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Thermal damage during humeral reaming in total shoulder resurfacing

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ABSTRACT

Introduction: Total shoulder resurfacing (TSR) provides a reliable solution for the treatment of glenohumeral arthritis. It confers a number of advantages over traditional joint replacement with stemmed humeral components, in terms of bone preservation and improved joint kinematics. This study aimed to determine if humeral reaming instruments produce a thermal insult to subchondral bone during TSR.

Patients and Methods: This was tested *in vivo* on 13 patients (8 with rheumatoid arthritis and 5 with osteoarthritis) with a single reaming system and *in vitro* with three different humeral reaming systems on saw bone models. Real-time infrared thermal video imaging was used to assess the temperatures generated.

Results: Synthes (Epoca) instruments generated average temperatures of 40.7°C (SD 0.9°C) in the rheumatoid group and 56.5°C (SD 0.87°C) in the osteoarthritis group ($P = 0.001$). Irrigation with room temperature saline cooled the humeral head to 30°C (SD 1.2°C). Saw bone analysis generated temperatures of 58.2°C (SD 0.79°C) in the Synthes (Epoca) 59.9°C (SD 0.81°C) in Biomet (Copeland) and 58.4°C (SD 0.88°C) in the Depuy Conservative Anatomic Prosthesis (CAP) reamers ($P = 0.12$).

Conclusion: Humeral reaming with power driven instruments generates considerable temperatures both *in vivo* and *in vitro*. This paper demonstrates that a significant thermal effect beyond the 47°C threshold needed to induce osteonecrosis is observed with humeral reamers, with little variation seen between manufacturers. Irrigation with room temperature saline cools the reamed bone to physiological levels and should be performed regularly during this step in TSR.

Key words: Humeral reaming, thermal damage, total shoulder resurfacing

INTRODUCTION

Total shoulder resurfacing (TSR) provides a reliable and robust solution for the treatment of glenohumeral arthritis.[1] Resurfacing is more bone preserving, allows for accurate reconstruction of glenohumeral version, restores the geometric center of the humeral head and provides a more anatomical construct than with stemmed humeral components.[2-4] It has been shown to provide pain relief whilst maintaining a satisfactory range of functional movement.[5,6] Resurfacing is especially suited to the young, active patient with glenohumeral osteoarthritis.[7] It is been shown to be beneficial in inflammatory arthropathies such as rheumatoid arthritis, as it avoids a potential stress riser in between a stemmed total elbow replacement and a shoulder component,[8] for osteonecrosis of the humeral head[9-11] and in post-traumatic degenerative arthritis where implantation of a stemmed humeral component is often difficult due to malunion and consequent anatomical aberration.[12]

However, the success of this procedure may be tempered by failure of either the glenoid or the humeral component. Adequate fixation to the host bone of the proximal humerus is a critical factor in the success of resurfacing.[13] Glenoid loosening is a significant factor in failure of total shoulder replacement,[14] with the majority of revision arthroplasty performed to address this issue.[15] High temperatures have been noted at the implant glenoid interface[16] and glenoid reaming has been shown to generate high temperatures *in vivo*, beyond the physiological

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threshold required to induce osteonecrosis.[17] Hence reaming may contribute to resorption at the bone implant surface, resulting in prosthetic loosening.

Osteonecrosis can occur at temperatures exceeding 47°C for 60 s.[18] Thermal injury to bone after drilling with power driven instruments has been observed in both the animal[19] and human models.[20-22] The duration of heat exposure is also important, with higher temperatures resulting in osteonecrosis within as little as 5 s.[23] Damage at the cellular level is thought to be mediated by inactivation of alkaline phosphatase, which results in marrow necrosis.[24] Given this effect, the importance of regular irrigation has been stressed.[22,25,26] Recent work has also shown the potential for significant thermal injury generated by power driven reaming instruments to the femoral head in hip resurfacing, which may lead to implant failure secondary to osteonecrosis at the bone implant interface.[27] It is not known if humeral reaming produces thermal damage to the subchondral bone of the proximal humerus or if this varies with bone density or underlying pathology. It is feasible that reaming in sclerotic, osteoarthritic bone would generate higher temperatures than in soft rheumatoid bone.

Furthermore, humeral reamer design may influence heat generation. Reamer design varies depending upon the parent company. Modifications in reamer blade number, orientation, size and the so-called ventilation holes may influence heat generation. Subtle variations in such generic orthopaedic equipment have been noted to significantly influence the effect on bone, for example in the intramedullary reaming of long bones.[28-30] Implant design has been shown to be an important factor in stability following resurfacing.[31]

We hypothesized that humeral reaming would induce a thermal insult to the subchondral bone of the proximal humerus, and that the extent of this injury may vary depending on the underlying pathology. Our secondary hypothesis was that reamer design would have an effect on heat generation and would vary between different manufacturers.

PATIENTS AND METHODS

Ethical approval was obtained from the research and development department of the trust. All patients eligible for TSR, which consented to be part of the trial, were recruited during February-August 2009. Patients with distorted anatomy deemed not suitable for the humeral head resurfacing, those for revision surgery and patients who voluntarily opted out of the trial were excluded. Six males and seven females were included. The average age was 67 years (range 38-85 years). Informed consent was taken permitting infrared thermography and image recording during TSR. All procedures were performed by or under close supervision of one of the authors (PP. Sarangi) The surgery was completed in the standard manner without alteration to the accepted technique.[1] No cement was used on the humeral side.

The primary diagnosis was rheumatoid arthritis in eight patients and osteoarthritis in the remaining five. A thermal imaging camera (Thermovision A320, Flir Systems Inc., Wilsonville, Oregon, USA), which records surface temperatures in real time to accuracy of ±0.05°C, was placed on a tripod at a distance of 1.5 m from the operative field in a position that provided the optimum view of the proximal humerus. All measurements throughout the study were captured with the same camera, which was calibrated to the ambient room temperature and humidity prior to use in accordance with the manufacturer's instructions. The camera was connected to a laptop computer, running the software application required to control and record from the thermal imaging camera (ThermaCAM Researcher Pro, version 2.8, Flir Systems Inc., Wilsonville, Oregon, USA, http://www.flir.com/).

Software recording was commenced on exposure of the proximal humerus and continued until humeral preparation was completed. This was judged complete when the proximal humerus displayed the appropriate concentricity and matched the radius of curvature of the trial component. During reaming with a standard air — drive power reamer, the humeral head theater spotlights were turned off to reduce thermal artefact. In each case, the patients underwent arthroplasty using the Synthes (Epoca) system.

The data were then saved with the ThermaCAM Researcher Pro software. The maximum temperature of the bone was recorded for every image. Statistical analysis was performed with the Kolmogorov Smirnov test for normality and an unpaired *t*-test between the two patient groups.

Prior to commencement of the saw bone analysis, a power calculation was performed to estimate sample size required to generate a power of 0.8, significance level of 0.05 and to detect a 2°C difference between different types of humeral reamer. This showed at least 8 samples would be required in each group. Another 2 sawbones were added to each group allowing for technical fault. Three types of reamers: the Epoca (Synthes, Paoli, Pennsylvania), Conservative Anatomic Prosthesis (Depuy, Warsaw, Indiana) and Copeland (Biomet, Warsaw, Indiana) systems were compared. *In vitro* analysis was performed in a laboratory setting, set to reflect the operative environment. The ambient room temperature was set to 20°C. The thermal camera was mounted on a tripod and coupled with the computer as in the *in vivo* design. Synthetic humeral composite saw bones (Sawbones 3306, Pacific Research Laboratories, Inc., Vashon, WA) were placed in a vice 1.5 m from the thermal camera and orientated to mirror the position of the humeral shaft during reaming. Reaming was commenced in the standard fashion and continued until the sawbone displayed the appropriate concentricity and matched the radius of curvature of the trial component. Software recording was commenced prior to reaming and continued until prosthetic humeral preparation was completed. A cordless battery powered drill (Colibri, Synthes, Paoli, Pennsylvania) was used to complete the reaming.

ANOVA test was used to compare the three groups.

RESULTS

In vivo test

Humeral reaming with the Synthes Epoca instruments generated mean temperatures of 40.7°C (SD 0.9°C) in the rheumatoid group [Figure 1] and 56.5°C (SD 0.87°C) in the osteoarthritis group [Figure 2]. This was statistically significant ($P < 0.001$). Irrigation with room temperature saline cooled the humeral head to 30°C (SD 1.2°C) [Figure 3] within 3 s.

In vitro test

The maximum recorded temperature of the milled sawbones was 58.2°C (SD 0.79°C) when using Synthes (Epoca), 59.9°C (SD 0.81°C) with the Biomet (Copeland) reamers and 58.4°C (SD 0.88°C) with the Depuy (CAP) reamers [Figure 4]. This was statistically insignificant ($P = 0.12$).

DISCUSSION

The aim of this study was to assess the degree of thermal insult conferred by power driven humeral reamers. We have shown that temperatures exceeding the baseline required to cause necrosis (47°C) are generated both *in vivo* and *in vitro*, with maximal temperatures of 56.5°C in the former and 59.9°C in the latter, supporting our hypothesis.

Reaming *in vivo* creates temperatures above the threshold required to induce osteonecrosis of the subchondral bone in patients with osteoarthritis. However, reaming generates significantly lower temperatures in patients with rheumatoid arthritis (40.7°C), illustrating that the underlying pathology has an effect on the amount of heat generated. We assume that this variance is due to structural differences in the bone architecture and the relative osteopenia seen with inflammatory disease. We have also shown that reamer design does not have a significant effect on the thermal output at the instrument bone interface, as *in vitro* analysis with the three reaming systems highlighted no significant difference between manufacturers. From this, we conclude that subtleties in reamer design such as the number and orientation of blades has no significant effect. Cooling with room temperature saline reduced the surface temperature of the bone to physiological levels. This correlates to the findings of Augustin *et al.*[22] who found that cooling during drilling of cortical bone prevented a significant rise in the temperature of bone independent of drill bit size, drill speed, and the direction of drilling.

To our knowledge, this is the first study of this kind examining heat generation in reaming of the proximal humerus. Baker *et al.*[27] examined the effects on reaming *in vivo* during resurfacing of the femoral head. It was shown that temperatures up to 89°C are reached during milling of the proximal femur. The authors examined the effects of four different reamer designs *in vivo* and found that alternation in reamer design, in addition to pulsed irrigation and duration of reaming had

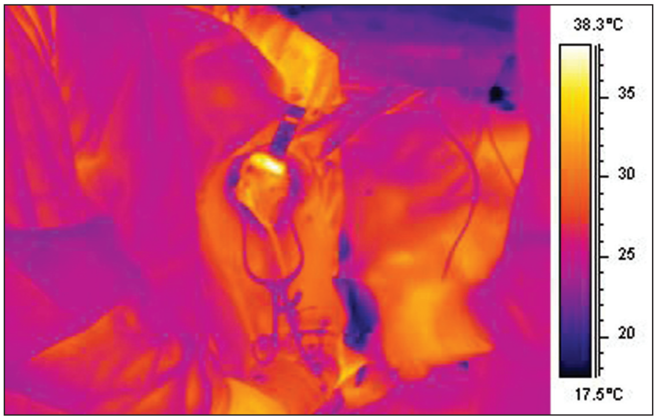

Figure 1: Calibrated infra-red thermal image during proximal humeral reaming in patient with rheumatoid arthritis

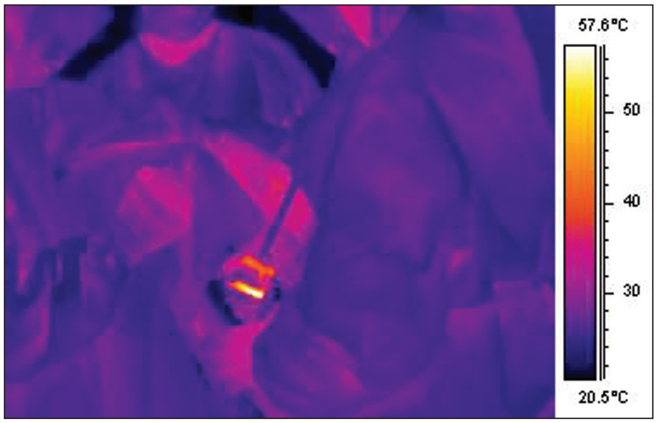

Figure 2: Calibrated infra-red thermal image during proximal humeral reaming in patient with osteoarthritis

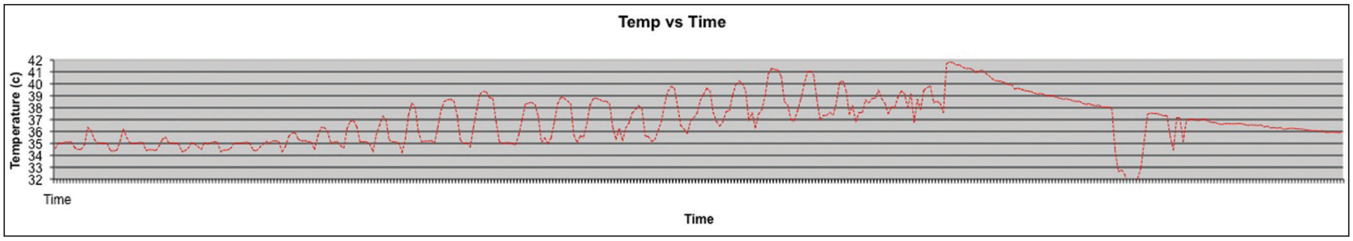

Figure 3: Temperature during reaming and subsequent saline irrigation

Figure 4: Calibrated infra-red thermal image during reaming on the sawbone model

an effect on heat generation. Despite observing a higher peak temperature, the mean temperatures observed were lower (47°C) than in our osteoarthritis group. It is difficult to account for this variation, but factors such as host bone quality, patient age, reamer design, reamer torque, and surgical technique will have a contributory effect. We did not have the facility to assess the effect of different reamers *in vivo*, but consider the saw bone testing performed in this study to provide a suitable model for the analysis of differing designs.

A number of complications after humeral resurfacing have been reported. These include infection (0.9%),[32] dislocation (4%),[32] residual pain,[33] poorer function as compared to stemmed total shoulder replacement,[34] and loosening of the components (25%).[35]

Loosening remains the primary clinical indication for revision[36] even in advance of developments made to the implant design and manufacture.[14] The exact incidence of the humeral component loosening is unknown but recent work by Pritchett found evidence of humeral loosening in a single resurfacing in a series of 74 shoulders at a follow up of 20 years.[37] This phenomenon may be underreported in the literature. However it is similar to loosening rates observed in the femoral head resurfacing, which is estimated at 1.3%-2.0%.[38] Levy and Copeland noted 30% incidence of radiolucency around the humeral component at 10 years.[39] The correlation between this and prosthetic loosening remains to be fully established.

Glenoid loosening remains a major mode of failure. It has been demonstrated by Olson *et al.* that reaming confers a significant thermal insult to the host bone during preparation of the glenoid.[17] Theoretically this may predispose to osteonecrosis, precipitating bone resorption and subsequent micro motion at the bone implant interface, leading to prosthetic loosening. In addition to the use of thermal imaging software, the authors augmented the *in vivo* analysis of 10 patients (nine with osteoarthritis and one rheumatoid arthritis) with a finite element heat conduction computer model to assess for depth of heat penetration. This was found to be directly proportional to the surface temperature at the glenoid. We did not assess for depth of heat penetration in this study, which represents a limitation to this work.

Other confounding factors include reamer fatigue and surgeon technique. The reamers used were new instruments and hence sharp. It is feasible that worn, older instruments would cause a more significant insult as it is accepted that blunt instruments confer a higher risk of thermal damage.[26] Another factor that cannot be accurately controlled for is the pressure with which the reamer is applied. However, in this study, all reaming was performed by the senior author (R Amirfeyz) using the standard method.

The heterogeneous mix of patients in this study corresponds to a standard case sample within our current practice. Patient demographics are comparable to the other studies examining the thermal effects of reaming.[17,27] Our study however, had a larger proportion of patients with inflammatory arthritis, in which the thermal changes observed with reaming are likely to be underestimated due to the relatively osteopenic bone.

All *in-vivo* resurfacings were performed without adjunctive cement fixation. It is feasible that if cement were used then the thermal damage may perhaps be even higher. Churchill demonstrated the thermal effects of cement polymerization at the glenoid in the cadaveric model and found a maximum average temperature of 64.7°C at polymethylmethacrylate curing.[16] It is therefore possible that cemented humeral resurfacings are subject to further damage after reaming.

The imaging technique employed with a thermal camera and its software is consistent with similar work in this field. It is a highly accurate method of determining surface temperature (within 0.05°C) and negates the technical difficulties associated with thermocouples, which are invasive and prone to artefact and inaccuracy with pressure variation.[40,41]

This work illustrates a number of important points. We have accurately demonstrated that temperatures capable of inducing osteonecrosis are generated during reaming of the proximal humerus in osteoarthritis, and that irrigation with saline cools the bone to physiological levels. Variation in reamer design has little influence on the heat production. Given the significant thermal effect conferred by power driven reamers on the proximal humerus, we suggest that reaming technique be modified to reduce the risk of heat induced osteonecrosis, which may contribute to prosthetic loosening. Firstly, that the subchondral bone is irrigated with room temperature saline at regular intervals and secondly, that the application of "pulsed" pressure on the reamer as opposed to constant forceful reaming is employed to reduce the length of time that the bone is exposed to the high temperature of the instrument.

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