EAN 2020
58th conference on experimental stress analysis

A Wear Resistance Analysis of Orthopedic Instruments

KUBÁŠOVÁ K.[1,a], SEDLÁČEK R.[1,b], HORNÝ L.[1,c]

[1] Czech Technical University in Prague, Faculty of Mechanical Engineering, Department of Mechanics, Biomechanics and Mechatronics, Technická 4, 160 00 Praha 6, Czech Republic

[a]Kristyna.Kubasova@fs.cvut.cz, [b]Radek.Sedlacek@fs.cvut.cz, [c]Lukas.Horny@fs.cvut.cz

Keywords: Milling cutters, Drilling, Wear, Experiment,

Abstract. This paper reports on an investigation into the wear problem of 5 types of orthopedic instruments. We conducted a series of experiments based on a proven methodology with modified parameters for the design and development of new instruments. A total of 3 wear cycles for 40 drill holes (respectively for 8 drill holes) per instrument were performed and supplemented by 4 measured cycles. The main monitored parameters were the resistive force and the torque. These parameters can evaluate the penetration of the instrument into the material. We then used statistical methods to evaluate the significance of the detected differences. In most cases, it was statistically proven that the wear did not change the monitored parameters. This implies that drilling 120 holes (respectively 40 holes) does not compromise the sharpness of the instrument.

Introduction

In surgical procedures, especially in the repair of complex fractures (with implanted screws) there is a need to use instruments that can penetrate through hard cortical bone. These instruments are reused (after sterilization). Repeated use of these instruments leads to a blunt cutting edge. An important factor influencing the healing of the surrounding tissue is the heat generated by the instrument in the drilling area – a blunt instrument generates more heat than a sharp instrument. This work employs a proven methodology to evaluate the wear rate of 5 sets of orthopedic instruments [1].

Methodology

The methodology was based on controlled drilling by instruments into beech blocks. The original methodology was adapted to the requirements of MEDIN, the company that produces the instruments [2, 3].

First, one instrument from each group was subjected to microscopy. Before using tools from group D, respectively group E, a hole with a diameter of 2.5 mm, respectively 3.5 mm was pre-drilled. During the experiment, instruments were inserted into the pre-drilled holes. Drilling was carried out at a constant speed of feed [$mm \cdot min^{-1}$], at a constant rpm [min^{-1}] to a depth of 5 to 12 mm. Three wear cycles were performed with 40 holes, respectively 8 holes in each cycle. After each wear cycle, we performed a control measurement cycle using MTS 858 Mini Bionix. The measured value was the resistive force [F = N] required to penetrate the instrument into the material. Due to the specially designed fixture, it was also possible to measure the torque [M = N·m]. The measured value is the torque required to compensate the rotation of the workpiece in the cutter/drill direction [3, 4].

The control measurement cycle was carried out with new tools and with worn tools. The instrument wear was carried out under the same cutting conditions (as the measurement cycle) on the vertical cantilever milling machine. The control measurement drilling was performed using a BOSCH hand drill attached to the frame of the MTS 858.02 Mini Bionix system (MTS, Minnesota, USA) with a force sensor (MTS, 440 N) and a torque sensor (MTS, 5.7 Nm). The figure below shows one cycle of our experiment (see **Chyba! Nenalezen zdroj odkazů.**).

The table (see Table 1) contains information on the speed of the feed, the drilling depths, the rpm and the number of wear cycles in one period. Three wear cycles were performed with all tools after the initial force and torque measurements. Each period was followed by a measurement cycle of the force and the torque.

Fig. 1: One cycle of the experiment: 1. Olympus LEXT OSL 3000, confocal microscope, photo and profile; 2. MTS 858.02 Mini Bionix, measured *F, M*; 3. Defined drilling wear, 40 cycles or 8 cycles; 4. MTS 858.02 Mini Bionix, measured *F, M*; 5. Olympus LEXT OSL 3000 confocal microscope, photo and profile

Table 1: Drilling and wear parameters

	RPM n [min^{-1}]	Speed of feed u [mm·min^{-1}]	Hole depth u [mm]	Number of cycles per period	Number of wear periods	Diameter of the hole [mm]
A	360	63	5	40	3	-
B	360	63	10	8	3	-
C	360	63	5	40	3	-
D	360	63	12	40	3	2.5
E	360	63	10	40	3	3.5

The resistive force during drilling and the temperature of the cutting instrument were both measured. The temperature was measured in each control measurement cycle on the MTS Mini Bionix, i.e. in the initial measurement of the intact instrument and then after each wear period. The temperature was also measured during the first wear cycle. The temperature measurement was always performed before drilling and then immediately after the instrument was removed from the workpiece. The monitored value was the temperature difference, i. e. the increase in the temperature at the tip of the instrument due to drilling. The measurement was carried out using two devices. The FLUKE 574 three-point infrared thermometer was used during the control measurement cycles, and the FLIR E60 thermal camera was used in the first wear cycle [4].

Due to insufficient temperature measurement accuracy, the measurement was terminated after evaluating the first wear cycle. We continued to measure temperature only during the control measurement cycles.

The cutting surfaces of the instruments were subjected to microscopic examination, during which micrographs and height profiles of the material of the instrument were taken. Microscopy was performed using an Olympus LEXT OSL 3000 laser confocal microscope.

Evaluation and Results

Time, displacement, resistive force and torque were recorded during loading. The data were plotted – the dependence of the resistive force (see Fig. 2) and the torque (see Fig. 3) on the feed (for example, the graphs of sample B3). The data were fitted by a polynomial of the 6th degree (purple curve).

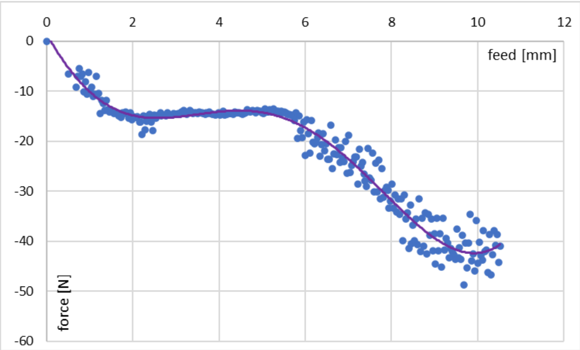


Fig. 2: The dependence of the resistive force on the feed – 1st wear cycle – sample B3

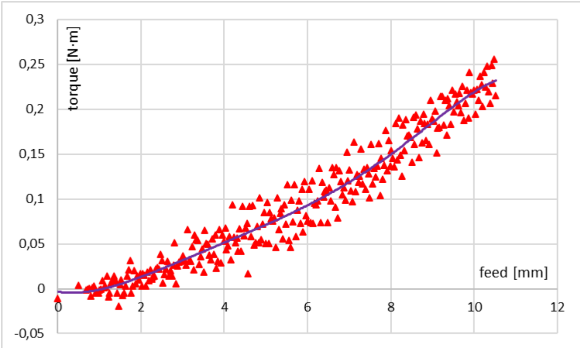


Fig. 3: The dependence of the torque on the feed – 1st wear cycle – sample B3

Histograms and boxplots (see Fig. 4) were also compiled for a better visual comparison of the differences between the measured data. The data were subjected to a statistical evaluation. For each instrument, the hypothesis that the wear affected the measured resistive forces and torques was verified using the Kruskal-Wallis (KW) test. We used the Dunn (D) test to determine the differences between the groups [5].

We presumed that a worn instrument increases the absolute value of the resistive force, and that a blunt instrument transmits more torque to the workpiece.

Thus, if the instrument had been worn out, the resistive force and the torque would have increased gradually over the wear cycles. However, if the mean values of the forces (torques) fluctuate, the random effects prevail over the effects of wear. The results were divided into 3 classification categories:

level 2: The increase is monotonic – damage is accumulated – the force/torque measurements show a statistically significant increase after all three wear periods relative to the values for new instruments (each value is greater than the previous value)

level 1: There is an increase without the accumulation of damage – the force/torque measurements show a statistically significant increase in wear against the values for new instruments (each value is greater than the initial value, not greater than the previous value)

level 0: There is no increase – there are fluctuating results – the force/torque measurements show fluctuating results, there was no significant effect of wear damage on the cutting conditions

Fig. 4 shows the boxplots of the resistance force and the torque for the selected instrument of Group E3.

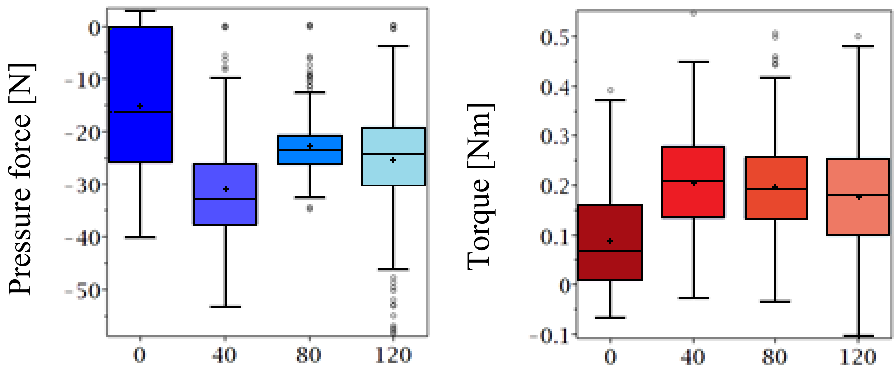


Fig. 4: Boxplots of instrument group E3 across all wear cycles

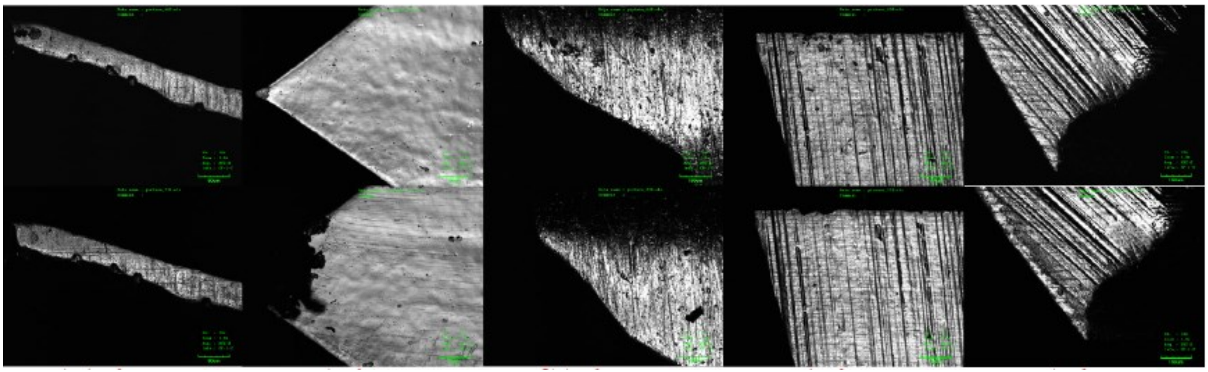
Table 2: Results for each group of instruments by levels

Group	Measured parameter	Sample number					Total
		1	2	3	4	5	
A	*F*	0	0	0	0	0	**0**
	M	0	0	0	0	**1**	**1**
B	*F*	0	**1**	**1**	0	0	**2**
	M	0	0	0	0	0	**0**
C	*F*	0	0	0	0	0	**0**
	M	0	0	0	0	0	**0**
D	*F*	0	0	0	0	0	**0**
	M	0	0	0	**1**	0	**1**
E	*F*	0	**1**	**1**	0	0	**2**
	M	0	0	**1**	0	0	**1**

Note: 0 – no increase; 1 – an increase without accumulation of damage; 2 – the increase is monotonic

On seven occasions (14 %), wear was demonstrated by the measured parameters (see Table 2) – on four occasions (16 %) in the resistive force measurement, and on three occasions (12 %) in the torque measurement. Level 2, i.e. monotonically increasing force or torque relative to wear did not appear anywhere. In several cases, an increase in force or in torque relative to the new instrument was observed. However, there were no differences among the results for the worn-out instruments.

A1–0 B1–0 C1–0 D1–0 E1–0



A1–80 B1–16 C1–80 D1–80 E1–80

Fig. 5: Confocal microscope images – above, intact instruments, below, the instruments after the second wear cycle

Photographs of the blades taken by an Olympus LEXT OSL 3000 confocal microscope are shown above (Fig. 5). Intact instruments are shown above, and the instruments after the second wear cycles are shown below. In the case of instrument A, and especially in the case of instrument B1, we can see some signs of wear. In the case of instrument B1 there was major tip breaking. For instruments C1, D1 and E1, a visual inspection was inconclusive. The scale for A1 and B1 is 80 μm, and for C1, D1 and E1 the scale is 160 μm.

Conclusions

In total, we performed 4 control measurement cycles and 3 wear cycles for 5 types of instruments (5 items per group). We measured the resistive force and the torque for each instrument. The statistical tests showed that a monotonic increase was never achieved. There was no systematic permanent increase in resistive force and in torque during the 3 wear cycles (120 holes, respectively 24 holes). We can state that there was no significant change in the measured parameters representing resistive effects. This conclusion is consistent with the microscope observations. It was therefore possible to use the instruments up to 120 times (respectively 24 times) without signs of wear. Although the temperature measurements were not accurate, and temperatures were not measured during the wear cycles, the temperature measurement during the control measurement cycle never exceeded the limit of 50° C, a value which doctors have found to be the maximum acceptable level.

Acknowledgements

The work has been supported by grant-funded project FV30348 of the Ministry of Industry and Trade of the Czech Republic and by the Grant Agency of the Czech Technical University in Prague, grant number SGS19/155/OHK2/3T/12.

References

[1] K. Kubášová, R. Sedláček, L. Horný, Evaluation of Wear of Milling Cutters for Drilling of Nail Holes Used for Osteosynthesis of Long Bones of Lower Limbs, in: Strojnícky časopis – Journal of Mechanical Engineering, SjF STU Bratislava, 2019, 69(3), 69–74.

[2] T. Staroveski, D. Brezak, T. Udiljak, Drill wear monitoring in cortical bone drilling, 2015, 37(6), 560-566

[3] M. Litschmannová, Martina Litschmannová: Katedra aplikované matematiky, Ostrava: WordPress, Graphene Theme., 2019

[4] E. Jantunen, A summary of methods applied to tool condition monitoring in drilling, International Journal of Machine Tools and Manufacture, 2002, 42(9), 997-1010

[5] P. Nestrojil, Léčení zlomenin dlouhých kostí, SANQUIS: Časopis o umění, medicíně a zdravém životním stylu, Brno: Audabiac, o. s., 2002, 2002(22), 52