Chapter 32
Effect of Sequential Drilling Process on In-situ Bone Temperature

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Abstract In orthopedic surgery, sequential drilling is the process of making multiple holes to facilitate the implant fixation. During the bone drilling process, the generated heat will cause thermal damage that affects the implant fixation strength because of “osteonecrosis,” a permanent death of the tissues around the drilling site. In this work, an attempt was made to identify the effects of sequential drilling of cadaveric human femur bone on the heat accumulation. To perform the sequential drilling process, the rotational speed of 1500 rpm and 80 mm/min feed rate was considered with the 4 mm deep holes. Thermal images were captured using Sonel® infrared thermography during the drilling process. It was identified that the accumulated heat increased as the number of sequential holes increased. It was also observed that the distance between the drilled holes influenced the amount of temperature rise. The number of sequential holes drilled and the distance between the holes greatly influenced the temperature rise. This study showed the accumulation of heat during sequential drilling and its consequences in the temperature rise. It is recommended to the surgeons to increase the field of a drilling site in such a way to increase the distance between the subsequent holes to avoid thermal damage to the bone to prevent from further complications.

Keywords Orthopedic surgery · Sequential drilling · Femur bone · In-situ temperature · Osteonecrosis

32.1 Introduction

Bone drilling procedure is one of the most commonly employed surgical procedures in orthopedics, during joint replacement and implant fixations. During the drilling of bone, the interaction between tool and bone; and the contact between the chip

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and the drill bore, creates friction which in turn induces heat [1]. When the generated temperature exceeded the threshold will lead to a condition called "thermal necrosis," a permanent death of the bone cells and because of that, the strength of the bone will reduce [2]. The phenomenon of necrosis will lead the bone to loss its healing capability and this will become more common in case of drilling, especially in multi-pass or sequential drilling [3]. This kind of thermal damage increases with increase in temperature and also with respect to the exposure time [4]. Apart from the threshold value that causes the thermal necrosis, the time being exposed also decides the severity of the damage. It has been reported in the literature that the necrosis condition will occur if the temperature is at 47 °C for 1 min and if the temperature increased to 53 °C, then the time to cause the failure will be less than a second [5, 6]. Based on the literature, it was identified that the temperature which is greater than or at 70 °C will result in a sudden state of thermal injury, and also even a lesser temperature with prolonged exposure time will provide the same adverse effects. Other than time, the significant parameters that increase the temperature rise include the thickness of the bone considered and also depth of the holes drilled [7]. Even though the temperature generated during drilling can be reduced with the help of irrigation, it is not recommended in some actual clinical cases [4]. Because of the low thermal conductivity of bone as reported in the literature, the dissipation of heat will be difficult and the build-up heat due to the multi-pass drilling will be more [8]. The main objective of this work was to identify the effect of heat accumulation in the sequential drilling with respect to the distance between the drilling sites, as the severity due to the temperature is large when compared with the single-hole drilling of femoral cortical bone. Based on this work, necessary recommendations can be provided to the surgeons to aid the drilling process in clinical trials.

32.2 Materials and Methods

Sequential drilling was performed in a vertical CNC milling machine (MTAB Maxmill®). Sonel® KT-160A infrared thermal imaging camera was used to capture the temperature data and processed with the Sonel ThermoAnalyze® software. Figure 32.1 shows the experimental setup considered. The surgical drill bit of 3.2 mm diameter was used in this study. Sequential drilling was performed at a rotational speed of 1500 rpm and feed rate of 80 mm/min with 4 mm deep holes to study the accumulation of heat.

The most commonly used parameter range for orthopedic surgery was identified through the literature and from surgeon guidance. The combination of rotational speed and feed rate that provides the higher temperature rise was identified through trial experiments. Based on that, the parameters were selected for this work. To facilitate the process of drilling, the femur bone was cut into pieces and mount into polymethylmethacrylate (PMMA). In order to replicate the clinical case, the dwell time of 1 s was provided between each pass. The accumulation of heat during the sequential drilling is due to the adjacent holes. In general, the thermocouple is

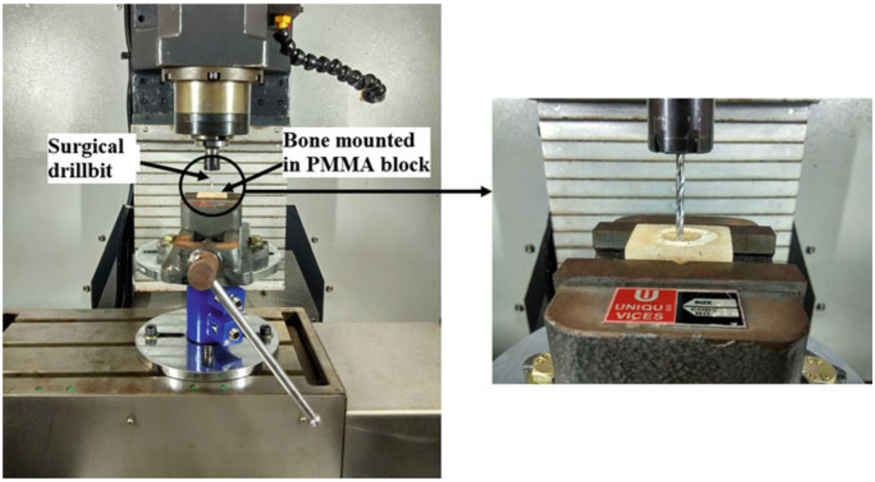

Fig. 32.1 Experimental setup used to conduct the sequential drilling in bone

employed to capture the data during single-hole drilling. But, in the case of sequential hole drilling, the multiple placements of thermocouple require several holes to house the thermocouples, which affects the integrity of the bone [9]. Because of this, the thermocouple is not employed in this study. A 2 × 3-hole array was considered and its schematic representation is shown in Fig. 32.2. The scheme considered for the sequential drilling is based on the distance from margin to margin (4 mm) of the drilled hole. Two points A and B were selected to study the accumulation of heat with respect to the drilling (Fig. 32.2). Six holes were drilled and two reference points "A" and "B" were considered as an analyzing region to identify the heat accumulation phenomenon.

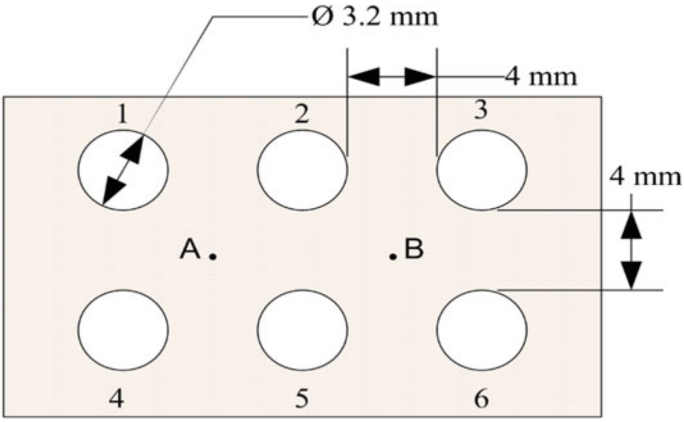

Fig. 32.2 Drilling sequence considered in this work with the reference points A and B

32.3 Results and Discussion

The variation in temperature (*T*) with respect to the time (*t*) for each drilling action is shown in Fig. 32.3. A representative thermal image and the corresponding thermal profile (Temperature, *T* vs. Distance, *d*) captured are shown in Fig. 32.4 for illustrative purpose. Based on the considered feed rate (80 mm/min), to achieve the full depth (4 mm), 3 s was taken. The dwell period provided was 1 s and thus a total time period of 4 s was taken to complete a single hole. The upright line, shown in Fig. 32.3 represents the hole number and the corresponding abscissa provides the time (*t*).

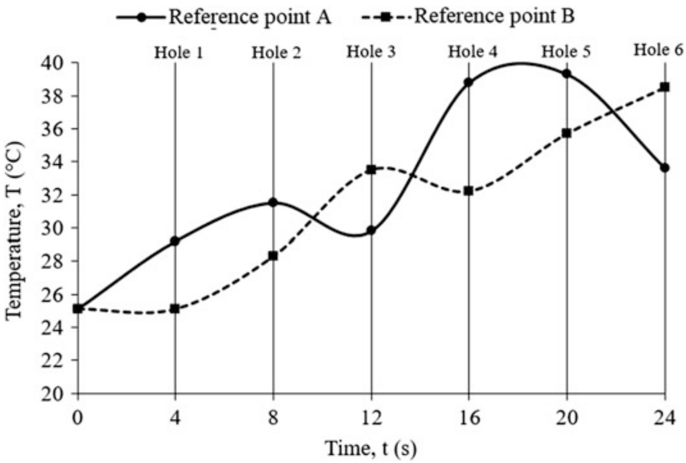

Fig. 32.3 Captured temperature data with respect to the time during sequential drilling

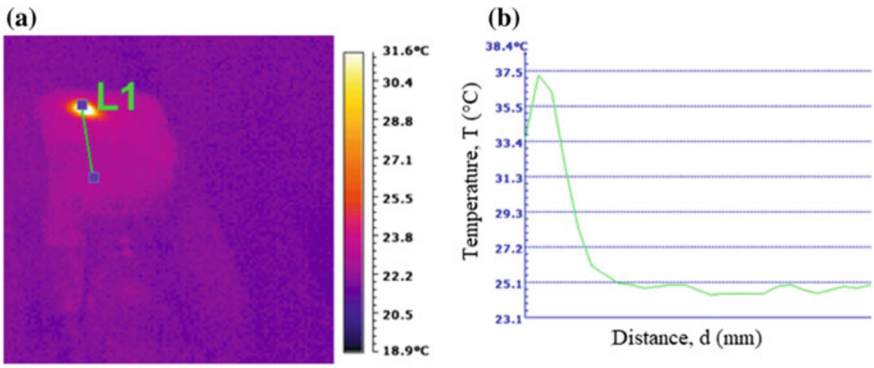

Fig. 32.4 Representative temperature data, **a** thermal image captured during the drilling with its temperature contour and **b** temperature profile of the processed thermal image

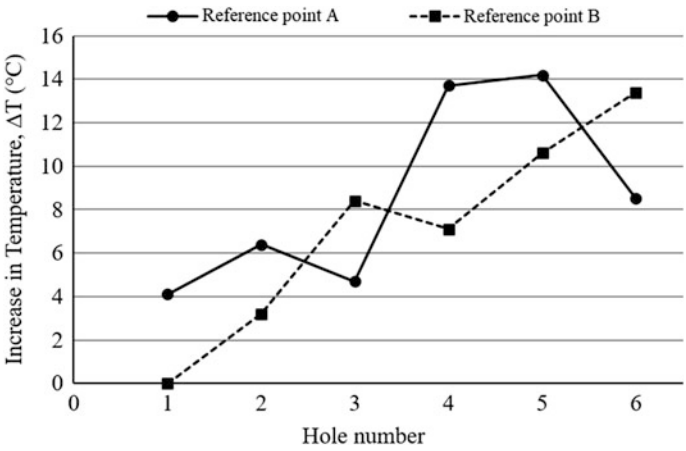

Fig. 32.5 Temperature rise during drilling with respect to the hole number

As the sequential drilling procedure starts, the reference point A (RP_A) responds first and then the reference point B (RP_B). This can be identified through Fig. 32.5, which shows the relation between the increase in temperature rise (ΔT) during the drilling and the hole number.

When drilling was made at the position of the hole number 1, the temperature information was obtained through RP_A and at this particular instance, the absence of heat was observed at RP_B. As the sequential drilling process proceeded through the subsequent passes, the accumulation of heat was clearly visible. The temperature rise was decreased substantially as the position of RP_A was far from the hole number 3. When the drilling site is in proximal (hole number 4) to the RP_A, again the temperature was increased drastically, which may be due to the accumulation of heat. Hole number 6 also showed the same trend as that of hole number 3. In the case of RP_A, it may be reported as the heat accumulation was increased for the drilling sites which are proximal to RP and gets decreased when the drilling site was farther. In the case of RP_B, it is noticed from the obtained data (Fig. 32.5) that there was not an initial rise in temperature when drilling was performed at hole number 1. A similar trend was obtained in the case of RP_B, in such a way that the heat accumulation was greater when the RP_B is at nearer to the drill site. Also, it can be noticed from Fig. 32.5 that the temperature rise at RP_A and RP_B follows the opposite trend. It may be due to the reason that the considered reference points A and B are at opposite to each other. Due to this, at a particular instance, for a considered drilled hole higher temperature rise or heat accumulation was observed at the reference point which is nearer to the drilled hole. Thus, the RP_A responds in a greater way to the sites 1, 2, 4, and 5; the RP_B provides the temperature information for the sites 2, 3, 5, and 6. The farther distance might be the reason for the RP_B for not providing any information about hole number 1 at the initial time. As the sequential drilling is involved in the drilling of more than a hole, the heat gets accumulated and gets transferred to the next drilling site. Due to this, more chance for the osteonecrosis condition when the temperature reaches 47 °C. So to avoid that in sequential drilling, the surgeons are advised to select the drilling site farther from the previously drilled hole. In this present work, even though, the sequence of the holes to be drilled is changed since the distance between the drilling sites were maintained at the same distance, the temperature profile will not vary. As a preliminary work, those effects were not included in this study. Based on the conducted experiments, it may be concluded that the temperature rise during multi-pass drilling can be reasonably reduced by increasing the dwell time, and this discussion is in good agreement with the numerical study reported earlier [10]. By increasing the dwell period or the time interval between the passes, more time to disintegrate the heat generated can be obtained so that the accumulation can be reduced.

32.4 Conclusion

In this work, an attempt was made to investigate the accumulation of temperature in the cadaveric human femur bone during sequential drilling with a 3.2 mm surgical drill bit for orthopedic applications. Temperature is higher at the margin of the drilled holes, but the accumulation of heat was analyzed at the considered reference points A and B. Accumulation of heat was found to be increased during the subsequent passes of the drilling. From the investigation made, it may be concluded that the distance which is considered as a datum for comparison has a significant impact over the captured temperature information. Because of this kind of heat accumulation due to the sequential drilling, the thermal damage occurred during the orthopedic surgery will be more. By this preliminary study, it was identified that by increasing the margin to margin distance between the drilled holes, the thermal damage can be decreased through the decrease in the heat accumulation or temperature rise. The main limitation of this work is that the observations provided were based on the very limited experimental study. So more follow-up experiments are need to be conducted to have better repeatability and understanding about the effects of sequential drilling. The postoperative success of the drilling process in orthopedic surgery not only depends on the reduction of temperature rise through the identification of optimal distance or optimal parameters but also the geometry of drill bit design, which reduces the efforts in the process of surgery. The authors tend to travel in further directions of this work in such a way to explore the effects of exposure time and the distance between the holes to the thermal damage caused, to implement this phenomenon in the virtual orthopedic surgery protocol. As the temperature generation is more at the proximity of the drill site, and it is also necessary to optimize the way in which the sequential drills can be made to avoid heat accumulation. So the association between the personnel from engineering and physicians is required to develop the surgical protocol for the automated surgeries.

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Ethical Approval This study was approved by the local ethics committee of the Institute and the participants' next of kin provided informed consent before commencing the present study.

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