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Initial Stability Analysis of Spine Pedicular Screws Using Modal Analysis Method

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Abstract

Low back pain is a common medical problem. There is no clear cause for the back pain problem, but in most cases, spinal instability can be noted. Lumbar spine fixation is performed to treat some problems of low back pain with or without surgery. The pedicle screw fixation devices are the dominant stabilization systems for a wide variety of defects in human spinal column. Accordingly, pedicle screw design has been the main parameter affecting the fixation strength as measured by the pullout force and insertion torque, sometimes with contradicting results. Five different designs of pedicle screw were used. To reduce the effect of bone quality variations, the bovine tibia cortical bone was chosen. After recording maximum torque during screw insertion in the bone samples, first modal analysis was carried out by recording the sounds of the impact. Then, the conventional pullout test was performed for the comparison purpose. The effect of different designs on the natural frequency derived from the modal analysis and ultimate pullout force were respectively determined. The highest natural frequency of 1653 Hz and pull-out strength of 884 N were all obtained in conical thread screw. In addition, it was confirmed that self-tapping is not a parameter that can affect the fixation quality. Modal analysis was found to be a reliable, non-destructive and accessible method with excellent repeatability pattern which could be considered as a prospective replacement of the pull-out test in the assessment of the pedicle screw fixation stability in vitro and potentially in-vivo.

Keywords: Modal analysis, Pull-out force and insertion torque, Non-destructive, Screw fixation and primary stability.

A. Introduction

Lower back pain is one of the major health problems around the world. One of the causes of lower back pain is spinal instability. Spinal fusion with or without instrumentation is the treatment of instabilities where the former has a higher success rate than the uninstrumented fusion. All in one, for every implantation, two kinds of stabilities are defined. Primary fixation stability is the immediate stability after implantation of a screw into the bone and comes from the mechanical engagement [1]. To evaluate the mechanical fixation stability of the orthopaedic and spine bone screws, investigators have incorporated various methods to examine different parameters, e.g., the cyclic fatigue test, pullout test and insertion torque. Standard test methods for pull-out strength of orthopaedic screws are indicated in ASTM F543-17 [2].

Modal analysis is currently used to evaluate mechanical primary and secondary stability of dental implants, and it is anticipated that it can be used in orthopaedic and spinal systems, as well. This is a non-destructive method, and it can be repeated for each sample several times. According to this method, each mode of a vibrational system can be stimulated, and natural frequencies can be recorded. These natural frequencies are in relation to stabilities [3].

The purpose of this study was set to propose a new approach for biomechanical assessment of orthopaedic metallic bone screws using modal analysis method, as utilized in predicting the fixation strength of the dental implant.

B. Material and method

1. Screw insertion

Four metaphysis portion of two tibial bovine samples (Fig. 1.a) were selected from both legs in order to decrease bone density variations and provide cortical bone as a sample test. The samples were provided from a local butchers and no sacrificing was occurred for this study purpose. Five different pedicular screws in term of designs (Fig. 1.b) were selected to evaluate first the effect of thread shape and second the effects of existence of self-tapping features both in conventional pull-out test and modal analysis. The design characteristics were shown in table 1. All screws were inserted in the same insertion depth *i.e.* 10 mm and same orientations according to ASTM F-543-17 [2].

2. Modal Analysis Test

First, impact was applied to the head of each screw. Secondly, the impacting sound was recorded using a simple recording device. The recorded sound was processed in MATLAB R2019 software and using Fast Fourier Transform (FFT), data was converted from time domain into the frequency domain. The location of the peaks illustrated the natural frequencies at different modes. The first peak in this frequency response was selected as the first mode of vibration. The sound recording analysis was repeated for all samples four times to determine the natural frequency of the screw-bone set up.

3. Pull-out test

The pull-out test was performed according to the ASTM-F543-17, using a uniaxial tensile testing machine (Zwick /Roell, DTM, Germany. Displacement rate was selected 5 mm/min, and data collection was kept on until it was pulled out from the bone completely. Load-displacement data were recorded at a rate of 25 Hz. After the placement of pedicle screw within the bone, the orientation of the pedicle screw and tensile hook manipulated in the coaxial orientation. Then the load cell was zeroed, and the peak pull-out force was recorded for each test case.

C. Results and discussion

Maximum natural frequency and pull-out force occurred in the screw number three which has a conical core and non-constant crest thickness. The minimum natural frequency and pull-out force belongs to the screw number two which has cylindrical core and constant crest thickness. The results of conical and cylindrical core agree with the study of Kim et.al as a point of pull-out force [4]. By comparing the screw number one or two with other conical screws this fact can be concluded that conical screws have higher primary stability than cylindrical ones ($p<0.05$). According the results showed in Fig. 1.c no significant difference between uniform and non-uniform crest thickness was happened due to comparison of screw numbers four and five. Also the length of threads in screw number one and two could not differ the dependent variables significantly. For self-tapping feature it can be concluded from the results of screw number three and five that although slight increase has happened in screw number three with self-tapping tip but this increase was not the significant order of magnitude and this conclusion are in the same line as Ketata et al. [5].

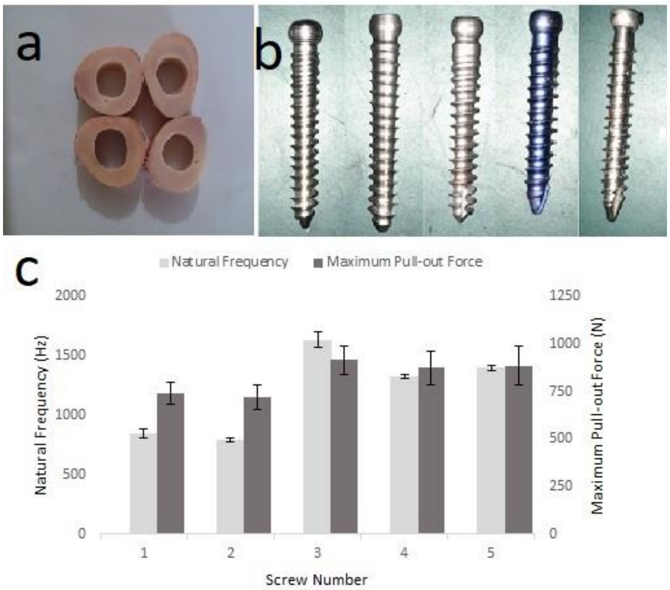

Fig. 1. a) Divided cortical bovine samples from tibial portion, b) Screw samples with different thread distribution and specification mostly different in core shape, crest thickness and self-tapping feature, and c) Natural frequency and maximum pull-out force versus every screw number based on the table 1.

Table 1. Screw specifications with 6.5 mm thread diameter and Cylindrical thread shape

Screw No.	Thread Length (mm)	Crest Thickness	Self-tapping	Core shape	Depth of threads	Weight (gram)
1	50	Constant	Yes	Cylindrical	Constant	4.25
2	44.8	Constant	Yes	Cylindrical	Constant	4.04
3	50.3	Non-Constant	Yes	Conical	Non-Constant	4.57
4	47.6	Constant	NO	Conical	Non-Constant	4.65
5	45	Non-Constant	NO	Conical	Non-Constant	4.59

D. conclusion

In this study, modal analysis was employed to investigate the primary stability of spinal pedicle screw fixation. Furthermore, the correlation between modal analysis and peak pull-out strength (representative of primary stability) of a screw-bone structure were examined. Moreover, the influence of design factors of screw on the natural frequencies and pull-out forces was demonstrated. Modal analysis was found to be a reliable and non-destructive method with excellent repeatability which could be considered as a prospective replacement of the pull-out test which is not considered to use in real surgeries. Modal analysis can be used to assess the stability of all implantable screws. The proposed approach is reliable, accessible, repeatable on the same sample and accurate in predicting the primary fixation stability of the pedicle screws. The new method has the potential to be applied for the assessment of the pedicle screw fixation stability in-vivo.

There are different parameters which can affect pull-out and insertion torque values. i.e., the mechanical properties of the block test and time-dependent variables. It can also be shown that the length of the screw out of bone as well as the loading rate are other factors probably affecting the natural frequency and primary fixation stability.

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E. References

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