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Initial validation of automatic torque-limiting bone screwdriver system

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Abstract: Bone screw tightening torque is important to achieve the best patient outcomes in orthopedic procedures. Here, an automatic method was tested for determining the stripping torque of a screw during the initial insertion of the screw. This involved an inverse model to determine material strength, followed by a forward model to estimate stripping torque. This method was tested on 2 different densities of polyurethane foam as a substitute for real bone. It was found the model-identified/estimated strengths/torques closely followed the datasheet/measured values. This method shows promise for predicting stripping torque. However, further work is needed to better quantify the accuracy.

I. Introduction

Bone screws are used in many orthopedic procedures to hold broken bones in place to assist healing, or securing implants which may restore mobility (e.g. artificial hips). It is important, however, to ensure that the screws are correctly torqued; too loose and they may come out with time [1], too tight and they may break the threads in the bone [2]. Both situations are a failure of the fixation, and may require risky revision surgery, or if that is no longer possible (such as after repeated hip replacements), the patient may become permanently impaired.

Current surgical practice generally involves surgeons tightening screws by hand, and using their experience and judgment to achieve good results. While often successful, this can be influenced by human factors like fatigue, and junior surgeons may not have the same experience as their seniors. Sometimes torque-limiters are used, however, this still requires judgment from the surgeon to select the correct torque limit.

Previous work has proposed an automated torque-limiting screwdriver to provide a more objective method of screw torque regulation [3]. This is based upon determining the strength of the bone via parameter identification (inverse model) combined with a model of screw insertion [4], then using this strength value to predict the failure torque based on the known screw and hole geometry (forward model) [5]. Other empirical methods have also been presented in literature [6], [7], while we use physically based modelling, which may extrapolate better if the underlying mechanics are well understood.

The inverse and forward models have been previously tested independently [5], [8]. This paper will present the methods and some initial results testing them together.

II. Material and methods

II.I Experimental

A bone screw (ISO 5835:1991 HB 6.5 screw, 30 mm length) was inserted once into 2 different densities of polyurethane foam (SikaBlock M150 and M450) using the test rig shown in Figure 1. The screw was inserted into pre-drilled 3.0 mm holes, and tightened against a plate with a matching spherical shape to the underside of the screw.

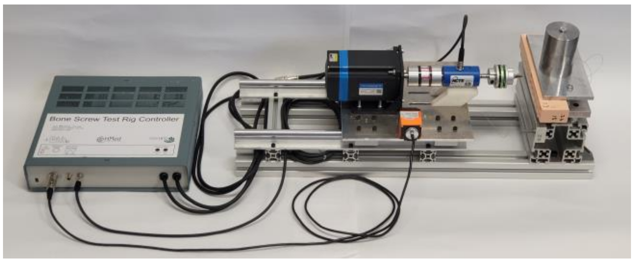

Figure 1: Test rig used to insert screws while recording torque and position/rotation profiles.

The screw was inserted at 30 RPM until it fully stripped the threads (torque peaked and then declined). The torque and rotation were measured with an NCTE 2300-5-1-AU-0-0 rotational torque sensor with a range of ±5 Nm (0.5% accuracy) and 0.25-degree resolution. The linear motion was measured with a draw-wire encoder with 0.025 mm resolution (A40/D5.2501.2421.1000, Fritz Kübler GmbH).

The data was recorded at 1000 Hz and saved to a file via a serial link to a PC. The data was then processed in MATLAB.

II.II Data Processing

The recorded data was preprocessed to extract only the period of screw insertion.

The period of insertion before tightening was used to estimate the strength of the material. The torque-displacement curve was used to fit eqn. 1 and find the material strength. G_1 and G_2 are geometrically derived constants based on the screw and hole, μ is the friction coefficient between the screw and hole, and was set to 0.3 [N/N], α is the angular length of the thread-cutting section of the screw, σ_{ucs} is the unknown material strength, and ϕ and τ_z are the measured angular positions and torques, respectively. The full model/equations can be found in Wilkie et al., along with parameter values for the screw used [9].

$$\tau_z = \sigma_{\text{ucs}} G_1 + \mu \sigma_{\text{ucs}} G_2 \left(\phi - \frac{\alpha}{2}\right) \qquad (1)$$

The identified material strengths were then used to calculate an expected stripping torque using the forward model from Wilkie et al. [5]. This was compared with the true maximum value observed during screw insertion.

III. Results and discussion

Table 1 presents a comparison between the datasheet strength and identified strength, as well as between the measured stripping torque and estimated torque.

Table 1: Comparison of estimated strength and torque values against known values.

	Test 1	Test 2
Material	M150	M450
Datasheet Strength	1.6 MPa	10 MPa
Identified Strength	1.22 MPa	6.25 MPa
Strength Error	-24 %	-38 %
True Stripping Torque	1.21 Nm	5.10 Nm
Est. Stripping Torque	1.23 Nm	5.96 Nm
Torque Error	+1.7 %	+17 %

The identified strength increases with the true/datasheet strength. However, both identified values are lower than the datasheet values. This may be due to inaccuracies arising from modelling assumptions, or manufacturing variation in the test blocks. Nevertheless, the trend indicates that the screwdriver system is adapting it's estimate as the real strength changes, and the offsets may be resolved with calibration.

The estimated stripping torques are even closer to the true ones than the strengths were. In this case, if an 80% torque target was used, the stripping torques would (if only just) not be exceeded. The differences in the errors between the two materials are approximately opposite to the differences in the strength errors. Again, as was the case with the strength, the stripping torque estimate roughly follows the trend in true stripping torque, suggesting this model would work to pre-emptively stop before actual stripping.

While these initial results are promising, further testing is needed. Both with more tests on each material to better quantify the accuracy of the method, and with more materials/screws to determine if there are any limits to the practical applicability.

IV. Conclusions

A system was tested for automatically determining the stripping torque of bone screws based on data recorded during screw insertion into 2 different densities of polyurethane foam.

Reasonable agreement was found between the estimated and real strengths and stripping torques. This gives confidence that this model is adapting, as intended, to the changes in material strength.

The primary focus for future work should be on expanding the testing to a wider variety of materials and performing more thorough testing on each material to better understand the statistical reliability of the method.

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References

[1] M. Evans, M. Spencer, Q. Wang, S. H. White, and J. L. Cunningham, 'Design and testing of external fixator bone screws', *J. Biomed. Eng.*, vol. 12, no. 6, pp. 457–462, Nov. 1990, doi: 10.1016/0141-5425(90)90054-Q.

[2] A. Feroz Dinah, S. C. Mears, T. A. Knight, S. P. Soin, J. T. Campbell, and S. M. Belkoff, 'Inadvertent Screw Stripping During Ankle Fracture Fixation in Elderly Bone', *Geriatr. Orthop. Surg. Rehabil.*, vol. 2, no. 3, pp. 86–89, May 2011, doi: 10.1177/2151458511401352.

[3] J. Wilkie, P. D. Docherty, and K. Möller, 'Developments in Modelling Bone Screwing', *Curr. Dir. Biomed. Eng.*, vol. 6, no. 3, pp. 111–114, Sep. 2020, doi: 10.1515/cdbme-2020-3029.

[4] J. Wilkie, P. D. Docherty, T. Stieglitz, and K. Möller, 'Geometric Generalization of Self Tapping Screw Insertion Model', in *2021 43rd Annual International Conference of the IEEE Engineering in Medicine Biology Society (EMBC)*, Nov. 2021, pp. 4387–4339. doi: 10.1109/EMBC46164.2021.9630157.

[5] J. Wilkie, P. D. Docherty, and K. Möller, 'Stripping Torque Model for Bone Screws', *IFAC-Pap.*, vol. 54, no. 15, Art. no. 15, Jan. 2021, doi: 10.1016/j.ifacol.2021.10.296.

[6] R. L. Thomas, K. Bouazza-Marouf, and G. J. S. Taylor, 'Automated surgical screwdriver: Automated screw placement', *Proc. Inst. Mech. Eng. [H]*, vol. 222, no. 5, pp. 817–827, May 2008, doi: 10.1243/09544119JEIM375.

[7] K. J. Reynolds, A. A. Mohtar, T. M. Cleek, M. K. Ryan, and T. C. Hearn, 'Automated Bone Screw Tightening to Adaptive Levels of Stripping Torque', *J. Orthop. Trauma*, vol. 31, no. 6, pp. 321–325, Jun. 2017, doi: 10.1097/BOT.0000000000000824.

[8] J. Wilkie, P. D. Docherty, T. Stieglitz, and K. Möller, 'Quantifying Accuracy of Self-Tapping Screw Models', in *2021 43rd Annual International Conference of the IEEE Engineering in Medicine Biology Society (EMBC)*, Nov. 2021, pp. 4391–4394. doi: 10.1109/EMBC46164.2021.9630646.

[9] J. A. Wilkie, G. Rauter, and K. Möller, 'Determining relationship between bone screw insertion torque and insertion speed: Bestimmung des Zusammenhangs zwischen dem Drehmoment beim Eindrehen von Knochenschrauben und der Eindrehgeschwindigkeit', - *Autom.*, vol. 70, no. 11, pp. 976–991, Nov. 2022, doi: 10.1515/auto-2022-0009.