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Technical note

Design, fabrication and characterization of a pure uniaxial microloading system for biologic testing

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ABSTRACT

The field of mechanobiology aims to understand the role the mechanical environment plays in directing cell and tissue development, function and disease. The empirical aspect of the field requires the development of accurate, reproducible and reliable loading platforms that can apply microprecision mechanical load. In this study we designed, fabricated and characterized a pure uniaxial loading platform capable of testing small synthetic and organic specimens along a horizontal axis. The major motivation for platform development was in stimulating bone cells seeded on elastomeric substrates and soft tissue loading. The biological uses required the development of culturing fixtures and environmental chamber. The device utilizes commercial microactuators, load cells and a rail/carriage block system. Following fabrication, acceptable performance was verified by suture tensile testing.

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1. Introduction

The body is continually in a state of loading. As such, cells at the microscopic scale reside in highly dynamic environments and are subjected to a variety of loading modes [1]. The loads are believed to be critical to cell development, function and survival. For example, cell differentiation, migration and signal transduction are influenced by mechanical loading [2,3]. Mechanical forces are particularly critical to bone cells, and it is known that mechanical forces at least in part, regulate bone remodeling [4–6]. Given that the mechanisms and pathways by which bone cells coordinate activity in response to normal loading have yet to be elucidated, research aimed at understanding the role of load in bone disease (eg, osteoporosis), overload and disuse must first focus on understanding the role physiologic loading plays in bone adaptation. *In vivo* these mechanisms can be difficult to test and observe. *In vitro* systems offer the opportunity to investigate these mechanisms and pathways of interest in an isolated, simplified environment [7,8].

To mechanically load cells in a biomimetically appropriate environment, specialized platforms are often fabricated in-house [3,5,9–16]. Commercial platforms can be cost prohibitive and customization is highly dependent upon user expertise [13–15]. Most commercial loading machines work off the principle of a fixed platform and one mover on a central axis. During testing, specimens are clamped in fixtures such that one end of the specimen is fixed to the stationary base of the platform and one end is attached to the mover. As such, tension/compression testing in a commercial machine is not pure, or equal and opposite. Since the exact mechanical loading patterns experienced by cells are difficult to replicate, creating the most uniform loading possible, such as in pure loading, is important. This will begin to allow us to correlate cellular activity to specific loading patterns. Ultimately, the goal would be to adequately simulate and verify complex *in vivo* loading scenarios. The goal of this study was to design, fabricate and characterize performance of a microactuated pure uniaxial loading platform for straining bone cells seeded on polydimethylsiloxane (PDMS). However, given that the platform was intended as a generic system, it could be used to test a variety of small specimens in pure tension/compression. As such, once fabricated device performance was initially characterized/validated with suture testing.

2. Methods

A pure uniaxial platform was designed. The device centered around 2 commercial microactuators, 2 commercial load cells and 1 rail/carriage block system. The microactuators (Zaber Technologies) were selected to provide the necessary resolution and smooth motion. To accommodate a variety of potential uses, 2 sets of microactuators were purchased with either a 30 mm (NA11B30) or 60 mm (NA11B60) travel range. Both models had a 67 N force capacity, 58 N peak thrust, 0.9302 µm/s speed resolution and either a 25 µm (NA11B30) or a 36 µm (NA11B60) unidirectional accuracy. The microactuators utilized a precision lead screw drive

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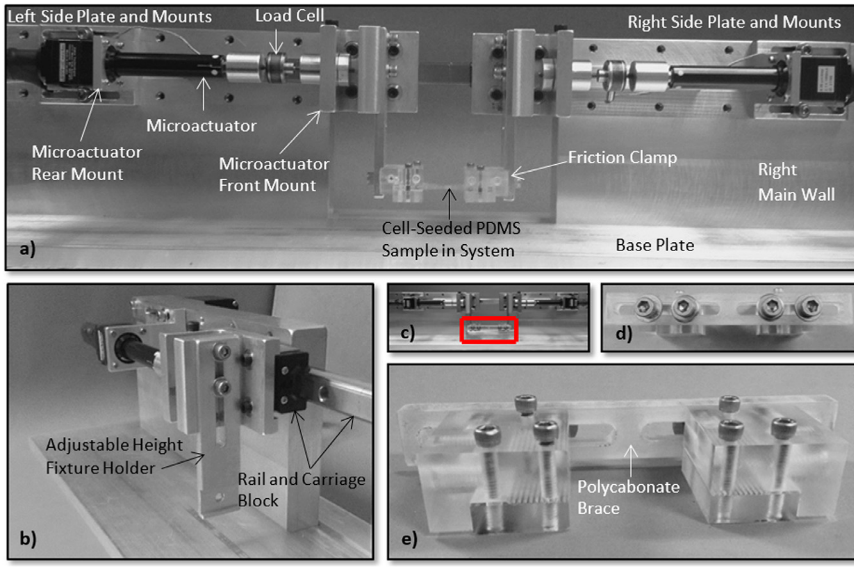

Fig. 1. (a) and (b) A pure uniaxial loading platform was designed around commercial components and fabricated from aluminum 6061-T6. (c)–(e) Friction clamps with polycarbonate brace to eliminate unintended loading effects during manipulation of the sample before experimentation.

mechanism, stepper motor and a 24 V controller (A-MCA, Zaber Technologies). Canister load cells (44.5 N, Honeywell, Sensotec) were selected for their small profile, robustness and user familiarity. The rail/carriage block system (9184T31, McMaster Carr) was selected as a convenient and cost effective way to ensure pure uniaxial loading on center. The maintenance-free system uses two ball bearing carriages that ride on a 15 mm wide track, has a 7800 N dynamic load capacity and is corrosion resistant (400 series stainless steel). The commercial components were purchased and the platform was designed to accommodate them.

The goal of the platform was to apply equal, uniaxial strains (linear displacement) to small-scale specimens in an accurate and reproducible manner. This included ensuring that pre-load was not applied during manipulation of the samples pre-testing. In addition the platform was designed to accommodate synthetic (fibers) and biological (tissues) materials. For the latter, an environmental chamber and fluid reservoir were fabricated. A horizontal loading approach was selected for easy submersion of the samples during testing given that a major focus of the device was cell stimulation research.

2.1. Device main wall

The dimensions of the commercial components dictated the design and scale of the platform. All fabricated components were machined from stock aluminum 6061-T6. The basic design consisted of a base plate and 2 side (left and right) plates, Fig. 1a and b. A track was machined into the base plate to accommodate the thickness of the side plates and maintain alignment, Fig. 2a–c. Clearance holes were drilled through the bottom of the base plate in the track to secure each side plate via holes that were drilled and tapped. A track was machined into the front face of each of the side plates to mount the rail of the commercial rail/carriage system. In addition, a series of drilled and tapped holes on the front face flanked the track to accommodate the actuator mount, Fig. 2b. These holes allowed for placement adjustability of the actuator mount and spanned the entire length of each side plate. This allowed objects ranging in gauge length from 1 mm to several centimeters to be tested on the same platform. The commercial rail was attached to the track using the mounting (clearance) holes in the rail and drilling and tapping holes in the side plate track. The rail was mounted stationary between the side plates. The 2 side plate approach in comparison to 1 large side plate was selected to provide clearance in the event that an overhead camera was required in future testing. The rail/carriage system was purchased as a unit and consisted of 1 rail and 2 carriages. Each carriage mounted one actuator to the rail.

2.2. Friction clamps and brace

Although the platform can be used for pure compression testing, it was designed for tensile loading of soft tissues, synthetic fibers and cell-seeded elastomers. To this end, serrated friction grips were fabricated for tensile testing specimens; compression platens were not fabricated. The serrated grips, Fig. 1c–e, consisted of a left and right fixture with each fixture made up of a top and bottom piece. The fixtures were machined from Plexiglas and the serrations were milled on the face using a double angle cutter (90°). Given that a major purpose of the platform is to subject small tissues and bone cells seeded on PDMS to precise strain, there was concern that the manipulation loads applied to the specimens in setting up the test could exceed those applied during the test. To avoid unintended pre-loads, a polycarbonate brace was developed to mount between the right and left fixtures. For cell work, the PDMS substrates were clamped in the fixtures and the cells were then seeded on the substrate. Stainless steel screws were used and 5 sets of the fixtures and braces were fabricated to accommodate preparation of multiple samples at the same time. Fixtures were able to be sterilized with alcohol and UV light before each use.

2.3. Actuator mounts

Each actuator used two mounts, a rear mount and a front mount. The stationary rear mount, previously described, connected the actuator body to the side plate via the track, Fig. 2. The front mount attached the tip of the actuator to the carriage block via connectors that accommodated the load cells, Fig. 3a–c. The front and rear mounts were machined from 6061-T6 aluminum 90° angle stock. To ensure reproducible alignment of the angle stock in the track (rear mount), a key was made on the underside of the mount by adding a rectangular plate to the base, Fig. 2e. The plate

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