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Original research

Normative MRI, ultrasound and muscle functional MRI findings in the forearms of asymptomatic elite rowers

Michael K. Drew[a,b,c,*], Larissa Trease[d], J.P. Caneiro[e], Ivan Hooper[a], Chin-Chin Ooi[f,g], Peter Counsel[h], David A. Connell[h,i], Anthony A. Rice[j], Emma Knight[k], Gregory Hoy[l], Gregory Lovell[m]

[a] Department of Physical Therapies, Australian Institute of Sport, Australia
[b] Department of Physiotherapy, Faculty of Health, University of Canberra, Australia
[c] Australian Centre for Research into Injury in Sport and its Prevention (ACRISP), Federation University, Australia
[d] Department of Sports Medicine, Rowing Australia, Australia
[e] Department of Physiotherapy, Curtin University, Australia
[f] Department of Diagnostic Radiology, Singapore General Hospital, Singapore
[g] Department of Diagnostic Radiology, Monash University, Australia
[h] Imaging at Olympic Park, Australia
[i] Department of Medicine, Nursing and Healthcare, Monash University, Australia
[j] Department of Physiology, Australian Institute of Sport, Australia
[k] Department of Performance Research, Australian Institute of Sport, Australia
[l] Melbourne Orthopaedic Group, Australia
[m] Department of Sports Medicine, Australian Institute of Sport, Australia

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ABSTRACT

Objectives: Forearm injuries are common and debilitating to elite rowers. Chronic exertional compartment syndrome, intersection syndrome and proximal radial bone stress injuries have been documented in this population. This paper explores the imaging findings related to these conditions in asymptomatic elite rowers.
Design: Observational study.
Methods: 19 asymptomatic senior elite and under-23 rowers currently competing at National level or above underwent ultrasound (US), Magnetic Resonance Imaging (MRI) and muscle functional MRI evaluation of their forearms. A comprehensive evaluation sheet identifying characteristics of bone stress, intersection syndrome and chronic exertional compartment syndrome was utilised based on a literature search and review by senior clinicians working with this population.
Results: Peritendinous fluid of Extensor Carpi Radialis Longus ($n = 10$, 53%) or Extensor Carpi Radialis Brevis ($n = 6$, 32%) was a common finding on US. MRI had a higher rate of identification than US. Extensor Digitorum (Coeff = −1.76, 95%CI −3.04 to −0.49), Flexor Carpi Radialis (Coeff = −2.86, 95%CI −5.35 to −0.38) and Flexor Carpi Ulnaris (Coeff = −3.31, 95%CI −5.30 to −1.32), Pronator Teres (Coeff = −3.94, 95%CI −6.89 to −0.99), and Supinator (Coeff = −168, 95%CI −3.28 to −0.02) showed statistically significant changes immediately post-exercise. Mild proximal radial marrow hyperintensity was present ($n = 15$, 78.9%) with three participants (15.8%) also having mild periosteal oedema of the radius.
Conclusions: Imaging findings commonly seen in symptomatic populations are observed in elite, asymptomatic rowers. Care should be taken when diagnosing bone stress injuries, intersection syndrome and compartment syndrome on imaging findings alone. Data presented can be utilised as a normative dataset for future case studies.
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1. Introduction

Forearm injuries in international rowers are associated with high loss of training days.[1] Of these, intersection syndrome, chronic exertional compartment syndrome (CECS), and proximal radius stress reaction have been recorded in an Australian population.[1]

* Corresponding author at: Corresponding author.
E-mail addresses: Michael.drew@ausport.gov.au, michaelkdrew@gmail.com (M.K. Drew).

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A record of normative imaging findings in this population currently does not exist and imaging studies of forearm injuries in this population are devoid of control groups.[2–4] Therefore establishing normative imaging results in this population is imperative to allow for better comparisons and eventually improved diagnostic procedures and statistics in this population. This may assist clinicians to understand the pathogenesis of the three conditions.

Intersection syndrome (IS) is described as a non-infectious inflammatory condition localised to the area at the intersection of the first and second dorsal extensor compartments. Typical signs and symptoms consist of tenderness on palpation, pain on wrist movements (particularly extension), local swelling, erythema and crepitus with flexion and extension of the wrist.[2–5] The aetiology of this condition is still under debate. A recent ultrasound study has found peritendinous oedema and small amounts of synovial fluid within the tendon sheaths at the point of intersection, thickened tendons and hyperechoic nodules within the fluid related to proliferation of the synovial membrane.[3] This indicates tendinopathic processes. In a case-series (Level IV evidence), compartmental tearing between the first and second dorsal comparts has been shown surgically with authors proposing early surgical management.[6] It is therefore plausible that intersection syndrome may be two separate pathologies that can also be coexistent; tendinopathic changes and inter-compartmental tearing. If these changes can be imaged it could streamline care to either surgical or conservative management. It is currently unknown whether MRI and/or ultrasound can assess the integrity of the compartmental fascia at the intersection and whether tearing is present in asymptomatic, elite rowing populations.

Chronic exertional compartment syndrome is a state of intermittent and reversible elevation of intra-compartmental pressure related to exertion. It has been documented in athletes of motorcycle racing,[7,8] weight lifting[9] and kayaking[10] and is under-reported in the rowing literature[11] when compared to recent Australian data.[12,13] The diagnostic value of MRI scans in chronic exertional compartment syndrome of the lower leg has been shown to be of high value.[14,15] However, diagnosing CECS in rowers presents a unique challenge due to the nature of it being a water-based sport. The ergometer is a viable alternative to use in the replacement of on-water rowing however, it neglects the "feathering" action (rotation of the oar to change the angle of the blade) and repetitive gripping tasks (such as rope winding exercises) may over accentuate the feathering action. Muscle functional MRI (mfMRI) studies have been used recently to determine the level to which a muscle is involved in a functional task.[16]

The purpose of this study was to: (i) establish US imaging results in asymptomatic elite rowers; (ii) establish MRI findings in asymptomatic elite rowers (iii) establish muscle functional MRI changes following a set stationary ergo workload and (iv) to assess the relationship that level of competition and gender has on the imaging findings.

2. Methods

Elite asymptomatic rowers ($n = 20$) competing in senior ($n = 7$, male: female 4:3) and under-23 levels ($n = 13$, male: female, 7:6) were recruited through the Victorian Institute of Sport during the domestic season of competition (January, 2013). Inclusion and exclusion criteria are presented in Table 1. This study was approved by the Australian Institute of Sport Ethics Committee and was performed following the Declaration of Helsinki. All patients provided written informed consent.

All participants underwent a standard radiological examination procedure. The study design is shown in Supplementary Fig. 1. All images were taken on the inside arm of sweep rowers (ipsilateral side to the oar) and the dominant arm of scullers.

Table 1
Inclusion and exclusion criteria.

Inclusion criteria	Exclusion criteria
Currently competing at National level Full training without restrictions or limitations Able to complete the ergometer test >18 years of age	Current injury or illness anywhere in the body Previous history of injury to the forearm or wrist region Previous symptoms in the wrist such as tightness and/or pain that required medical or physiotherapy treatment or prevented training Contra-indication to MRI or standard safety procedures in accordance with standard radiology policies

All participants underwent a standard ultrasound procedure to evaluate the intersection region. The standard assessment incorporated results from a literature search and the clinical experience of the authors with backgrounds in sports medicine, radiology, surgery and sonography (LT, GH, GL, OC, and DC). All ultrasound examinations were performed using a Philips iU22 (Philips Healthcare, Bothell, WA) that was equipped with a 17.5 MHz high resolution linear transducer. A single sonographer (OC), with greater than 10 years of experience in musculoskeletal ultrasound, performed the scans. Patients were seated facing the sonographer, with their forearm rested comfortably on the examination couch, elbow in mid-flexion and the wrist in pronation. A pre-programed scanning technical protocol (with optimised scanning parameters such as depth, frequency, focal zone and colour Doppler setting for perfusion) was used to ensure consistency of results obtained. Multiple transverse and longitudinal scans were acquired at the dorsal aspect of the distal forearm and wrist, with particular attention paid to the point of the intersection region. The anterior-posterior (AP) thickness and cross-sectional area (CSA) of the tendons in the first and second compartments were measured. The presence of tendinopathic signs (subcutaneous oedema, peritendinous fluid, fluid between the first and second extensor compartments, breaching or tearing of the synovia, hypervascularity of tendons, compartment thickness at the intersection and tendon hypoechogeneity) were observed and documented. In addition, dynamic real-time scanning with flexion–extension of the patient's wrist was performed and mobility of the tendons at the level of intersection was evaluated for presence of staccato tendon movement.

All MRI scans were taken in a single Philips Ingenia 3T scanner (Philips, Veenpluis, Best, Netherlands) using a 32 channel phased array body coil (Invivo, Gainesville, FL, USA) with their arm extended in a true anatomical position. The scans were obtained from the wrist to the elbow in the axial plan at the pre-exercise, immediate post-exercise and delayed post-exercise time points. The scan parameters were as follows. Pre-exercise axial PD spin fast spin echo technique (40 slices at TR 3400 ms, TE 30 ms, 12.0 cm × 12.0 cm Field of View (FOV), 512 × 512 matrix, 3.0 mm slice thickness, 7 to 9 mm gap, ETL of 14 and 1 NSA) extending from the distal radioulnar joint to the proximal. Pre-exercise T2 SPAIR (fat sat) axial fast spin echo technique was the same 40 slices with a constant FOV, slice thickness and slice gap. The matrix size was 432 × 432 and using a TR of 8500 ms, TE 50 ms, ETL of 14 and 2 NSA. The immediate post-exercise and delayed scans used the same parameters as the pre-exercise T2 Axial SPAIR.

Muscle functional MRI (mfMRI) techniques were utilised to evaluate the effect of ergometer rowing on the forearm muscles. The participants rested for 30 min prior to the mfMRI. This occurred simultaneously with the ultrasound evaluation. The ergometer protocol consisted of a standardised warm up of 3 min at a self-selected rate and wattage; following this the participant completed

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