

Influence of surgical drills wear on thermal process generated in bones

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The influence of the wear rate of drills used in bone surgery on the temperature distribution in the femur models (Sawbones) is presented in the paper. Surgical drills of diameter $d = 4.5$ mm and diverse edge geometry (90° and 120°) were selected for the study. In order to carry out thermal analysis with the use of finite element, experimental studies of wear process were necessary. These studies, among others, consisted in determination of average values of axial forces and cutting torques as a function of the number of drilled holes. The study showed an impact of the drill geometry on values that describe cutting process. It was found that the greatest values of torques and axial cutting forces occur in drills of point angle of 120° . Next, in order to determine the effect of wear rate on the generation of temperature in the cutting zone, thermal analysis of the drilling process using the finite element method was carried out. It was found that higher temperatures in the bone are observed for drilling with the use of the drill of point angle equal to 120° , as in the experimental study. For the tools of such edge geometry the wear of cutting edge is more intensive and the generated temperature in femur for the wear land $VBB = 0.32$ mm has reached the critical value associated with the process of thermal necrosis.

Key words: surgical drills, finite elements methods, thermal analysis, bone surgery

1. Introduction

A significant increase of osteosynthesis procedures performed requires suitable surgical instruments. However, it should be noted that the more complicated treatment is, the more complex and expensive the instruments are. Therefore, an important feature of these tools should be their durability and reliability. A lifetime of adequate surgical drill is determined mainly by their correct geometry (adjusted to particular treatment), and appropriate mechanical properties of the metal material to guarantee the transfer of loads generated during surgery. The usefulness of these tools is mostly determined by correct edge geometry, that is, the 2κ point angle of

the edge, which, in practice, is in the range of 90° – 120° . The results of numerical and experimental analysis realized by the authors [1]–[4] indicate that the preferred solution is to use tools with an angle of $2\kappa_1 = 90^\circ$. Using such a tool geometry makes it possible to use higher cutting speeds, resulting in a reduction of cutting forces. Consequently, this provides a lower intensity of wear process of drills used in surgical procedures.

Reduction of wear intensity of surgical tools is associated not only with their durability and cost of use, but also has a medical aspect. This is due to the fact that the operation performed with a blunt tool is dangerous for a patient. For example, the process of drilling into the bone with a blunt tool generates a high temperature, which consequently may lead to

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the so-called thermal necrosis of bone tissue. The literature data show that bone cells are destroyed already at about 55 °C. Any fixation based on such holes will eventually become unstable. Therefore, in this work the influence of wear of drills used in orthopedic surgery on temperature generation in the femur during the drilling process was studied.

2. Material and methods

2.1. Thermal analysis

In the study, thermal analysis of drilling in femur as a function of the number of holes was carried out with the use of finite element method. Surgical drill with straight shank of diameter $d = 4.5$ mm and diverse geometry ($2\kappa_1 = 90 \pm 1^\circ$ and $2\kappa_2 = 120 \pm 1^\circ$) was chosen (Fig. 1). To develop geometrical models Inventor Professional software was used.

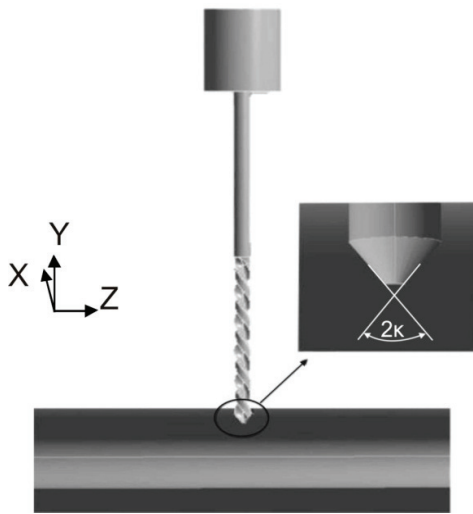


Fig. 1. Geometric model of the surgical drill–femur system

To model heat flow, type II (von Neumann) boundary condition was applied [1], [5]. It describes the heat flux density q taken over by the surface. Heat flux density can be calculated from the formula

$$q = \frac{P_c}{S} \quad (\text{W/m}^2) \quad (1)$$

where

- P_c – total cutting power (W),
- S – area (m^2).

For the thermal analysis appropriate boundary conditions were adopted to reflect the phenomena occurring in the real system. The following assumptions and process parameters of cutting were established [1], [6]–[10]:

- rotational speed from range $n = 365$ rpm,
- feed motion speed $V_f = 100$ mm/min,
- the supports immobilize the bone along the X , Y and Z axes and the bushing along the X and Z axes,
- heat flux density (q) was simulated in the contact area of the tool edge and the bone,
- at the point of contact of the bone with the surgical drill frictional process was simulated (coefficient of friction $\mu = 0.42$),
- simulations were carried out for the time $t = 5$ s, which corresponds to one drilled hole.

For the model developed, the following material parameters were set [1], [3], [13]–[17]:

- surgical drill (martensitic steel X39Cr13):
 - thermal conductivity $\lambda = 47.7$ W/m °C,
 - heat capacity $c = 490$ J/kg °C,
 - density $\rho = 8750$ kg/m³.
- femoral cortical tissue:
 - thermal conductivity $\lambda = 0.38$ W/m °C,
 - heat capacity $c = 1260$ J/kg °C,
 - density $\rho = 1700$ kg/m³.

2.2. Experimental research

To perform thermal analysis it was necessary to perform experimental studies in order to determine the absorbed heat flux q . This kind of study was possible thanks to the development and proper assembly of the test stand, Fig. 2. These studies included the assignment of the cutting characteristics, determining average values of axial forces and cutting torques as a function of the number of holes in the femur. The drilling was conducted in a single layer of the femoral model (Sawbones). The use of such model resulted from the fact that both in terms of geometric features, construction (taking into account the presence of cortical and cancellous layers) and mechanical properties the model reflects the actual bones. The process of drilling was carried out by performing a pre-established number of holes $n_0 = 20$ at a constant speed $n = 365$ rpm and feed $V_f = 100$ mm/min. The choice of this value of the speed was purposeful. It enabled a comparative analysis with the use of the rotational speed appropriate for both drills (the process of drilling the first hole did not initiate thermal necrosis) [1].

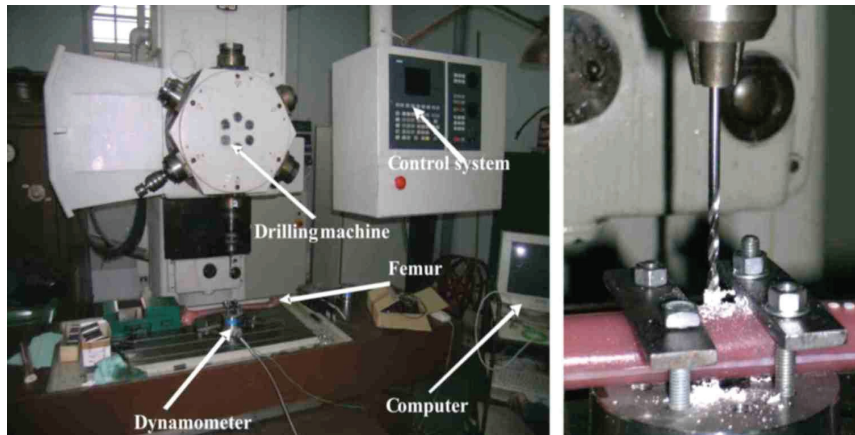


Fig. 2. The test stand for wear rate of surgical drills [1]

3. Results

3.1. Results of thermal analysis

Based on the study, it was found that the higher the wear of a surgical drill is, the higher the temperature in

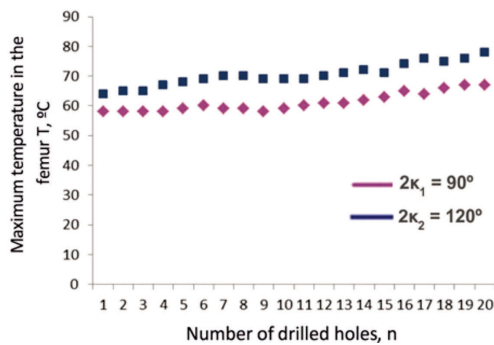


Fig. 3. Distribution of maximum temperature in the femur as a function of the number of drilled holes n

the femur during the drilling process is observed, regardless of the drill geometry ($2\kappa_1 = 90^\circ$ and $2\kappa_2 = 120^\circ$), Fig. 3. The thermal analysis carried out using the finite element method has shown that the greatest temperature increase occurs in the femur for the drill of point angle equal to $2\kappa_2 = 120^\circ$ in place of contact of the tool with the workpiece material. The temperature after the first hole had been drilled was equal to $T_{max} = 64^\circ C$, while after the 20th hole had increased by 14° , and was equal to $T = 78^\circ C$. In the case of drilling with the drill of point angle $2\kappa_1 = 90^\circ$, the temperature was lower and reached $T = 58^\circ C$ (after one hole) and increased to $T = 67^\circ C$ (after 20 holes), Fig. 4.

Important information from this type of analysis is primarily an area of bone in which the temperature is $T_{max} \geq 55^\circ C$. Exceeding this temperature outside the drilling zone carries the risk of tissue damage caused by the process of thermal necrosis of bone. It has been found that if the angle is $2\kappa_1 = 90^\circ$ this value is exceeded after 12 holes. In turn, for the angle $2\kappa_2 =$

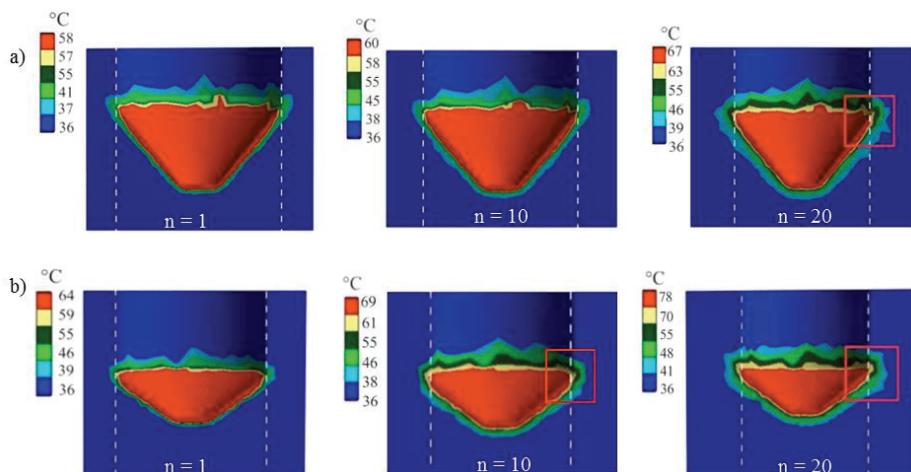


Fig. 4. The temperature distribution in the femur during the drilling of n holes with the drill of point angle: (a) $2\kappa_1 = 90^\circ$, (b) $2\kappa_2 = 120^\circ$

120°, temperature exceeding 55 °C outside the drilling zone already occurs after 5 holes, Fig. 5.

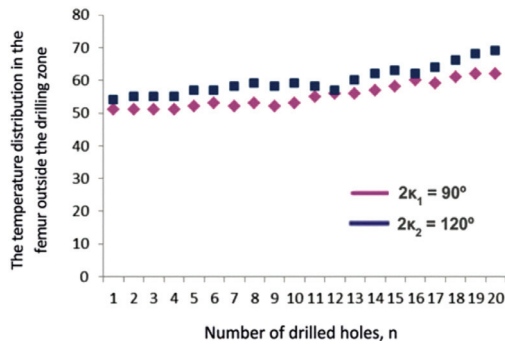


Fig. 5. The temperature distribution in the femur as a function of number of holes outside the drilling zone

3.2. Results of experimental research

Based on the measurements, it was found that with the increase of the number of drilled holes the value of axial force and cutting torque increased for both point angles analyzed, Figs. 6 and 7. During the drilling of the first hole, values of cutting force and torque were: $F = 225$ N and 0.39 Nm for the angle $2\kappa = 90^\circ$ and

$F = 330$ N and 0.41 Nm for angle $2\kappa = 120^\circ$. After drilling the $n_0 = 20$ holes, these values increased and amounted to $F = 298$ N and 0.45 Nm for angle $2\kappa = 90^\circ$ and $F = 475$ N and 0.58 Nm for angle $2\kappa = 120^\circ$.

4. Discussion

Conducted analysis and measurements are a continuation of research aimed at development of methodology for tailoring functional properties of drills used in the osteosynthesis procedures [1]–[4]. Based on the present study the impact of wear rate of surgical drills on generation of temperatures in femur during drilling process, regardless of the drill's edge geometry was determined; Figs. 3–5. To perform a thermal analysis using finite element method an experimental study of drill wear was necessary to carry out. The drilling was conducted in the femoral biomechanical model of Sawbones. The aim of this study was to determine the cutting characteristics on the basis of which the mean values of axial forces and cutting torques as a function of the number of drilled holes were determined. Based on the obtained characteristics, it was found that larger values of the forces and torques are observed for the

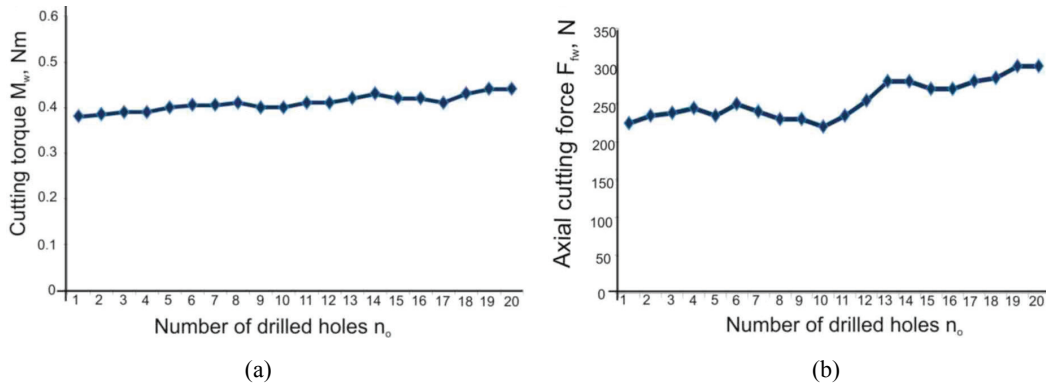


Fig. 6. Dependence of the cutting resistance as a function of the drilled holes for the drill $2\kappa = 90^\circ$: (a) changes of cutting torque, (b) changes of axial cutting force

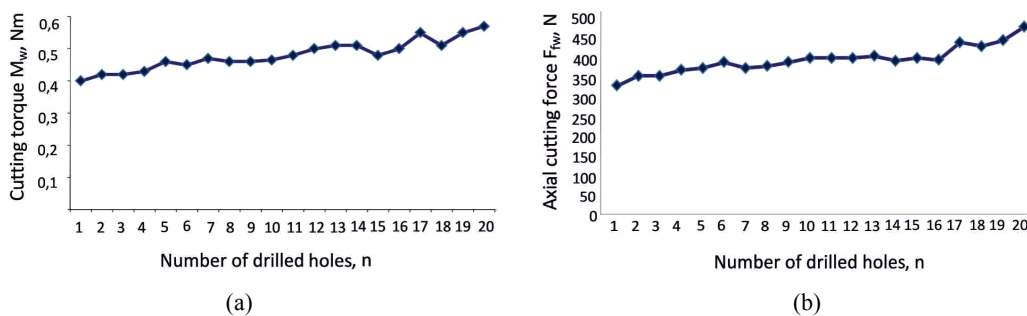


Fig. 7. Dependence of the cutting resistance as a function of the drilled holes for the drill $2\kappa = 120^\circ$: (a) changes of cutting torque, (b) changes of axial cutting force

drills of point angle equal to $2\kappa_2 = 120^\circ$. In addition, it was also found that with the increase of number of the drilled holes, cutting axial force and torque increased for both values of point angles analyzed, Figs. 6, 7.

For the thermal analysis, it was necessary to apply appropriate boundary conditions. Among the broad range of approaches to the modeling of heat flow it was decided to apply the boundary condition of the second kind (von Neumann). This condition describes the heat flux density q taken by the surface. In order to describe this parameter the results of the forces and torques obtained in the experimental studies were used. Based on the results of thermal analysis, it was found that the higher the temperature distribution is performed by n holes drill bit during drilling $2\kappa_2$ apex angle = 120° . The temperature after the hole was $T_{\max} = 64^\circ\text{C}$ for angle $2\kappa_2 = 120^\circ$ and $T = 58^\circ\text{C}$ for angle $2\kappa_1 = 90^\circ$. The holes 20 after the temperature has risen by 14° and was $T = 78^\circ\text{C}$ and 9°C and was $T = 67^\circ\text{C}$ respectively for angle $2\kappa_2 = 120^\circ$ and $2\kappa_1 = 90^\circ$. Important information from this type of analysis is primarily an area of bone in which the temperature is $T_{\max} \geq 55^\circ\text{C}$. Exceeding the maximum temperature outside the drilling is dangerous due to the process of destroying tissue thermal necrosis of bone. Based on these results, it was found that if the angle $2\kappa_1 = 90^\circ$ this value is exceeded after the 12 holes of the turn angle $2\kappa_2 = 120^\circ$ occurs already after 5 hole, Fig. 5. In addition, based on previous studies [1] found that the maximum width of the cutting edge of battle VB_B does not cause dangerous temperature exceeded 55°C for drill $2\kappa_1 = 90^\circ$ is about $VB_B = 0.54\text{ mm}$ (equivalent to 11 holes drilled) in turn, the angle $2\kappa_2 = 120^\circ$ is about $VB_B = 0.30\text{ mm}$ (equivalent to drilling 4 holes). In summary, we can conclude that the use of a side angle drill $2\kappa_1 = 90^\circ$ provides a lower intensity of the consumption and consequently lower generated temperature in the cutting zone. Withdrawal from the use of over-used tools improve the safety and quality procedures surgical. Thus, this phase of the work may provide a basis to define the critical values of wear, which will determine the appropriate useful life of the tool, since it is fundamentally affect the accuracy of surgical procedures performed cal.

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