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Study of bone drilling dental tools wear: measure and relation with cutting forces

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Abstract
Tool wear is a fundamental phenomenon that must be characterized to optimally plan machining operations. While wear is a well-known phenomenon for macrotools, with well-established wear parameters, the literature is less comprehensive in the field of microtools. The forms of microtool wear differ in general from macrotools.

However, wear of microtools must be controlled. For example, referring to microtools used to drill the bone for dental implants, the control of tool and bone temperature is relevant, as the exposition of the bone to a high temperature can cause osteonecrosis. An uncontrolled tool wear can generate a local increase of temperature.

The proposed contribution aims at showing our results on the three-dimensional geometric characterization of bone drilling dental tools wear and its relationship with cutting forces, considered as an indicator of the tool condition. An experimental campaign has been run, including 3D scans of the new tools and after the use. The comparison between scans allows a preliminary identification of the wear mechanisms. From these results, it will be possible to propose wear parameters for dental tools, which are expected to be reliable for microtools in general. Then the wear parameters will be associated to the cutting forces, and particularly the cutting torque, so that it is possible to decide whether a tool can still be used or has reached its end-of-service. The final aim is the definition of guidelines for the surgeon stating the correct use of bone drilling dental tools.

Tool wear, Microtools, Wear Characterization, Wear Parameters, Dental tools

1. Introduction

Drilling operations in dentistry, as opposed to other mechanical processes, face several problems strictly related to the organic nature of the work material. The temperatures generated during a dentistry drilling operation must be kept below a specific threshold, commonly identified as 47 °C [1]. If this temperature is exceeded for more than one minute, the bone suffers from thermal damage, specifically osteonecrosis, and will not be able to heal properly once an implant is inserted, leading the operation to fail. This temperature is mainly related to two factors: cutting condition, and tool wear. Today there is not any general guideline to the problem of characterizing the wear of tools for drilling dental bone material (in the following "dental tools") and, most important, there is no indication about when a dentist surgeon should stop using a dental tool because of wear. Two ways were identified and discussed in a previous paper [2] to guarantee the correct use of tools:

- an indication can be given about the maximum number of holes that can be drilled with a single drill bit;
- the wear condition can be correlated with signals from the tool itself, e.g. the cutting torque.

This research aims at providing these two approaches. The first task is a preliminary study of dental tools, to understand the differences between a conventional tool and dental tool wear. Then, extensive experimental campaign is required to analyze the tool life, and the relationship between the cutting parameters and the cutting forces. The wear of the tool and its mechanics will be studied in 3D, to develop suitable parameters for the characterization of the dental tool. Automation will be the aim in the estimation of the wear parameters.

1.1. State of the art

Two sources of osteonecrosis induced by bone machining are commonly considered in literature: heat generation and mechanical vibration [3] . Necrosis generated by thermal damage causes a breakdown of the bone in the implantation site, leading to a loosening of the fixation. Although tool wear is recognized as a cause of heat generation [4], few studies have been proposed in literature.

Ercoli et al. [5] studied the effect of wear on temperature, together with several other factors. In general, they found drill geometry, material, coolant, and mechanical properties to be signficant. About wear, they state that "implant drills can be used several times without causing bones temperatures that are potentially harmful to the bone tissue".

But Bertollo and Walsh [6] instead indicate the tool wear among the main causes of heat generation. They studied the types of wear of a surgical tool, and identified abrasive and plastic wear as primary forms of tool wear and the possible causes of crater formation. Finally, they found a linear relationship between temperature rise and wear.

Staroveski et al. [7] studied the problem of cortical bone drilling. Their aim is in the design of a system able of continuously monitoring of the tool wear state, in order to state when the tool has reached its end-of-service. They found that the acoustic emission and the servomotor signals are well correlated with the current wear state of the tool.

2. Preliminary study

A preliminary study has been run by drilling synthetic bone 40 PCF-CP grade 40 (Nacional Ossos©, Brazil) samples with a 2.3 mm diameter bone drill made of HSS (chosen as a reference drilling tool , usually adopted as the first drilling tool in the bone cavity preparation, and then finding the hardest cutting conditions). During the drilling operation, the thrust force and the cutting torque were recorded. In total, 180 holes were drilled with a single drill bit.

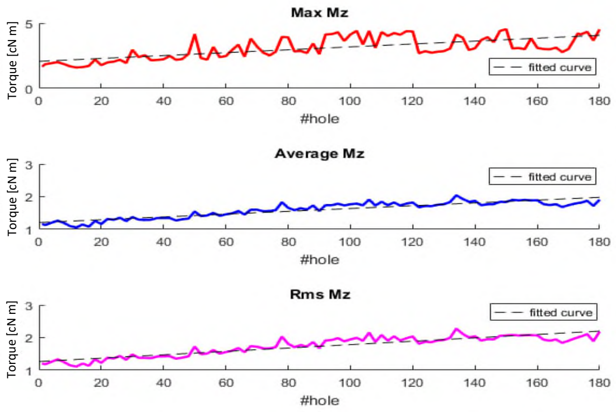

Figure 1. Cutting torque as the number of drilled holes increases.

The experiment was interrupted at 180 holes, as the drill looked completely worn at visual inspection. The results of the experiment have shown that the thrust force is not significantly influenced by the number of drilled holes, i.e. by the wear. Figure 1 instead shows that, as the number of drilled holes increases the average, maximum and root mean square (rms) of the cutting torque tend to increase. This behaviour suggests that the cutting torque can be an effective indicator of the tool wear condition. Today dental spindles with integrated cutting torque sensors are available to guide the surgeon and prevent him to increase excessively the cutting torque. The definition of a maximum cutting torque in a specified condition could be a good indicator of whether the tool can still be used or needs to be replaced.

3. Automatic analysis of the 3D measurement

The drill bit was scanned by means of an “Alicona InfiniteFocus” 3D focus variation microscope in new and worn conditions. The resulting meshes can be compared, allowing the identification of any surface modification due to tool wear. However, our study has shown that, in the case of microtools, bulk plastic deformation, affecting entirely the tool, can change the global geometry of the tool: identification of the tool face and flank is difficult. As such, we developed an automatic algorithm for the identification of the cutting edge of the drill bit, which is usually the most worn surface. This allows a correct comparison of the cutting edge local meshes and, in the future, the development of automated procedures for the quantitative wear measurement in 3D.

The algorithm is structured as follows (more details can be found in [8]):

1. Considering only the lower part of the tool (secondary cutting edges), identify the points characterized by a high mesh curvature (in the 95th percentile).
2. Separate the mesh patches and consider the most numerous two. As the cutting edge has a high curvature, these two are likely to define the two secondary cutting edges.
3. Based on these patches, estimate the helix angle of the drill.
4. Deform the mesh based on the estimated helix angle. The result is a “virtual” drill bit with a 0° helix angle.
5. In the virtual tool, select the points angularly close to the identified secondary cutting edges.
6. Discard the points with a large (secondary edges) and small (tool notch) radius. The remaining are two patches belonging to the primary edge face and flank.
7. In these two patches, identify the points characterized by high curvature (cutting edge) and fit them with a straight line.
8. Select, as final result for the identified primary cutting edge, the points at small distance from the straight line.

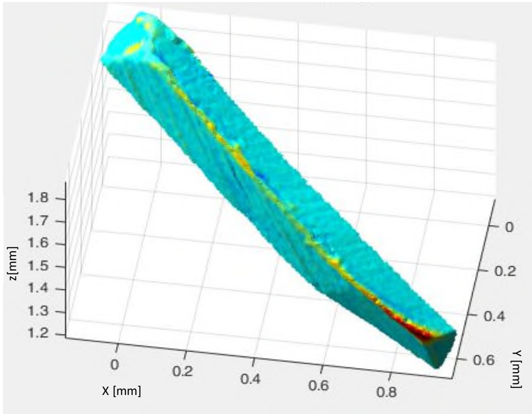

Figure 2. Difference between new and worn cutting edge.

Having identified the primary cutting edges in both the new and worn tool, it is possible to compare the two. Figure 2 clearly shows that the most worn area is the external part of the primary cutting edge (on the right in the image), as expected (this area works at the highest cutting speed).

4. Conclusions

The research on dental tool wear monitoring is still in its early stages. Today, the decision whether a tool needs to be substituted or not is left to the surgeon, but more quantitative approaches are needed. In this work, we have shown that measuring the wear on dental tool and monitoring it by considering the cutting torque is possible.

Future steps of this research include the study of more drilling bits of different geometry, the identification of specific quantitative wear indicators, and the study of the relationship among cutting parameters, force, temperature and wear in bone drilling.

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