Use of a Flex Constant to Monitor Implant Stability in a Porcine Model

Authors: Weiwei Xu, Yen-Wei Chen, Kanako J. Nagatomo, Garrett Porter, Irving S. Scher, I. Y. Shen

Affiliation: University of Washington, Department of Mechanical Engineering & School of Dentistry

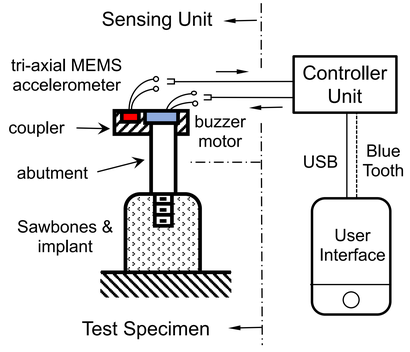
Academy of Osseointegration

Motivation

- Dental implant stability is essential for successful osseointegration and long-term implant success.
- Its sensitivity to bone condition changes is examined in a porcine model, and if validated, the flex constant (displacement over force) could serve as a physics-based parameter to complement existing stability measurements and aid in detecting implant stability.

Objective

- Evaluate the feasibility of using flex constants (displacement-force ratio) as a measure of implant stability, and compare its effectiveness with ISQ.



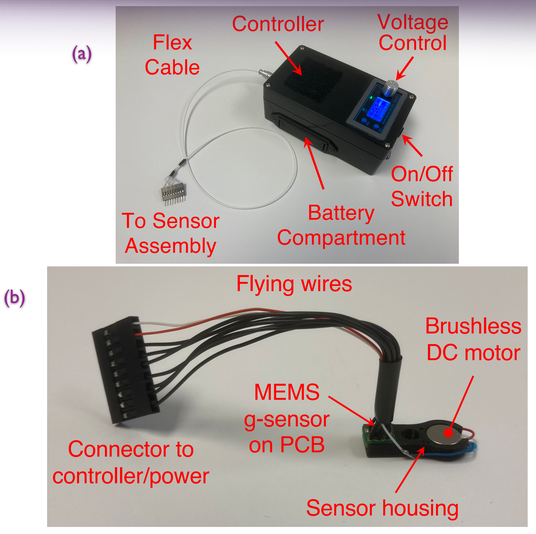
Setup and Instrumentation

Methods

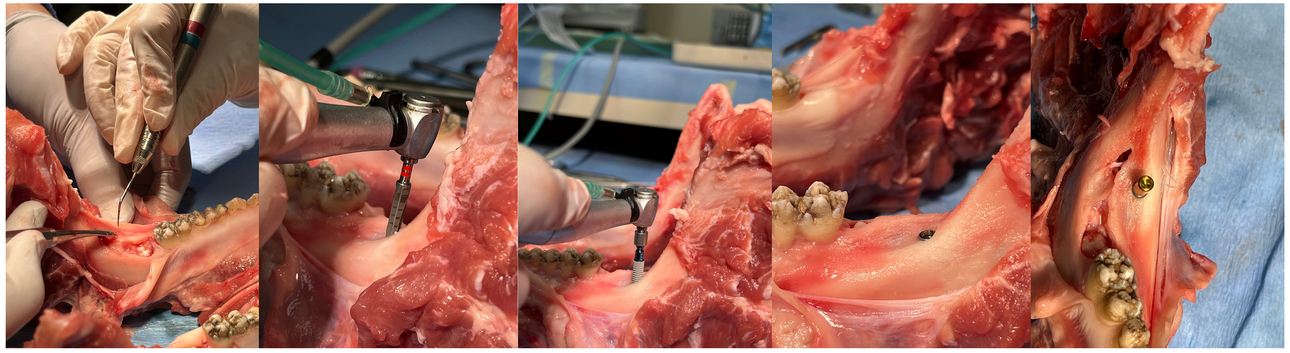
- Implant Placement Procedure
  1. A fresh porcine mandible was used in this in-vitro implant stability study. After clinical and radiographic assessments of the anatomic structures, the implant site was determined to be at the retromolar area of the mandible. A muco-periosteal flap was reflected, and the alveolar ridge was flattened.
  2. A Straumann BL 4.1mm x 10mm SLA implant (Straumann, Switzerland) was selected for this study. A sequence of drills was used to prepare the implant site following the manufacturer's surgical protocol. The implant was inserted into the osteotomy site with the motor set at a torque of 35 Ncm and manually placed at the level of the alveolar bone crest using the Straumann torque-controlled wrench.
  3. A regular connection (RC) Locator abutment, 6mm in length, was connected to the implant platform and secured with a torque of 10 Ncm using the dedicated wrench. The mandible was frozen to simulate high-stability conditions before thawing trials.

Experimental Setup

- A custom-made motor-sensor unit was mounted on a locator abutment to apply a controlled lateral force F to the implant and measure the corresponding displacement response Δx. The flex constant was obtained as Δx/F.
- The flex constant Δx/F was measured over time during thawing of a frozen porcine mandible, wherein the thawed and frozen states simulate step changes in bone stability.
- Implant stability quotient (ISQ) was concurrently measured to compared with the flex constant Δx/F.



Sensor Assembly for Measuring Flex Constants: (a) External view of the controller with USB-C port, power switch, voltage control knob, and flex cable connection; (b) Sensor assembly with a brushless DC motor, MEMS accelerometer, and press-fit angular stiffness sensor on the locator abutment.



(a) (b) (c) (d) (e)

Key Stages of the Implant Placement Procedure: A Visual Overview

Use of a Flex Constant to Monitor Implant Stability in a Porcine Model

Authors: Weiwei Xu, Yen-Wei Chen, Kanako J. Nagatomo, Garrett Porter, Irving S. Scher, I. Y. Shen

Affiliation: University of Washington, Department of Mechanical Engineering & School of Dentistry

Results & Observations

- ISQ Findings:
  - Frozen state: 86-89 (high stability).
  - Thawed state: dropped to ~72, stabilizing after 38 minutes.
- Flex Constant Findings:
  - Frozen state: 0.4-0.5 (um/N).
  - Thawed state: Increased to 1-1.4 (um/N), stabilizing after 30-40 minutes.
- Key Observations:
  - Both flex constant and ISQ detected stability changes during thawing.
  - The flex constant increased at the thawed state, indicating greater displacement per applied force and lower stability.
  - The spike in the flex constant was likely due to condensation on the abutment, which reduced friction and temporarily increased displacement over force before stabilizing.

Future Work

- Develop algorithms to convert flex constant measurements to angular stiffness, providing a consistent and reliable metric for implant stability assessment.
- Validate angular stiffness in clinical settings to indicate stability.

Implications

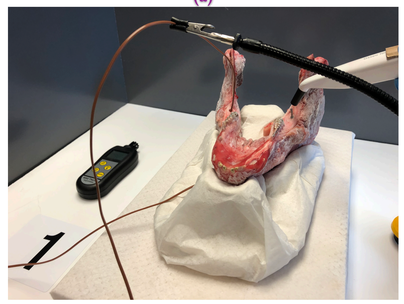
- Flex constant provides an alternative way to measure stability than ISQ.
- Flex constant is a physical quantity (displacement-force ratio), not an artificial index, to indicate implant stability.
- Flex constant can be converted to angular stiffness, which is independent of abutment geometry and height, to indicate stability.

Publications/Patents

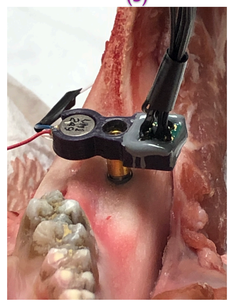
- Xu W, Chen Y, Nagatomo K, Liu Y, Zhou J, Dard M, Shen I. Development of an Angular Stiffness Sensor to Measure Dental Implant Stability In Vitro. Sensors, 2024; 24(21):6959. DOI: 10.3390/s24216959
- Xu W, Wood D, Liu Y, Shen I. A Vibratory, Subresonant Diagnostic Device to Measure Dental Implant Stability Via Angular Stiffness. J Med Devices, 2021; 15(3):031015. DOI: 10.1115/1.4051832
- Methods and Devices to Measure Angular Stiffness of Dental and Medical Implants. PCT/US2022/017795, February 2022.

(a)

(b)

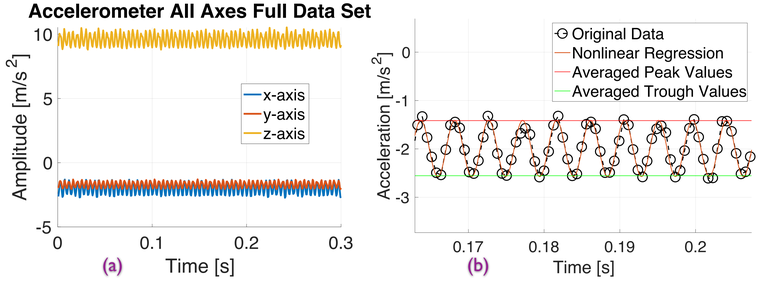


(c)



(d)

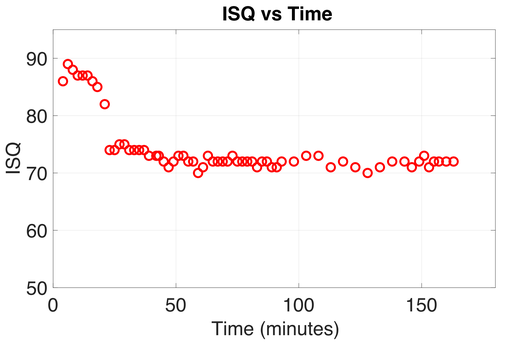
Experimental setup – (a) Porcine mandible model in the frozen state, (b) Close-up of the dental implant with a locator abutment in the frozen state, (c) ISQ measurement using the Penguin RFA device, and (d) Flex constant measurement using a sensor-motor coupler prototype.



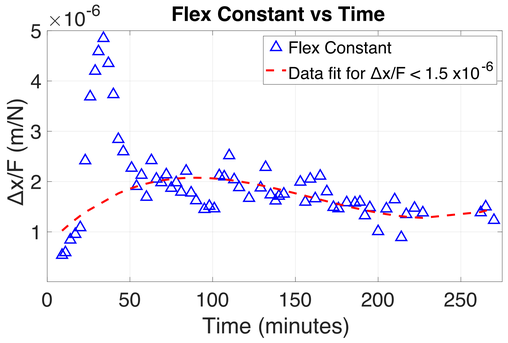
(a) Accelerometer Sensor Data for All Axes—Full Data Set; (b) Extraction of Frequency and Amplitude Using Non-Linear Regression of the Axes in the Buccolingual Direction

Conclusions

- Flex constant can adequately detect changes of implant stability.
- Flex constant is a physical quantity, not an artificial index. It offers a direct physical measurement of implant stability.



Implant Stability Quotient (ISQ) Measurements Over Time During Thawing of a Frozen Porcine Mandible



Flex Constant (Δx/F) Measurements Over Time During Thawing of a Frozen Porcine Mandible