Tissue Changes During Operational Load Bearing in UH-60 Aircrew Using Magnetic Resonance Imaging

Kenneth E. Games; Roger O. Kollock; Jerrod Windham; Gregory S. Fischer; JoEllen M. Sefton

INTRODUCTION: Warfighters involved in mounted operations often experience prolonged periods of tissue loading, leading to injury. Determining how anatomical structures are affected during loading aids in the prevention and treatment of injury. The purpose of this study was to develop a magnetic resonance imaging (MRI) compatible seat system that simulates a UH-60 Blackhawk in-flight sitting posture.

METHODS: Eight men were scanned with a 3.0 Tesla MRI. Scans were collected with and without 6.38 psi of pressure applied to the buttocks via two air bladders and an MRI-compatible robot controller system.

RESULTS: Scans revealed that 6.38 psi of pressure applied to the buttocks significantly decreases total soft-tissue thickness beneath the left and right ischial tuberosities by 3.6 and 3.8 mm, respectively.

DISCUSSION: At operational load bearing pressures seen in the UH-60, the soft tissue structures of the buttocks are compressed. These findings aid in our understanding of the etiology of repetitive trauma disorders in aircrew due to prolonged sitting. This study serves as the foundation for future work examining the anatomical changes associated with prolonged restricted sitting and other operational activities. A better understanding of the anatomical characteristics associated with mounted operations is invaluable to the prevention and treatment of injuries reported by warfighters and civilian populations.

KEYWORDS: military, load-bearing stress, musculoskeletal injury, extended combat endurance, low back pain in aviators.

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Mounted warfighters, specifically UH-60 Black Hawk helicopter aviators, are often engaged in missions lasting 6-12 h.[12] The Black Hawk helicopter originally had a maximum flight duration of 2.3 h; however, advances in technology and mission demands have increased flight duration. This has led to increased pilot reports of seat discomfort and temporary lower extremity paresthesia, which have also been noted in drivers of other military and nonmilitary vehicles. Estimates indicate 82% of rotary-wing aviators experience discomfort and 20% report pain, numbness, or tingling in the buttocks and lower extremity during prolonged flights.[10,11] These symptoms are known to impair mission performance.[1,9]

Previous works using subjective discomfort scales[1,5,8] and seat interface pressure mapping devices[5,7,8] found that prolonged restricted sitting in aircraft results in discomfort and high peak pressures at the buttocks and posterior thigh.[1,5] Theory suggests localized pressure on the buttocks and thigh compresses the nervous and vascular tissue, resulting in discomfort, altered sensory function, and paresthesia. Research studies examining pressure distribution[5,7] and physiological data support this hypothesis.[4]

The use of magnetic resonance imaging (MRI) enables accurate measurement of soft tissue structures,[6] which may provide information on the effects of local pressure application on anatomical structures and physiological function during prolonged restricted sitting. Current constraints (e.g., seat material, bore size) of MRI scanners make the evaluation of a helicopter seat

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system impractical. However, large bore scanners (≥70 cm) provide opportunities to develop a MRI compatible seat system that enables simulation of prolonged sitting situations. Additionally, compression under load-bearing conditions can compromise both neurological and vascular structures, which result in both acute and chronic pain. Not only will this pain likely impact the career lifetime of the aviator, but it may also immediately impact flight safety. Therefore, the purpose of this proof-of-concept project was to determine the effect of operational load bearing on soft tissue thickness under the ischia in an occupationally relevant (seated) position.

METHODS

This study used a repeated measures crossover design. The independent variable was pressure condition with 2 levels (pressure on, pressure off). The dependent variable was total soft tissue thickness over the right and left ischial tuberosities. The study protocol was approved in advance by the U.S. Army Medical Research and Materiel Command and the Auburn University's Institutional Review Boards. Each subject provided written informed consent before participating.

Subjects

Eight healthy male volunteers (age = 24.1 ± 2.8 yr, height = 176.2 ± 7.4 cm, mass = 76.6 ± 8.6 kg) completed the study. Subjects were civilian volunteers with no formal flight training. They met U.S. Army flight status minimal/maximal body segments measurements and minimum/maximum weights. Subjects self-reported no history of cardiovascular, neurological, or metabolic disease; no current or 2-yr history of surgery or fracture in the lumbar spine or lower extremities; no current history of low back pain, lower extremity injury, or use of prescription/nonprescription pain relievers. Subjects with claustrophobia or metal implants were excluded.

Procedure

Participants reported to the MRI Research Center one time and were positioned in a 3.0-tesla MRI scanner (Magnetom Verio, Siemens Medical Systems Inc., Malvern, PA) in a custom-built MRI-compatible seat system. The wooden seat and positioning apparatus was designed to position participants at 105° of hip flexion and 90° of knee flexion. These joint angles were selected based on the geometry of the UH-60 seat. The "sandwich" design of the seat pan placed two polypropylene rubber rectangular air bladders (Universal Inflatable Lumbar Air Bladder, Sports Imports LLC, Rockville, MD) between a nonmovable base and a movable sitting surface, providing seat pressure mimicking pressures encountered by pilots during flight (**Fig. 1**). The bladder design, in addition to the seat position, resulted in pressure application to the ischial tuberosities and the proximal third of the posterior thigh. The bladders were inflated/deflated with air using a custom-built, MRI-compatible pneumatic modular robot. Fiber optic cables connected the robot to the control computer outside the scan room. Custom software inflated/deflated the air bladders to 6.38 psi of pressure. This pressure level was based on previous research examining the effects of local pressure application at the ischial tuberosity/posterior thigh.[3] The software received feedback and adjusted bladder pressure to maintain a constant level of pressure throughout testing.

Participants were secured with four, 2″ nylon straps: one across the chest, one at the anterior superior iliac spine, one across the proximal upper leg, and one across the distal upper leg to prevent movement during pressure application. The MRI bed was moved out of the bore and the participant/seat system was slid into the center of the scanner bore on the MRI rail. Pilot scans with MRI test phantoms determined optimal participant location for testing. Foam pads were placed under the participant's feet to position the knees at the in-flight angle and support the lower legs during testing. Nonpressure control scans and with-pressure test scans were completed. The 6.38 psi pressure was equalized for 60 s prior to scanning.

Magnetization-prepared rapid acquisition with gradient echo MRI images of the pelvis and proximal upper legs were obtained during both the pressure off control and pressure on intervention conditions. A medium flex radio frequency coil was placed under the seat pan for maximal signal strength. Total scan time for each condition ranged from 4-8 min.

The thickness of the soft tissue between the ischial tuberosity and the surface of the skin was measured from the MRI images using Slicer 4 Software (www.slicer.org, Cambridge, MA).[2] Two trained investigators independently measured the distance (in millimeters) from the lowest point of both the left and the right ischial tuberosities to the surface of the skin using the sagittal view on the Digital Imaging and Communications in Medicine images (**Fig. 2**).

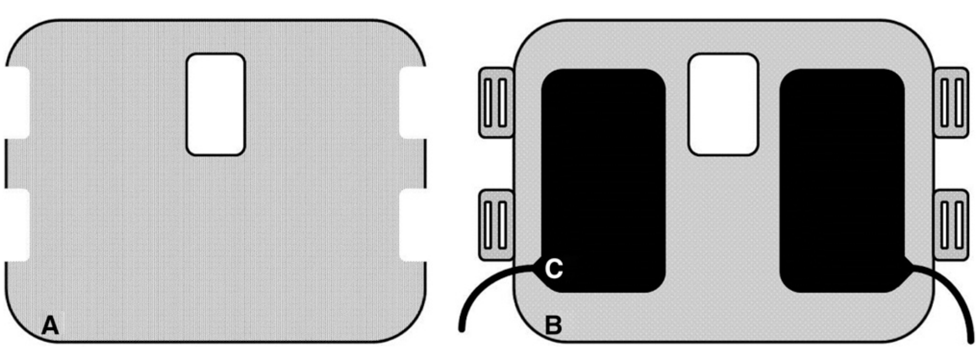

Fig. 1. Illustration of the components used in the sandwich design seat pan which allowed for pressure application during testing. A) Sitting surface (constructed of wood); B) nonmovable base with locations for strapping (constructed of medium density fiberboard); C) air bladders used to provide pressure connected to a MRI-compatible pneumatic modular robot controller (not shown).

Statistical Analysis

Data were analyzed using statistical software (SPSS version 19, SPSS Inc., Chicago, IL). The interrater reliability between

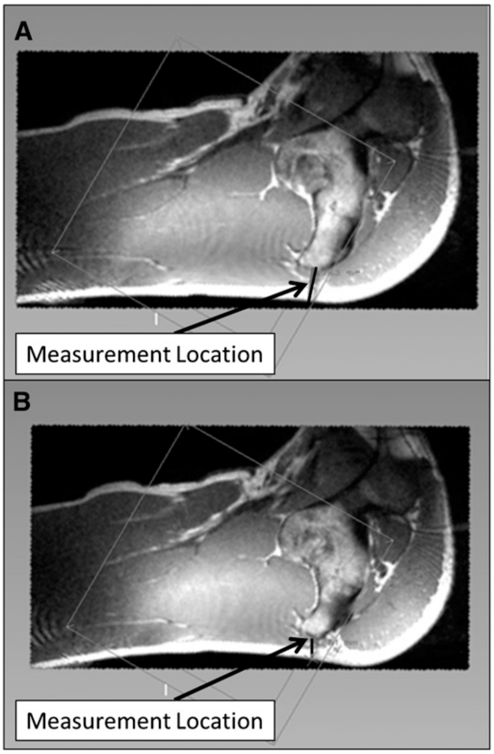

Fig. 2. Examples of Slicer 4.0 images used to collect tissue thicknesses. A) Left ischial tuberosity, pressure off condition (mean 35.1 mm); B) left ischial tuberosity, pressure on condition (mean 31.5 mm).

investigators was evaluated using the intraclass correlation coefficient ($ICC_{3,1}$) and standard error of measure (SEM). Four paired-sample *t*-tests assessed the change in soft tissue thickness under the left and right ischial tuberosity. Two dependent *t*-tests were completed for each reviewer. Significance levels for all analyses were set a priori at $\alpha \leq 0.05$.

RESULTS

Means, SDs, and 95% confidence intervals for each test location and condition are presented in **Table I**. The interrater $ICC_{3,1}$ ranged from 0.91 to 0.99 with a SEM between 0.91 and 2.63 mm (**Table II**). Soft-tissue thickness under the ischial tuberosity significantly decreased during the pressure on condition for both reviewers. Reviewer one reported thickness decreases under the left [3.6 ± 2.3 mm; $t(7) = 4.33$; $P = 0.003$] and right [3.8 ± 1.7 mm; $t(7) = 6.06$; $P = 0.001$] sides. Reviewer two reported significant decreases under both the left [3.7 ± 2.2 mm; $t(7) = 4.75$; $P = 0.002$] and right [2.2 ± 1.2 mm; $t(7) = 4.99$; $P = 0.002$] ischial tuberosities.

DISCUSSION

Our findings indicate that a custom-built MRI-compatible seat apparatus enabled the assessment of the effects of operational prolonged restricted seating in a 3.0-tesla MRI scanner. The MRI scans revealed that soft-tissue thickness under the ischial tuberosity significantly decreased bilaterally with the addition of pressure. Clinically, this suggests the soft tissues of the sitting surfaces are compressed in the helicopter seat system. This pilot investigation was the first to objectively quantify the changes in soft tissue thickness during a simulated operational scenario using high-field MRI.

The transient soft tissue changes found in the present investigation have implications for the immediate and career health of aviators. Anatomical compression of the structures of the posterior thigh have physiological and functional consequences, including decreased blood flow, increased pain, and impaired neurological function.[3,4,7] When left unaddressed, these physiological changes can impact the career longevity of aviators and decrease mission safety through decreased situational awareness. Understanding these anatomical and physiological changes is the first step in protecting the short-term and long-term health of aviators and improving mission safety.

We demonstrated an MRI-compatible device that does not interfere with MRI function and is capable of applying variable, programmable pressure to the sitting surfaces of the body that accommodates the required range of UH-60 Black Hawk aviator body sizes. This study serves as the foundation for future work examining the anatomical changes associated with both civilian and military operational requirements. A better understanding of the anatomical characteristics associated with mounted operations is invaluable to the prevention and treatment of injuries reported by warfighters and civilian populations (e.g., heavy equipment operators).

Although the procedures in the present study provided information on anatomical changes associated with pressure application to the soft tissue of the buttocks and posterior thigh, future MRI investigations using advanced scan sequences designed to image neural and vascular structures specifically are needed to provide insight into the effects of pressure application on tissues of the lower extremities. Future research should also seek to develop advanced MRI-compatible seat

Table I. Means, SD, and 95% Confidence Intervals for Raters 1 and 2.

	MEAN (mm)		SD (mm)		MD (mm)		95% CI FOR MD (mm)	
BUTTOCK CONDITION	**R1**	**R2**	**R1**	**R2**	**R1**	**R2**	**R1**	**R2**
Left pressure off	36.8	33.5	8.5	8	3.6	3.7	1.6–5.5	1.8–5.5
Left pressure on	33.2	29.8	9	9.1				
Right pressure off	35.6	33.1	9.3	8.7	3.8	2.2	2.3–5.3	1.2–3.3
Right pressure on	31.8	30.8	9.1	8.8				

R1 = rater 1; R2 = rater 2; SD = standard deviation; MD = mean difference; CI = confidence interval; mm = millimeters.

Table II. MRI 3-D Slicer Interrater Reliability.

MEASURE	$ICC_{3,1}$	SEM (mm)
Pressure off, left ischial tuberosity	0.91	2.53
Pressure off, right ischial tuberosity	0.96	1.85
Pressure on, left ischial tuberosity	0.91	2.63
Pressure on, right ischial tuberosity	0.99	0.91

SEM = standard error of measure; ICC = intraclass correlation coefficient; mm = millimeters.

systems to allow for examination of tissue structures at different seating angles. The ability of this seat apparatus to provide multiple pressure conditions in a programmable order allows for imaging of vehicle specific vibration and shock patterns. Applying vibration and shock profiles that match ride profiles provides researchers the unique ability to emulate the forces experienced by individuals under operational conditions. Additionally, future work could build from the current work through investigation of blood perfusion in the compressed tissue through the use of real-time positron emission topography scanning or advanced MRI scanning techniques.

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