ARTICLE IN PRESS

Journal of Biomechanics xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Journal of Biomechanics

journal homepage: www.elsevier.com/locate/jbiomech
www.JBiomech.com

# Muscle tension increases impact force but decreases energy absorption and pain during visco-elastic impacts to human thighs

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ARTICLE INFO

*Article history:*
Accepted 28 November 2017
Available online xxxx

*Keywords:*
Discomfort
Injury risk
Collision
Muscle activation

ABSTRACT

Despite uncertainty of its exact role, muscle tension has shown an ability to alter human biomechanical response and may have the ability to reduce impact injury severity. The aim of this study was to examine the effects of muscle tension on human impact response in terms of force and energy absorbed and the subjects' perceptions of pain. Seven male martial artists had a 3.9 kg medicine ball dropped vertically from seven different heights, 1.0–1.6 m in equal increments, onto their right thigh. Subjects were instructed to either relax or tense the quadriceps via knee extension (≥60% MVC) prior to each impact. F-scan pressure insoles sampling at 500 Hz recorded impact force and video was recorded at 1000 Hz to determine energy loss from the medicine ball during impact. Across all impacts force was 11% higher, energy absorption was 15% lower and time to peak force was 11% lower whilst perceived impact intensity was significantly lower when tensed. Whether muscle is tensed or not had a significant and meaningful effect on perceived discomfort. However, it did not relate to impact force between conditions and so tensing may alter localised injury risk during human on human type impacts.



## 1. Introduction

In sport, during crashes and accidental collisions if there is forewarning it is the norm to 'tense up' to receive an impact, and this is beneficial at the whole body level. Within sports with impacts players tense up both to deliver and receive impacts, and do so differently in varying conditions (Cazzola et al., 2015; Seminati et al., 2016), as well as specifically training and pre-activating muscle groups to reduce impulsive head loading (Eckner et al., 2014). Tensing muscle can reduce limb and torso acceleration and displacement (Muggenthaler et al., 2008), reduce whiplash (Bauer et al., 2001; Brolin et al., 2005), and reduce chest compression (Kemper et al. 2014). Research into the effects of muscle tension on injury risk has been primarily on thoracic stiffness during in vivo crash test studies. Early work found thoracic stiffness increases of 121 – 337% between tensed and relaxed human volunteers (Lobdell et al., 1973; Stalnaker et al., 1973; Patrick 1981; Backaitis and St. Laurent, 1986). However, Kent et al. (2003, 2006) suggested that muscle tension was an unnecessary consideration for crash injury analysis as it made a negligible difference in thoracic stiffness above the injury compression threshold for irreversible injury.

With the development of whole body models for crash test simulations, both finite element models and multibody models (e.g. THUMS, HUMOS, MADYMO), and the development of more biofidelic testing methods for personal protective equipment (Pain et al., 2008; Hrysomallis, 2009; Payne et al., 2016), the effects of muscle tension on impact response needs better quantification. Tensing muscle has been found to change the kinetics of impacts without altering the gross kinematics due to soft tissue intrasegmental motion. Increased muscle tension led to decreased intersegmental tissue movement, increased peak force, decreased time to peak force (Pain and Challis, 2001, 2002, 2004, 2006) and soft tissues were found to account for up to 70% of energy dissipated (Pain and Challis, 2002). Given the ubiquity of tensing musculature for an impact in sport it is surprising there is almost no literature examining effects of muscle tension on localised response to an impact, and whether, or how, it can reduce the risk of localised injuries.

Skeletal muscle contusions are one of the most common muscle injuries (Whiting and Zernicke, 2008; de Souza and Gottfried, 2013). In their review 'Muscle Injury: Review of experimental models' de Souza and Gottfried (2013) described the crush model and the more common, and ecologically valid, blunt non-

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https://doi.org/10.1016/j.jbiomech.2017.11.032
0021-9290/

Please cite this article in press as: Tsui, F., Pain, M.T.G. Muscle tension increases impact force but decreases energy absorption and pain during visco-elastic impacts to human thighs. J. Biomech. (2017), https://doi.org/10.1016/j.jbiomech.2017.11.032

penetrating impacts model, invariably performed on animals. Crisco et al. (1996) performed blunt impacts with a solid nylon impactor onto the gastrocnemius of rats whilst the muscle was tensed for one limb and relaxed for the other. They had hypothesised that impact severity and severity of contusion would be greater in the tensed state but found the peak force decreased and less energy was absorbed during the impact when the muscle was tensed. They ascribed this reversal of their hypothesis to the tensed muscle stopping the impact being dominated by the bone of the limb, with the stiffer muscle reducing the compression of the muscle tissue between the impactor and the bone.

Very few equivalent impactor studies on humans have been carried out even at lower relative impact energies. In the PhD of Hrysomallis (1996) impacts to the relaxed and tensed thigh of human volunteers were reported, but in a published paper of this work, Hrysomallis (2009), only the relaxed impact results were presented. Hrysomallis (1996, 2009) performed a series of drop tests onto the thighs of 18 volunteers using a steel 2.23 kg impactor from between 10 cm and 130 cm, with >90% of drops from 50 cm or less, giving energies up to 21 J. Some of the subjects withdrew after impacts from the higher heights, with more withdrawing after relaxed impacts than tensed impacts. Iwamoto et al. (2015) used a material testing indentor to examine the force deformation relationship of a single subject's upper arm, biceps side, in tensed and relaxed states. They found a marked change in the force displacement curves after 5 mm of depression, with the tensed condition reaching twice the force of the relaxed condition at ~ 13 mm. Muggenthaler et al. (2008) used a 0.93 kg aluminium impactor with impact energies up to 3.64 J to impact the biceps side of the upper arm in both relaxed and tensed conditions for seven subjects. They found slightly higher decelerations and much greater energy absorption in the relaxed condition, similar to Crisco et al. (1996). However, the use of metal impactors can severely limit the biofidelity of testing for human on human impacts as these are between two non-linear visco-elastic bodies (Pain et al. 2008; Tsui and Pain, 2012). The impact velocities and energies are often greatly reduced in metal impactor and anvil tests from those seen in human on human impacts and a more compliant impactor is therefore preferable (Milburn et al., 2001; Pain et al., 2008).

Despite uncertainty of its exact role, muscle tension has shown an ability to alter human biomechanical response and may have the ability to reduce impact injuries or injury severity. The aim of this study was to examine the effects of muscle tension on human impact response in terms of force and energy absorbed and if muscle tension influences the subject's perception of pain. A visco-elastic impactor was used, allowing impacts with greater energies than previously utilised and a more biofidelic human on human type impact. It is hypothesised that being tensed will reduce the severity of the impact as determined by mechanical and subjective measures.

## 2. Methods

Seven male martial artists (age 27 ± 8 yrs, height 1.76 ± 0.04 m, mass 83.2 ± 8.0 kg) provided informed consent to participate in this study in accordance with the protocol outlined by the Loughborough University Ethical Advisory Committee. Subjects were selected based on their familiarity with, and tolerance to, impacts to the legs, with each subject training for at least four hours per week in martial arts. This ensured that the impact intensity levels were not unfamiliar and that they would be able to distinguish between perceived intensities. Subject numbers were determined from a power analysis for an ANOVA to detect force changes, with a power of 0.8 and $p < .05$, based on the force results from Crisco et al. (1996) and kept to the minimum subject number needed for ethical reasons. The thigh was chosen as the impact area as it is a favoured target in full contact martial arts with good impacts resulting in the common injury of a dead leg (muscle contusion and numbness) (Bracker, 2012). A dead leg is also a common injury in other impact sports such as rugby (Micheli, 2010). The thigh is a relatively safe place to test given its large ratio of muscle to bone mass and that the major blood vessels and largest nerves are more posteriorly positioned in the thigh. Thus it is likely that discomfort will be due to muscle compression and if there was to be an unexpected injury it would likely only be a muscle contusion.

Each subject sat in an upright posture with their right thigh resting on the middle of a 0.5 m wide bench with the right foot planted flat on the ground. Bench height was adjusted until a resting knee angle of 90° was achieved. The left leg was positioned off the side of the bench, just posterior and inferior to the right leg, to provide an unencumbered view of the impacted thigh. After a short warm-up, consisting of sub-maximal isometric knee extensions, each athlete performed a single isometric maximum voluntary contraction (MVC) for knee extension against an ankle strap placed 2 cm proximal to the medial malleolus, and positioned perpendicular to tibial motion during knee extension/flexion. The strap connect via a steel cable to a bolt screwed into a Kistler 9281b force plate (Winterthur, Switzerland).

In each impact trial, a 3.9 kg medicine ball was dropped vertically from one of seven different heights, 1.0–1.6 m in increments of 0.1 m, onto the right thigh. Subjects were instructed to either relax (no muscle contraction) or tense the quadriceps via knee extension (≥60% MVC) prior to each impact. Muscle activation state was monitored via the force plate readings and visually in real time to check there was no contraction, and visually in the slow motion video between drops. Immediately post-impact, participants were asked to rate their level of discomfort ranging from 0 ('No Pain') to 10 ('Extreme Pain') on a Borg CR10 pain scale. In total each subject was exposed to no more than 20 impacts to obtain a good impact at each height, spread over two sessions with more than 2 days between sessions. This helped to reduce muscle fatigue and bias of their perceived discomfort due to the area becoming overly sensitized from repeated impacts. Drop heights were randomized, but care was taken to ensure that higher energy impacts were not administered in succession to allow for a period of recovery. Subjects were blinded both visually and aurally to the drop heights and the exact time of impact, and time between impacts was at least 120 s.

Two F-scan pressure insoles (Tekscan, Boston, MA) were wrapped around the quadriceps of the right thigh for each subject and secured with electrical tape. Sensors were orientated to maximize the measuring area but limit the overlap between sensors, and to prevent creasing or folding of the sensors (Fig. 1). In addi-

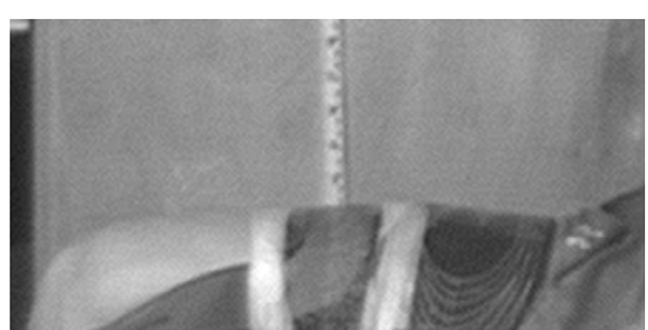

**Fig. 1.** Two F-scan sensors taped over the top and sides of the thigh to minimise overlap and to avoid creasing or folding.

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