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Technical note

A low-cost thermoelectrically cooled tissue clamp for *in vitro* cyclic loading and load-to-failure testing of muscles and tendons

Marc-Olivier Kiss [a,f], Nicola Hagemeister [a,b,d], Annie Levasseur [a], Julio Fernandes [a,f], Bertrand Lussier [e], Yvan Petit [a,c,*]

[a] *Imaging and Orthopedic Research Laboratory (LIO), Research Center, Hôpital du Sacré-Coeur de Montréal, Montreal, Canada*
[b] *Department of Automated Production, École de technologie supérieure, Montreal, Canada*
[c] *Department of Mechanical Engineering, École de technologie supérieure, Montreal, Canada*
[d] *Imaging and Orthopedic Research Laboratory (LIO), Research Center, Hôpital Notre-Dame, Montreal, Canada*
[e] *Faculty of Veterinary Medicine, Université de Montréal, St-Hyacinthe, Canada*
[f] *Faculty of Medicine, Université de Montréal, Montreal, Canada*

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ABSTRACT

In vitro cyclic loading and load-to-failure testing of muscles and tendons require a reliable linking device between tissues and the actuator that can transmit high loads without slippage or tissue damage. This article describes a simple custom-made thermoelectrically cooled freeze clamp. The effectiveness of the clamp to transmit loads without tissue slippage was evaluated on 10 canine quadriceps femoris myotendinous junctions in both load-to-failure and cyclic loading settings. Dynamic cyclic loading during an extensive period of time was successfully achieved. Loads up to 4.84 kN were applied in quasi-static conditions without evidence of clamp slippage or failure.

1. Introduction

During biomechanical load testing on cadaver specimens, linkage of an actuator to either muscle or tendon has always been a concern [1–6]. Slippage of tissues within linking devices tends to occur with increasing load as a result of low friction between the devices' material and the wet soft tissues [1]. To overcome this problem, many different techniques have been advocated such as using clamps (flat surfaced, serrated, self-tightening), sandpaper or other high friction surfaces, air-drying or glue on tendon ends. However, tissue slippage was still an issue and compressive forces resulted in transection of collagenous fibers and tendinous tears [1,6,7].

In 1982, Riemersa and Schamhardt described the 'cryo-jaw', a liquid carbon dioxide (CO_2) cooled clamp aimed at freezing tissues deformed by groove plates, preventing deformation of tissues submitted to very high loads. Since then, freeze clamps have been considered the gold standard for high load mechanical testing of soft tissues. Many authors used or described modified versions of the 'cryo-jaw' and proposed other cryofixation devices [2–5,8–11,15]. All of those devices require liquid CO_2, liquid nitrogen or dry ice. This gives rise to a certain complexity of setup as well as many manipulations during testing to prevent thawing of tissues, rendering those procedures cumbersome and impractical for long-term cyclic loading experiments.

More recently, a new type of freeze clamp relying on electrical power has been commercialized (ElectroForce Systems Group, Bose Corporation, Eden Prairie, MN). The gripping surfaces are cooled using thermoelectric devices (Peltier) to freeze the tissue. The tissues inserted between the jaws of the clamp conform to the grooves of the gripping surfaces. Once frozen in this conformation, the sample becomes mechanically rigid and stiff enough to prevent damage and slippage which may lead to unreliable results [12].

However, there is currently no published information available in the literature on the effectiveness of thermoelectrically cooled (TEC) tissue clamp to avoid tissue slippage. Therefore, the aim of the present study is to describe a low-cost and easy to build TEC tissue clamp and to present preliminary results on its potential to transmit loads without tissue slippage during cyclic loading as well as quasi-static load-to-failure testing.

2. Materials and methods

A custom-made freeze clamp was designed in this study by modifying a TEC VGA waterblock (MCW50-T, Swiftech, Lakewood, CA).

* Corresponding author at: Department of Mechanical Engineering, École de technologie supérieure, 1100, rue Notre-Dame Ouest, Montreal, Quebec, Canada H3C 1K3. Tel.: +1 514 396 8691; fax: +1 514 396 8530.
E-mail address: yvan.petit@etsmtl.ca (Y. Petit).

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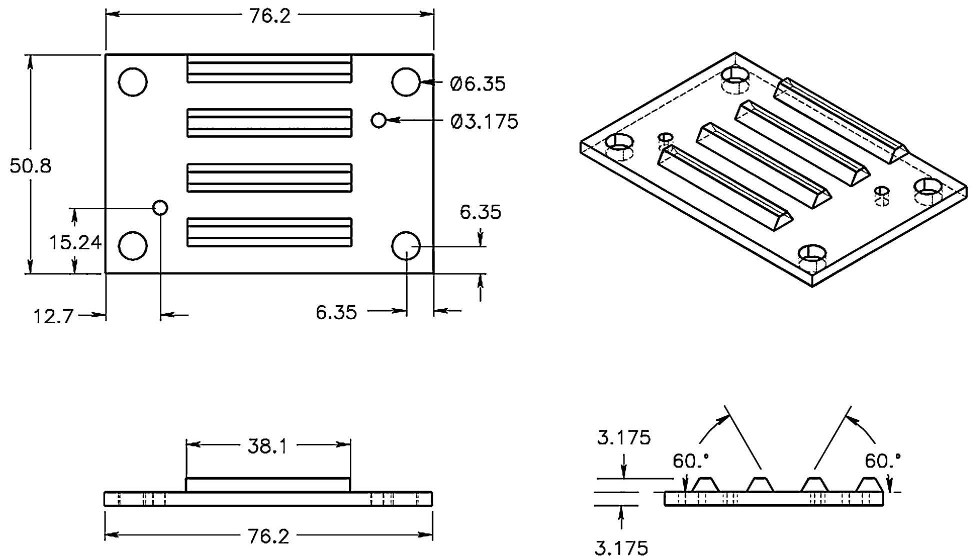

Fig. 1. Illustration of the custom-made aluminum indented plate. Apart from the two angles shown, all measurements are expressed in millimeters.

The waterblock is composed of a copper base plate, a thermoelectric module and a water reservoir. The thermoelectric module is a plate made of bismuth–telluride thermocouples that act as heat pumps when submitted to an electric current, which is known as the Peltier effect [13]. The heat is absorbed from the cold side of the module and released on the warm side. The temperature gradient obtained is constant for a given voltage and current. It increases as voltage and current are increased up to a maximal gradient, which is specific to the module used. The warm side of the thermoelectric module is directly submersed into the water flowing inside the waterblock which serves to optimize heat dissipation, allowing a subzero temperature on the cold side given the constant temperature gradient of the module.

In this device, the original copper base plate of the waterblock was replaced by a custom-made aluminum serrated plate (Fig. 1). This plate is grooved on one side and flat on the other side. Screw holes of the original copper plate were reproduced on this aluminum plate to allow it to be screwed to the water reservoir while keeping the original foam gasket for a watertight fit. Before assembly of the clamp, a thin film of thermal compound (Arctic Alumina^{TM}, Arctic Silver Inc., Visalia, CA) was applied on the thermoelectric module surface in contact with the aluminum plate. This is a ceramic-based compound that fills the microscopic gaps existing between the two surfaces and maximizes particle-to-particle contact area, thus assuring optimal thermal transfer. The clamp was then reassembled and completed by adding a second identical aluminum plate fixed upside down to the first one with four bolts and wing nuts (Fig. 2A). The water cooling system was composed of a small water tank, a submersible water pump (Supreme® Pondmaster® Mag-Drive^{TM}

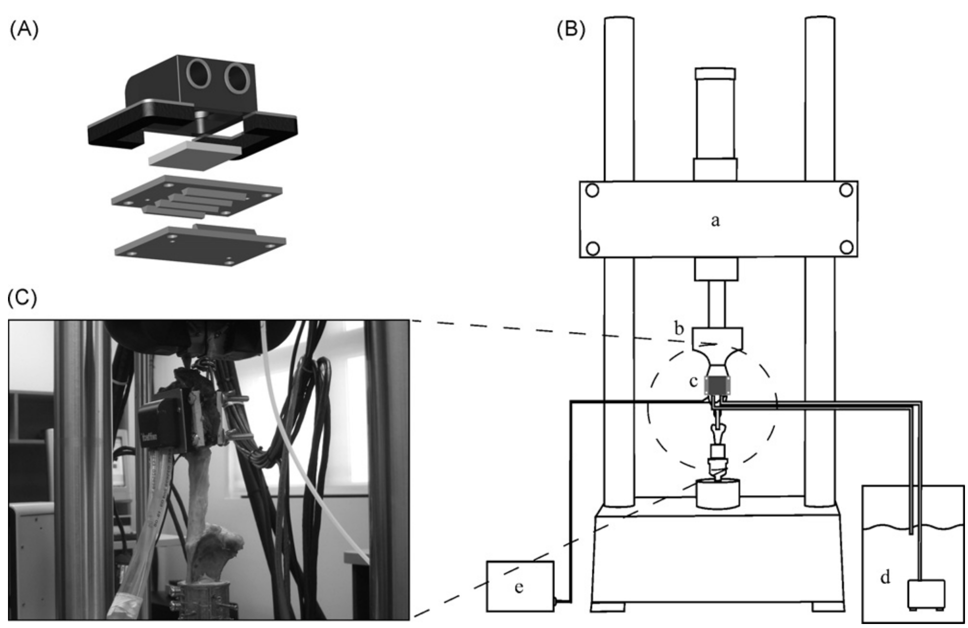

Fig. 2. (A) Exploded view of the custom-made freeze clamp. From top to bottom: water reservoir, isolating foam, thermoelectric module and aluminum serrated plates. (B) Illustration of the experimental setup: (a) servo-hydraulic testing machine, (b) pneumatic grip, (c) custom-made freeze clamp, (d) water tank and submersible pump and (e) power supply. (C) Picture of the experimental setup. The distal end of the quadriceps femoris is frozen within the clamp. The tibia is imbedded in a polyester resin inside a potting cylinder mounted on the servo-hydraulic testing machine.