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Testing surgical bone reamers: a biomedical project in the fluid mechanics laboratory

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ABSTRACT: A medical company submitted two surgical bone reamers for testing in order to determine the magnitudes of pressures they had generated during reaming operations. Engineering students in their junior year designed, built and tested a test stand to evaluate the performance of each reamer. They found that one reamer generated much higher pressures than the other; this suggested that how a reamer is designed has a significant effect upon the magnitudes and variability of the pressures that it generates during surgical operations.

INTRODUCTION

Recent literature indicates that effective methods and tools can be designed at the undergraduate level to engage students to advance their learning capabilities and levels of understanding through the use of real world problems [1][2].

In order to stabilise the fracture of a broken bone and give the body a chance to heal, surgeons use a type of fixation implant called an intramedullary nail [3]. One of the cutting instruments used in this procedure is called a *reamer*. A reamer is used to create a cavity in the canal of long bones into which the nail can be inserted (see Figure 1). It is commonly accepted that reaming increases the pressure inside the bone [4-7]. Also, the associated pressure gradients drive fat emboli and other medullary particles into the blood stream [8]. The presence of such particles changes the physical properties of blood, resulting in unwanted side effects such as increased strain on the heart, necrosis, enzymatic digestion of cell components, inflammatory responses, lung malfunction, and even death, in some cases [4][9-12]. Therefore, in designing a reamer, engineers should seek ways to reduce the pressures that its rotation is likely to create during surgery [12].

THE PROJECT

There are several companies around the world that design, manufacture and market surgical bone reamers. As their products reach the market, the natural question that arises in the mind of surgeons is whether or not a reamer made by company A produces more or less pressure increases than one made by company B, under similar conditions of operation.

A representative of a medical company brought two different reamers (A and B) to the undergraduate fluid mechanics laboratory at Indiana University - Purdue University Fort Wayne, Fort Wayne, USA, for testing. The reamers were made by two companies with different design philosophies. Reamer A had a rigid and hollow shaft, while reamer B had a flexible shaft; the latter was constructed by using a bundle of thin, but flexible, rods. It was reported to the researcher that a testing laboratory measured the pressures generated by the rotating head of each reamer and found that one of them generated much larger pressures than the other. However, at this point, no information had been given as to how each reamer performed. The task was to gain experimental results that would be compared to those already reported by the testing laboratory.

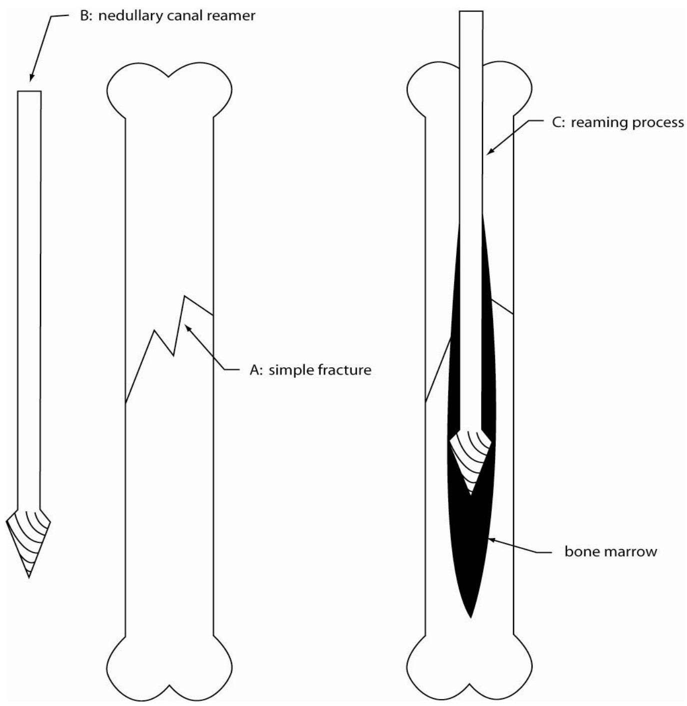

Figure 1: Bones and reamers.

As part of a class project, the instructor asked two groups of students enrolled in the fluid mechanics laboratory to undertake the following:

- Design a test stand;
- Select instrumentation to be used for testing;
- Devise and carry out a testing procedure that would allow them to compare the performances of the two reamers.

The physical characteristics of the two reamers are summarised in Table 1.

Table 1: The physical characteristics of the reamers.

Characteristic	Reamer A	Reamer B
Length of reamer	18 in (0.46 m)	18.5 in (0.47 m)
Shaft ID	2/16 in (3.17 mm)	3/16 in (4.76 mm)
Shaft OD	3/16 in (4.76 mm)	5/16 in (7.94 mm)
Length of cutting head	5/16 in (7.94 mm)	8/16 in (12.7mm)
Cutting head's ID	2/16 in (3.17 mm)	2/16 in (3.17 mm)
Cutting head's OD	3/16 in (4.76 mm)	5/16 in (7.94 mm)
Mass of reamer	1.59 oz (45 grams)	3.25 oz (92 grams)

THE TEST STAND

A cylindrical container was used to simulate a long bone. It was constructed from a graduated Plexiglas pipe that was 24 inches long, had an inside diameter of 1 inch, and was open to the atmosphere at the top but closed at the bottom by means of an end cap that had been glued to it there. A 0.28-inch hole was drilled through the wall of the pipe at an elevation of 2 inches from its base. This hole served two purposes: it was an exit orifice from which fluid could leave the pipe; it was also the opening into which a piezoelectric pressure transducer (Shaevitz) could be attached to the pipe in order to sense the pressure of the water in the vicinity of that hole.

The test stand itself consisted of a space delineated by two square plates that were arranged horizontally, one above the other, and supported by four vertical rods at their corners in such a way that the plate could be moved up and down, thereby varying the distance between the plates and, ultimately, making it possible to adjust the depth of submersion of the reamer into the cylinder. A reamer to be tested could then be inserted into this container from above. The upper end of the reamer was gripped by the chucks of an electric drill that was mounted vertically to the upper plate, so as to allow it to hold the reamer and let it hang vertically downward and into the pipe. The flow of electricity into the drill was regulated by means of a dimmer switch that had been designed, calibrated and labelled by the students in such a way that each major position of the switch knob corresponded to a known speed of rotation of the drill chucks. The pressure transducer was connected to the data acquisition that was being used in the laboratory at that time (Strawberry Tree); it was set up to display graphically the output voltage from the transducer versus time. Students had calibrated the transducer output voltage (mV) to the pressure (psi) in earlier experiments so that they knew the relation between them. The resulting experimental set-up is shown in Figure 2.

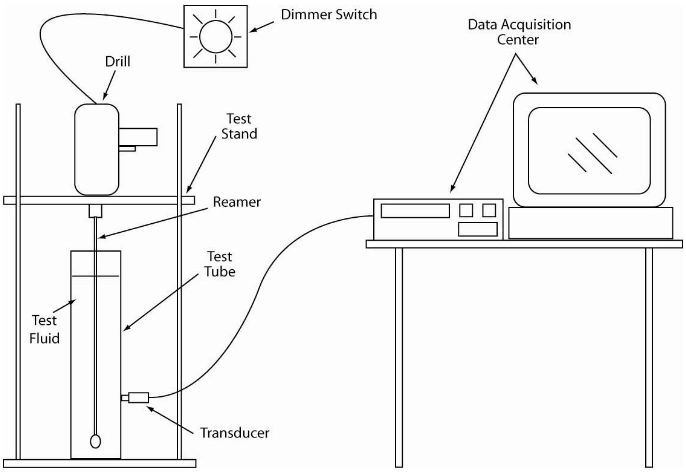

Figure 2: Sketch of a testing station.

EXPERIMENTAL PROCEDURE AND RESULTS

Enough laboratory water at room temperature was poured into the Plexiglas cylinder without filling it completely. A given reamer was then inserted into the fluid until its rotating head reached a predetermined height above the level of the exit orifice. Data acquisition was activated to record the reference voltage, which was subsequently scaled down to zero. The reamer was then set into motion and allowed to rotate at a set speed for approximately 30 seconds. The speed of rotation of the reamer was then increased to the next level, where, as before, it was allowed to rotate for 30 seconds. The process continued until a speed of 1,400 rpm was reached. Figures 3a and 3b show sample plots of voltage versus time for reamers A and B, respectively.

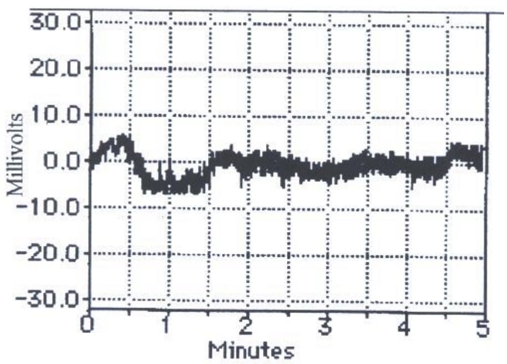

Figure 3a: Voltage versus time for reamer A

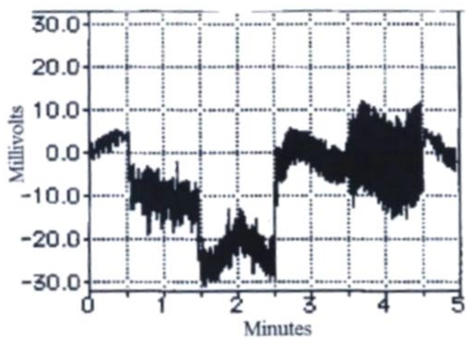

Figure 3b: Voltage versus time for reamer B.

In these two figures, it can be seen that the initial speed of rotation was 400 rpm; it was increased to 500 after 30 seconds, then to 600 after 30 seconds and so on, until a speed of 1,400 rpm was reached. It can be observed that, for most speeds of rotation, the magnitudes of the pressures generated by the operation of reamer A are smaller than those of reamer B. Also, the pressures generated by reamer A fluctuate less dramatically than those of reamer B, as one increases speeds.

CONCLUSIONS

Mueller, Frigg and Perren investigated the influence of the shaft diameters of reamers on the generation of intramedullary pressures during reaming [7]. They used Plexiglas tubes filled with a mixture of Vaseline and paraffin oil at 20EC and at reaming speeds of 450 rpm. They found that there were considerable differences in the pressures generated by the five different reamer systems they tested. For flexible shaft diameters, they concluded that pressure levels correlated directly with the shaft diameter.

In the laboratory described here, water was used at room temperature and a test stand designed, built and tested by students in order to evaluate the performance of two reamers. The test stand worked very well. The results obtained agreed qualitatively with what is available in the literature, which indicates that surgical reamers increase the intramedullary pressures of long bones [4-6].

The results also showed that the design of a reamer itself has a significant effect on the magnitudes and variability of the pressures that are generated [7]. It was revealed to the instructor at the end of the tests that the general pattern of the results observed by students supported the results that had been reported by the first laboratory, which had tested similar reamers.

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