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Suitability Analysis of Industrial Drills for Minimally Invasive Skull Base Surgery

https://doi.org/10.1515/cdbme-2022-0024

Abstract: Medical drilling processes, especially in the area of the otobase, pose a high risk to the patient due to the heat generated and introduced into the tissue. Two measures of reducing the heat are the parameters of the drilling process and the optimisation of the drill geometry. A spiral drill and a single-lip drill are evaluated for their suitability as medical drills in skull base surgery with the objective of integrating a temperature sensor in the tip of the drill. The two drills were chosen because of their promising heat generation properties in pre-testing. In this paper the chip formation behaviour and drilling channel quality are analysed. The single-lip drill shows lack in precision of the drilling channel and unsuitable bone chip transport, as material powder is left in the drilling channel. In contrast, the spiral drill shows a good transport of the chips and the drilling channel follows the planned path. As a result, the spiral drill is chosen for the further development of a drill with integrated temperature sensor for minimally invasive drilling.

Keywords: Skull Base Surgery, Medical Drilling, Temperature Measurement, Minimally Invasive

1 Introduction

Minimally invasive approaches for conventionally highly invasive surgeries are increasingly applied in every speciality of surgical medicine. The benefits of minimally invasive surgery include a shorter hospital stay and less trauma. [6] In ear, nose and throat (ENT)-surgery the cochlear implantation is an example where great effort in developing new minimally invasive approaches is made, mainly to facilitate a less traumatic electrode insertion. Access to the target area, for example the cochlea, is created through one or more drilling channels in the skull base [14]. The main risks for the patient arising from drilling in the skull base are mechanical damage to critical structures, like the facial nerve, due to a direct hit with the drill, and thermal damage due to an increased heat input into the tissue [16]. The risk of mechanical damage can be decreased with the use of stereotactical frames, image-guided navigation and/or robotic assistance [9]. Those techniques increase the positional accuracy of the initial drill position. At the beginning of the drilling process further risks through the choice of the drill geometry arise, like the centring of the drill, or the loss of the ideal trajectory through running. Furthermore, the choice of the drill geometry influences the heat generation in the drill ground during the drilling process. For quantifying the thermal risk, a drill with an integrated temperature sensor has been developed and is now an item of refinement. [11]

An analysis of drill geometries for further reducing the risk of mechanical damage and simultaneously decreasing the heat input in the tissue needs to be carried out. Therefore, literature research and a qualitative study of two drills on bone equivalent have been carried out. In the following, two promising drill configurations after heat generation analysis are evaluated for mechanical accuracy and drilling hole quality during drilling and with computed tomography (CT) imaging. The results show the favourable drill configuration for the further development of the drill with an integrated temperature sensor.

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2 State of the Art

This paper focuses on the identification of the ideal drill geometry for the further development of a drill with an integrated temperature sensor with respect to a reduced mechanical and thermal risk for the patient [11]. The diameter of the drill is preferably 2 mm or lower as this is a requirement for conducting a minimally invasive cochlea implantation in the narrow surrounding of critical structures [13]. For reaching the structure, like the cochlea or beyond, the drill must at least be 50 mm in length [14]. Additionally, the temperature sensor is guided through the cooling channel to the drill tip, as presented in [11]. Therefore, a cooling channel is a necessary feature of the drill. Furthermore, five requirements must be fulfilled for a safe medical drilling process in the skull base.

- Avoid slipping of the drill on the material surface [18]
- Drill guidance [3]

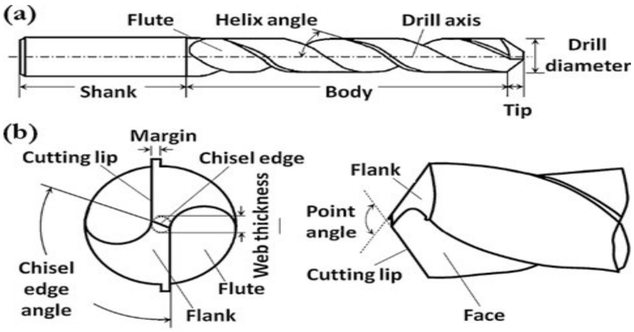

Fig. 1: Drill geometry [8]

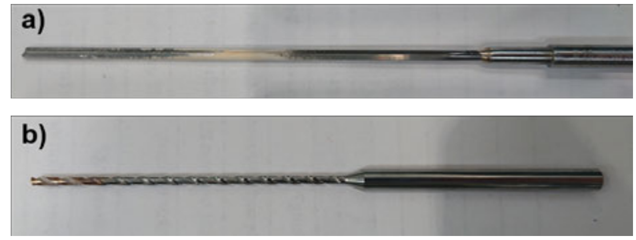

Fig. 2: Single-lip drill a) and Spiral drill b)

- Drill stability [7]
- Minimal heat generation [7]
- Complete chip removal from the drilling channel [15]

The drill geometry can be described by geometrical features that have a different impact on the defined requirements, see Figure 1. A larger drill diameter leads to a higher heat generation during the drilling process. [17] The smaller the point angle, the better the slip resistance of the drill. Thus, the heat generation rises, because of larger contact zones with the material. [7] An increasing helix angle supports the removal of chips from the drilling channel. Therefore, the smaller the helix angle, the less material is transported from the drilling channel and the more heat is generated during the drilling process. [4]

A detailed review of the influence of the drill geometry of medical drills on heat generation is presented in [1]. The study analyses a vast amount of literature published on the topic of heat generation during drilling that is related to the drill geometry. AKHBAR ET AL. highlight the ambiguity of results presented in studies and state that the optimisation of the drill geometry regarding the heat generation during drilling is still an open field of research. The suggestions for the optimal design of a drill geometry as a summary of the review arise from publications with contrary opinions. In the publication it does not become clear, why the author favours one opinion for the suggestions for the drill geometry optimisation. [1] For this reason, a use case specific analysis of suitable drill geometries is carried out.

3 Influence of Drilling Geometry on Suitability for Minimally Invasive Surgery

Five commercially available drills with different geometrical features the literature rated positive are examined for their suitability for minimally invasive procedures. As a first step, the heat generation of the five drills is analysed in drilling experiments with temperature measurements. Therefore, a hole is drilled orthogonally to the planned drilling path in a block of bone equivalent material (Synbone, Zizers, Switzerland). A thermistor for measuring the temperature elevation during drilling is inserted into the hole. Afterwards, the drilling path with the examined drill is placed as close to the tip of the sensor as possible drilling next to the inserted temperature sensor. The increase in the temperature compared to the initial temperature is measured for every drill. The temperature elevation of different drills is then compared considering that not the actual temperature in the drill ground, but the temperature conducted through the remaining material to the sensor is measured.

Two drills with the lowest temperature increase, approx. 0.4 K compared to approx. 0.55 K-0.6 K, are chosen for qualitative drilling experiments that aim at evaluating the suitability of the drills for a surgical procedure with high precision according to the requirements presented in Chapter 2. The drills to be evaluated are shown in Figure 2 and have the following geometrical features:

a) Single-lip drill with cooling channel (Gühring, Albstadt): length 125 mm, diameter 2 mm, point angle: 80 °, helix angle: 12 °
b) Spiral drill with cooling channel (Mikron GmbH, Rottweil): length 53 mm, diameter 1.6 mm, point angle: 140 °

For the experiments, four drilling channels, two with each drill, are brought into a block of bone equivalent resembling the mechanical properties of the skull. The material is a combination of two bone equivalent (mechanical equivalent) blocks that were glued together to resemble the denser (Foam Block 62.6 PCF, Synbone, Zizers, Switzerland) and less dense structures (Foam Block 20-30 PCF, Synbone, Zizers, Switzerland) of the skull. The drilling process is analysed for the chip generation, drill vibration and chip removal. Additionally, CT-images are generated to analyse the form of the drilling channel and the possibility of chip residue in the drilling channels.

The drilling process was carried out with robotic guidance on the demonstrator presented in [11]. Future experiments aim at examining the temperature behaviour in a rotational speed

Fig. 3: Chip formation with single-lip drill a) and spiral drill b)

range of 700 rpm-50.000 rmp, as those are the boundaries found in literature [2, 12]. The rotational speed of 7500 rpm was chosen because at higher rotational speeds the single-lip drill started oscillating in the tool holder. A higher feed rate of 7mm/s was chosen, because it leads to decreased process times and therefore reduces the time for heat input into the tissue. [5] The parameters were the same for both drills.

Video material (camera: nulaxy, Hunan, China) is mainly analysed for the behaviour of the drill outside of the material and for identifying peculiarities during the drilling process that may be related to the drill geometry. A special focus is on the generation and removal of the chip during the drilling processes. The spiral drill created long coherent chip pieces and material powder, see Figure 3 b), while the single-lip drill created short chip pieces, see Figure 3 a). The chip formation is mostly influenced by the flute geometry and the number of cutting lips. The flutes of the spiral drill are continuously generating chips during the rotation of the drill while the chip generated with the single-lip drill is cut at every rotation because there is no continuous flute. That leads to a long chip generated with the spiral drill and small pieces of chip generated with the single-lip drill.

Figure 4 shows the sectional view of the drilling channels in a CT-image. The left two channels were generated with the single-lip drill, while the right two channels were created with the spiral drill. The most obvious observation is the bulging form of the drilling channel generated with the single-lip drill. On the other hand, the spiral drill creates an exact cylindrical shape. Moreover, the drilling channels that were generated with the single-lip drill are filled with powdered material, which is attributable to the non-continuous flute in the rotational direction of the single-lip drill.

The bulging of the drilling channel created with the single-lip drill can be assigned to the length of the drill on the one hand, and the small core of the drill on the other hand. The length of the drill leads to an oscillation even at a slow rotational speed. As the drill has a single lip and a large flute for removing the chip, the core of the drill is small compared with the spiral drill. This might influence the stability of the drill during drilling and can cause the deviation in the cylindrical shape of the drilling channel.

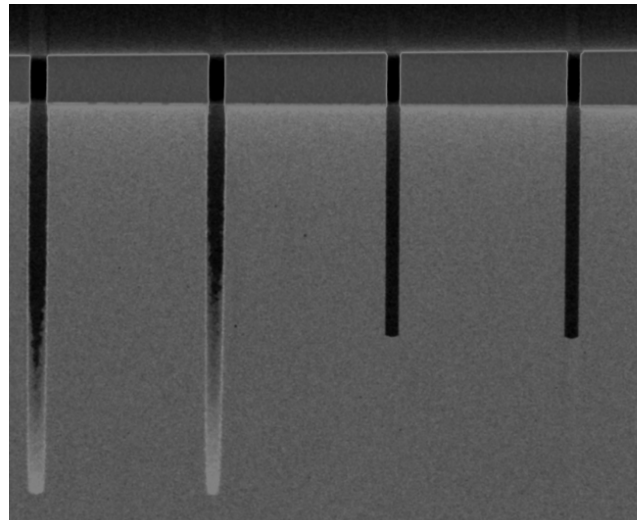

Fig. 4: CT-image of the drilling channels. The two channels on the left are drilled with drill a) and the two on the right with drill b).

4 Conclusion and Outlook

Although the single-lip drill was most promising in the heat generation experiments, the analysis of the drilling process shows that the single-lip drill is not suitable for medical drilling processes. The chip removal from the drilling channel is not optimal and powdered material remains in the drilling channel. The small pieces of chip might be a potential risk for contamination of the surgical field because they are not easily caught and can maybe not be removed from the operating area. Furthermore, the CT-images show a bulking of the drilling channel that is related to the length of the drill and the core stability. As medical drilling processes, especially at the skull base, pass many different risk structures and the tolerable deviations of the ideal drilling trajectories are generally low, this bulking of the drilling channels is unacceptable. Combined with the risk of breaking during the operation, because of the lack of core stability, the single-lip drills are excluded from the further development of the medical drill with an integrated temperature sensor.

The spiral drill did not only show promising results in the heat generation experiments but also the behaviour during the drilling process shows no peculiarities that might prevent the drill from being used with the necessary accuracy for medical drilling processes. During the drilling process, long chips are generated, that can be easily removed from the operating field. Due to the continuous form of the flutes, the powdered material is completely removed from the drilling channel. Also, the spiral form of the drill leads to better stabilisation during drilling and leads to cylindrical drilling channels that do not show large deviations from the desired trajectory. With a length of 53 mm the drill can reach the target structure and can therefore be used for the minimally invasive cochlea implantation. [14] For further securing the decision for the drill geometry, the transferability of the results presented in this paper to vivid bone should be analysed, as the water in the bone influences for example the chip formation. Additionally, the influence of drilling parameters on the drilling hole quality is to further be investigated e.g at different rotational speeds.

In the future, the spiral drill is used for the further development of the medical drill with an integrated temperature sensor. Nevertheless, currently not commercially available drill geometries, like the combination of a spiral drill with only one lip presented by FELDMANN ET AL., can be an object of future research. [5] For the integration of the temperature sensor into the cooling channel access must be created through the shank of the drill. Different machining principles such as eroding are assessed for the purpose. Additionally, the energy supply of the temperature sensor as well as the transmitting unit need to be placed on the shank of the drill. A miniaturised chip is therefore created and fitted into a compartment that can be glued to the shank of the drill. The energy supply of the sensor and transmitting unit also need to be miniaturised compared to the current drill model. [11]

Author Statement

Research funding: The results presented in this paper were created in the context of the research project Mambo - "Metrological safeguarding of a drilling process in image-guided minimally invasive procedures using the example of the otobase". The project is funded by the DFG (German Research Association) for a duration of 2 years. Conflict of interest: Authors state no conflict of interest.

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