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Automatic Bone Drilling in Surgery: Safety Conditions Improvement

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Abstract: *The paper discusses the feature and problems of bone drilling as an orthopedic surgery manipulation. The process of automatic drilling is considered with respect to the approaches for improvement of the safety conditions in ODRO robotized system.*

Keywords: *Automatic bone drilling, orthopedic surgery, control, safety conditions.*

1. Introduction

The first application of robots in orthopedic surgery is based on the industrial robots-manipulators. The advanced tendency in that field is oriented to the design of manipulative systems according to the specifics of concrete orthopedic manipulations. Taking into account that the objects under manipulation are the human being organs, the main requirement is assuring maximal reliability. The latter leads to the conclusion that the robot usage in surgery must be designed especially for specific operation only. Such an approach allows assuring:

- maximal simplifying of the robot mechanical system and minimizing its degrees of freedom;
- level of force action according to any specific case;

- sensor system and software simple enough to allow the surgeon efficient control of the robot executed manipulation.

2. Peculiarities of drilling as orthopedic manipulation

Orthopedic screws are often implanted in bones. This requires to realize the bone drilling process apriori. Until now, in orthopedic surgery the bone drilling is executed by hand entirely. But hand-drilling leads to some problems, such as getting the big outlets, breaking the tendons or blood vessels, protecting the rear bone wall (which brings one more cutting of the tissue), overheating and so on [3, 6]. These problems concern the precision and accuracy of the drilled holes.

The main factor causing the problems above mentioned is the variable resistant force at drilling. It is due to the non-homogeneous density of the bones and their structure (tube and soft one), as well as the various patient state (age, sex, health, etc.). At the same time the manipulation safety entirely depends on the surgeon skill, i.e., his subjective behaviour. Making the orthopedic operations automatic ones could solve many problems just by removing the subjective factor influence. Moreover, this can assure better accuracy, precision and reliability of the manipulation.

The safety problems are discussed in the paper as well as their kind of solution by robotized ODRO system.

3. Robotized system for bone drilling ODRO

Realizing research on automatic bone drilling in surgery, different experimental setups were designed and many experiments were executed [1, 2, 5]. As a result the drilling process parameters were investigated and the criteria were formulated, which must be satisfied by an automatic drill system.

The last prototype of automatic drill machine is presented on Fig. 1, as well as its accessories. In comparison with the previous ones, the hand grip is placed to the corpse middle aiming to reach better weight balance.

Fig. 1. Automatic drilling executive device and its accessories

Relatively simplified user interface is included in the system. It allows the surgeon to set the necessary working regime, to receive information for concrete manipulation execution in real time and to show on the display the final result of that manipulation.

4. Reliability and safety improving of the manipulation

As it was said the automatic bone drilling has to eliminate the subjective factor influence and to assure accuracy, precision and reliability of the manipulation. The manipulation reliability can be considered in two aspects:

- working ability of drilling system itself;
- reliability of the drilling process.

4.1. Working ability of the drilling system

The successful realization of the manipulation concerns the right functioning of the system elements – actuators, sensors, buttons, etc. This means that testing of these elements must be done before manipulation. That is why one program is realized immediately after switching on the machine – Self Test.

During the program execution the testing steps are:

- staring button (on/off);
- starting position;
- force sensor;
- step motor translation over the whole working zone, loading at free motion, checking of missed steps;
- brushless motor rotation.

The resistant force is calculated during the force sensor check and an average value is obtained which shows the normal motion. If a wrong motion occurs, that is a signal of damage. During the program execution, some messages are displayed on LCD to inform the surgeon about the test – starting button, waiting, working zone, free motion resistance (Fig. 2).

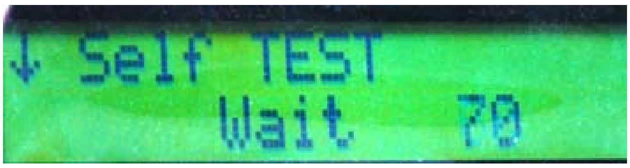

Fig. 2. Information during the task execution (Self Test, Wait, Press)

Criteria are set for the different elements testing which allow *taking decision* about their right or wrong functioning. After a successful test, the LCD displays a confirming message (Fig. 3) and the system is going to a working task regime setting.

Fig. 3. Successful test completion (Self Test OK)

If any of the elements is working in the wrong way, a message "Self TEST ERR" appears on the display and the machine is blocked. The operation may be prolonged after the damage is removed and a successful new test is accomplished.

4.2. Reliability of the drilling process

The drilling process reliability has to be understood in two aspects: the surgeon allowing to set the desired drilling parameters (hole depth, working regime, etc.) and control them in real time and at the same time not allowing the surgeon to influence the desired parameters during the drilling process itself, i.e. accuracy, pressure, end of the process, etc.

The bone drilling robot maintains two working modes:

- hand;
- automatic.

The machine is working as usual drilling in the hand mode. The rotation speed can be regulated by a potentiometer.

The automatic mode has two sub-modes:

- drilling the bone entirely (Cortex I, Cortex II);
- drilling the preliminary set depth (mm).

The sub-modes are chosen by the surgeon with the help of four buttons and a potentiometer connected with a display. The machine can do a motion when the surgeon just holds the starting button. If the button is released, the motion stops. Pressing the button again starts the program execution from the moment it has been stopped. After releasing the button, the surgeon can change the working mode or set another task without system restarting. The information displayed in real time shows what part of the working task is executed (Fig. 4). In that sense the surgeon can control the drilling process in real time.

Fig. 4. Temporary information during bone drilling

For the system functioning in the right way the surgeon must keep continuous contact between the bone and the machine. The control algorithm identifies the resistant force and controls the force at the translation motion excluding the possibility of bone damage due to overheating and over pressing. The surgeon cannot influence the drill bit force. The bad contact leads to errors in identification and machine decision for the end of drilling [3]. This results in errors in the passage between the bone and the soft tissues which is dangerous for the patient. For this reason the responsibility for successful manipulation is imposed on the surgeon. He must decide whether the displayed information answers to his skills of evaluating the real object and the real situation (X-ray information, other information about the patient).

The surgeon has to set the manipulation parameters (working mode, kind of drill bit, maximal desired penetration). The system maintains these parameters keeping the needed accuracy and it *guarantees not exceeding their values* (especially the depth of penetration). In the case of non correspondence between the preset parameters and the real conditions, the system displays warning messages. For instance, if the drill bit is less than the preset penetration, the display shows "Error Prop" (Fig. 5), i.e., such operation is impossible.

Fig. 5. Going over the working zone

Also, for safety reasons in an automatic mode for the whole bone drilling task (Cortex I, Cortex II), two parameters are set: the number of walls and the maximal depth of penetration (Fig. 6).

Fig. 6. Working regime setting

In this case the second parameter is more important (maximal depth – MAX mm). In this way the patient safety is guaranteed no matter whether the bone wall is determined wrong or some other mistake occurs. The drill bit will *never* go ahead so much as to damage the soft tissues, blood vessels, tendons, etc. which are close to the bone. In comparison with the standard manipulation, all depends on the surgeon skills and abilities.

In working mode of whole bone drilling, the following information is displayed after the end of manipulation (Fig. 7):

- length of the first bone wall;
- distance between both walls;
- length of the second bone wall;
- whole penetration length of the drilled off bone.

Fig. 7. The information at the end of a"whole bone" drilling regime

This information practically *eliminates entirely the need of one usual manipulation* – measurement of the penetration depth after the end of the drilling [4]. The operation time is shortened. The measurement of the distance between the bone walls and the walls size is done up to one millimeter accuracy. Really the level of measurement is many times bigger – 4032 steps/mm. But practically the orthopedic screw length increases by a 2 mm step, so that error allowance not bigger than 0.2 mm is enough (Fig. 7). The information shown on Fig. 7 is also very important to choose the optimal length of the implanted screw.

5. Conclusion

The safety conditions improvement of automatic bone drilling is generalized as:

- various tests are made for guaranteeing the working ability of the machine;
- the control system assures the patient safety;
- the information on the display allows the surgeon to control the manipulation execution in real time.

Therefore the automatic bone drilling has some advantages which cannot be achieved by hand drilling – accuracy, precision, reliability and safety.

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Автоматизированное пробивание костей в ортопедической хирургии: улучшение условий безопасности

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(Р е з ю м е)

В работе рассмотрены особенности и проблемы пробивания костей, что является одной из ортопедических манипуляций. Процесс автоматического пробивания обсуждается с точки зрения каким образом реализуется повышение надежности в роботизированной системе ODRO.