) generated less heat than the community reamers (52.3°C ± 3.58°C), a statistically significant difference of 4.1°C ([95% CI, 1.3°C to 6.9°C], $P = .007$). The community 50-mm reamer and the community reamer size 52 mm and above each generated significantly more heat than the new reamers (Table 3).

The community-used reamers were programmed to be reamed to the same depths as the new reamers of equivalent sizes by increasing the mean force from the baseline clinically measured force. Only the 47-mm, 49-mm, and 50-mm reamers were able to reach the same depth achieved by the new reamers (Fig. 3). When reamed to the programmed average depth of the new reamers, the community reamers generated more heat (65.1°C ± 11.2°C), a statistically significant difference of 16.8°C (95% CI, 8.1°C to 25.4°C; $P =$ .002). All the community reamers significantly passed the range for the average temperature threshold for osteonecrosis (50°C) compared with the new reamers when reamed to the same average depth, with the 50-mm, 49-mm, and 47-mm reamers having the greatest temperature increase above the average osteonecrosis threshold (Fig. 4).

When testing surgeons on the simulator, the highest force the surgeons could apply was a mean of 330.4 N ± 60.2 N, compared with their mean peak force applied in surgery which was 87.6N ± 8.6 N. There was not a statistically significant difference between the surgeon's average max effort force on the simulator and the forces required for the community reamers to reach the depths of the new reamers for every reamer size except for the 50-mm reamer ([95% CI, 56.1 to 262.1], $P = .01$) (Table 4).

There was a statistically significant difference between the force required for the new reamers to reach a specific depth (87.6 N) and the forces required for the used reamers to reach those same depths for every reamer size. The community reamers on average required 197.5 N more force than the new reamers. The 47-mm, 48-mm, and 51-mm community reamers also had the greatest percent increase in force from the baseline clinically relevant force (87.6 N) when reamed to the same average depth as the new reamers (Fig. 5).

Discussion

Pressfit acetabular implants rely on accurately underreaming the acetabulum by 1-2 mm to provide optimum mechanical stability [23,24]. Prior studies have documented inaccuracies in the finding that reaming can lead to less-than-optimal implant fixation and subsequent poor patient outcomes after total joint arthroplasty [14,18,25]. Previous studies on animal models have indicated instantaneous osteonecrosis can occur when exposed to temperatures at and above 56°C [13,15]. In a study analyzing the temperatures achieved during glenoid reaming of patients undergoing total shoulder replacement, Olson et al. reported an average temperature of 75.5°C among the cohort that did not receive irrigation; however, the amount of use the reamers had, reaming duration, and force applied to the reamer were not defined [26]. Bone necrosis and inaccuracy while reaming resulting in gaps of 50 μm or more in the bone-implant interface can result in excessive fibrous tissue growth preventing proper osseointegration of the implant [27]. The significant differences in depth achieved and temperatures generated between the community-used reamers and new reamers reported in the present study could contribute to acetabular loosening.

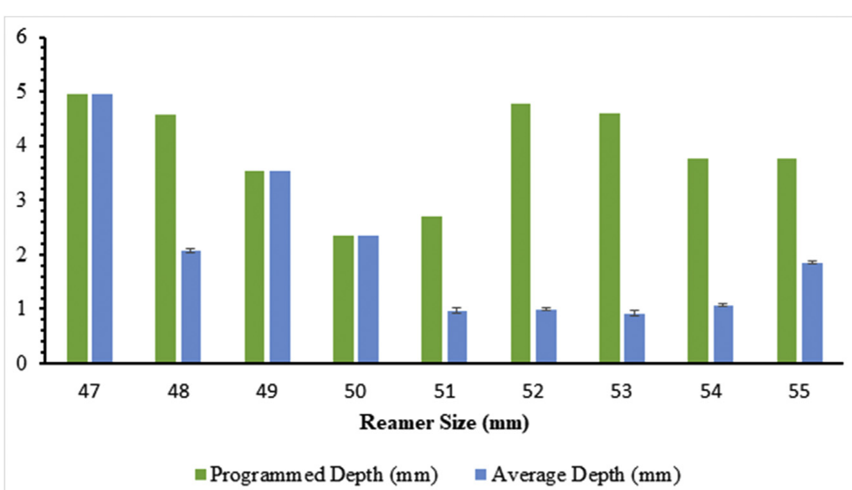

Figure 3. Depth reached by community reamers when reamed to new reamer average depth.

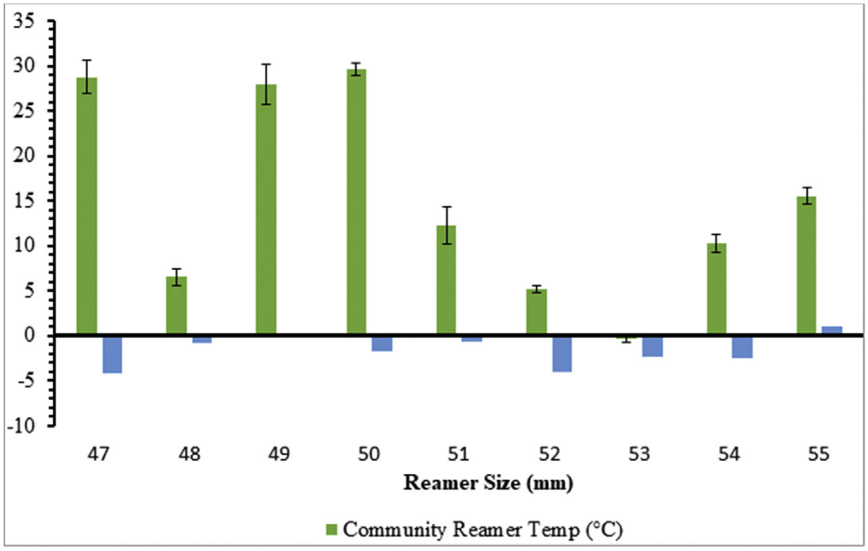

Figure 4. Threshold for osteonecrosis (50°C) for community and new reamers at new reamer average depth.

An average difference of 3.4 mm of penetration between the new and community-used acetabular reamers was demonstrated in this study using the clinically relevant force generated by practicing hip surgeons. Because the rate of loading and substrate chosen will greatly influence the variability of the reaming, biomechanical studies can prove difficult to translate to a clinical setting. One known acetabular reamer study investigating the accuracy of acetabular reamers used wax blocks of unknown density with a preselected linear advancement force to guarantee reamer depth to find a difference of 1.05 mm [6]. The present study used a homogenous substrate best representing cortico-cancellous bone and tested fellowship-trained surgeons to establish a force to best represent a clinical scenario. It has been documented even small discrepancies of 1 mm when reaming can lead to eventual implant loosening, so the average difference of 3.4 mm found in this study would be impactful in the operating room if not corrected for by the surgeon [6,23,24,28]. It was also reported reamers of different sizes within a community set displayed variations in depth of penetration, which could make reaming difficult as reamer to reamer can be as variable as set to set when use is unknown. The variation in depth achieved between reamers within a certain set can be expected as some reamers may be used more frequently than others. For example, at the authors' institution, a size 52 and 54 acetabular cups are the most common final implants placed in females and males, respectively. Therefore, the mid-range reamers (50 mm-52 mm) are used at a greater frequency during the sequential reaming process. In addition, with the ability to exchange individual reamers while not necessarily changing entire sets, surgeons are faced with the ongoing challenges of not knowing the differences in sharpness between reamers of the same set and having to adjust for reaming time and force accordingly.

This study is unique such that it provides data on the amount of thermal energy produced while reaming an acetabulum in a simulated environment; to the authors' knowledge, this has not been documented in previous literature. The present study demonstrated on average the community reamers generated temperatures 4.1°C greater than their new counterparts. This aligns with a study carried out by Allan et al. who investigated the difference in drill bit performance in cortical bone and demonstrated a linear relationship between the temperatures achieved during drilling and drill bit wear [29]. Further studies analyzing the rate at which reusable acetabular reamers wear with repeated use could provide additional insight into establishing a more standardized approach to knowing when it is appropriate to exchange reamers. This could be stratified to a further degree by analyzing the rate of wear between reamers of different manufacturers.

When reaming to the medial wall, often a surgeon has to ream through bone to a depth of 6-8 mm to seat a cup in optimum position without the knowledge of the reamer's sharpness. In the event of a dull reamer set, the surgeon is required to place additional force over a longer time period to reach a desired depth. The information sought was how much additional heat would be generated in this situation by forcing the community reamers to reach a depth the new reamers achieved with the clinically relevant

Table 4
Differences in force of community reamers to cut to average depth of new reamers vs max effort force.

Size (mm)	Force community reamers (N)	STE (N)	Average max effort force (N)	STE (N)	Difference	95% CI	*P* value
47	361.7	72.9	330.4	60.2	31.34	97.36 to 160.04	.56
48	330.9	14.9	330.4	60.2	−0.50	−93.85 to 92.85	.99
49	211.1	59.0	330.4	60.2	119.32	2.11 to 236.52	.05
50	171.2	38.1	330.4	60.2	159.13	56.14 to 262.12	.01
51	349.3	18.8	330.4	60.2	−18.92	−113.34 to 75.50	.63
52	287.2	4.6	330.4	60.2	43.18	−48.48 to 134.84	.28
53	282.2	11.0	330.4	60.2	48.14	−44.36 to 140.64	.24
54	248.1	16.6	330.4	60.2	82.30	11.47 to 176.07	.07
55	324.6	22.7	330.4	60.2	5.74	−89.99 to 101.48	.88

STE, standard error of the mean.

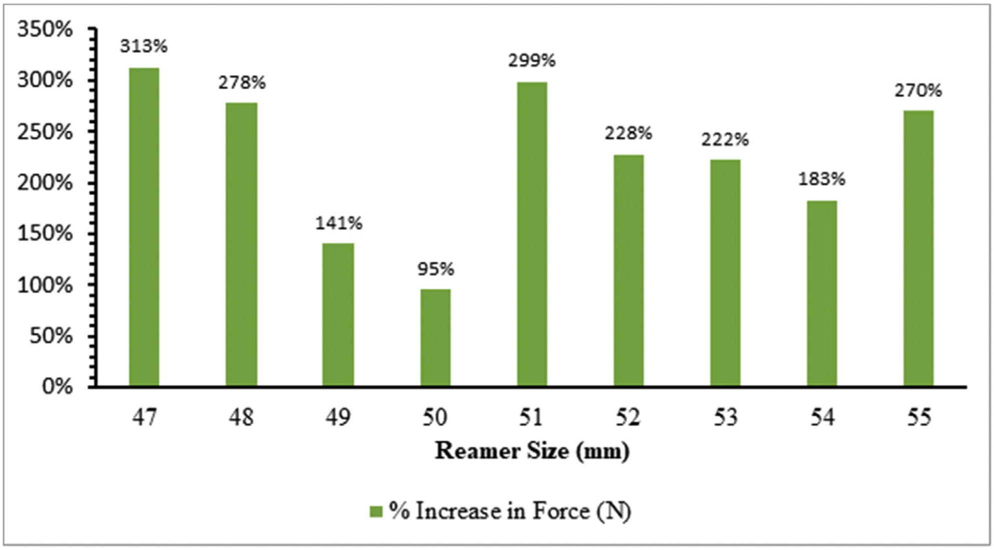

Figure 5. Percent increase in force of community reamers to cut to average depth of new reamers.

force. Even with doubling the allotted time, 6 reamers (48 mm, 51-55 mm) did not reach the same depth the new reamers did suggesting the difference surgically may result in even more time needed to get to a desired depth. When compared to max effort force, the force necessary to reach the predetermined depths were similar for all but one reamer size (50 mm), which indicates an unrealistic clinical scenario where a surgeon would have to exert max force for an extended period of time. The temperature differences generated in this scenario averaged 65.1°C, which was likely underestimated with the format to best represent a clinical scenario. The increased force and time of reaming necessary to reach the same depth could place patients at an increased risk of osteonecrosis when community-used reamers are used. These findings could be exacerbated in certain patients where sclerotic bone is present.

This study adds a novel methodology to assess acetabular reaming to the body of literature by development of an acetabular reamer with a force transducer to establish the mean force generated by surgeons clinically to determine clinically relevant mechanical forces in testing. The findings of significant differences in both reaming depth and heat production also emphasize the need to document the age of reamers and be aware of this factor. For example, most hospitals in the United Kingdom do not routinely monitor their drills for sharpness and wear [30]. As demonstrated in our study, wear variations also exist within individual reamer sets that impact depth and heat generated during reaming. Therefore, the age of the set itself is not an accurate metric for individual reamers, and each reamer's usage within a set could potentially be monitored. Applications could be developed for tracking and monitoring use and to also provide feedback for surgeons. Testing could also be performed on specific manufactures and disclosed to surgeons on how the use of reamers translates to heat differentials and depth variations at clinical forces.

This study has several limitations. A density of 0.48 g/cm^3 was chosen for the Sawbones blocks as to provide a reproducible environment for comparison and simulates the mean density between cortical and cancellous bone; however, bone density can vary significantly among patients. Although the extent of wear on the community-used reamers is unknown, this method was chosen purposely to emulate clinical conditions such that surgeons in the field are rarely aware of how many times a set of reamers has been used. When capturing the thermal profile, the reamer had to be stopped and removed from the socket in order for the infrared camera to capture a full profile of the socket. Not accounting for exact temperatures at the metal-to-bone interface and allowing the time necessary to remove the reamer before capturing the thermal profile could lead to temperatures being underestimated. While the continuous ream time of 8 seconds was based on observations of 4 surgeons to use a clinically relevant time parameter; variations in reaming duration, use of sequential, or intermittent reaming may affect the amount of heat generated.

Conclusions

Community-used reamers achieved significantly less penetration when placed under the same force and time variables than new reamers. The community-used reamers also generated significantly more heat under these same conditions. In addition, community-used reamers required a significantly increased amount of force to reach the same depth as the new reamers when allocated twice the amount of time. Variability in depth of penetration among the community-used reamers was also reported which suggests certain reamer sizes had more wear within the same set. A logical application of this study is for hospitals or device representatives to log reamer usage and create a standard use limit for reamers.

Conflict of interests

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: (1) Medacta (2) Signature Orthopedics (3) Biocomposites (4) AAOS Knee Content Committee.

For full disclosure statements refer to https://doi.org/10.1016/j.artd.2020.12.002.

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