Journal of Orthopaedic Translation (2016) 6, 1—9

Available online at www.sciencedirect.com

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journal homepage: http://ees.elsevier.com/jot

ORIGINAL ARTICLE

In vivo magnetic resonance imaging features of spinal muscles in the ovine model

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Received 19 December 2014; received in revised form 28 August 2015; accepted 10 September 2015
Available online 23 October 2015

KEYWORDS
animal models;
lumbar spine;
magnetic resonance imaging;
muscle fatty infiltration;
ovine

Summary *Background:* Muscle fatty infiltration (MFI) has been identified in patients with spinal pain using magnetic resonance imaging (MRI). Even though sheep are a commonly used animal model for the human spine, comparative sheep MFI data from MRI is not available. Determining MFI in sheep spinal muscles using acquisition protocols commonly used in man will identify the applicability of this approach in future sheep model studies, such that the effects of spinal interventions on muscle can be assessed prior to their use in a human (clinical) population.
Objective: To quantify ovine lumbar spine MFI using three-dimensional two-point Dixon and T1-weighted sequences.
Methods: T1-weighted and Dixon lumbar spine axial sequences were collected in 14 healthy Austrian mountain sheep using a 1.5-T MRI. At each vertebrae, the region of interest of psoas major and minor (PS), multifidus (M), and longissimus (L) were identified. To determine MFI from the T1-weighted images, the mean pixel intensity (MPI) was calculated as a percentage of subcutaneous or intermuscular fat. For the Dixon images, fat sequence MPI was calculated as a percentage of the summed fat and water sequence MPIs. Spinal degeneration was graded and correlated to MFI. Dixon MFI was compared to T1-weighted MFI obtained from subcutaneous and intermuscular fat.
Results: For every muscle, T1-weighted MFI calculated using subcutaneous fat scored significantly lower than Dixon MFI and T1-weighted MFI calculated using intermuscular fat ($p < 0.001$). There were no significant MFI differences between T1-weighted images calculated using intermuscular fat and Dixon images for M and L ($p > 0.05$), although significant differences were found for PS.
Conclusion: In sheep, Dixon sequences provide an acceptable comparison to T1-weighted sequences for lumbar extensor MFI based on intermuscular fat. However, compared to the human

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http://dx.doi.org/10.1016/j.jot.2015.09.004

literature, ovine lumbar musculature contains greater MFI, making interspecies comparisons more complex.

Introduction

Magnetic resonance imaging (MRI) is considered the imaging gold standard for quantifying muscle fatty infiltrate (MFI) [1]. Muscle composition has often been evaluated in patients with low back pain [2—6] and neck pain [7—11], as an increase in MFI in spinal muscles can been seen in these patients. Although T1-weighted images have been found reliable for MFI quantification in healthy females without neck pain [12], there are several more rapid imaging sequences that can be used to quantify [13] and correlate MFI with histology [1,14,15]. Sequences such as the Dixon method, where MFI data are collected when water and fat are in- and opposed-phase, have been used in healthy controls [16] and in patients with low back pain [17]. It has also been shown to be comparable to MFI obtained from T1-weighted imaging in the cervical multifidus in healthy adults [16].

The ovine is frequently used as an animal model for the investigation of spinal disorders and surgical interventions because of similarities in the *Homo sapiens* skeletal anatomy [18,19]. *In vivo* ovine studies investigating spinal implants are primarily performed to collect *in vitro* data on implant stability after the implant has been *in situ*, although other relevant *in vivo* data are not available [20]. Owing to the importance of the muscular system in spinal health [21,22], obtaining *in vivo* muscle parameters from animal models would be important to determine the validity of translational research between ovine and man. Although the amount of intramuscular fat in the ovine longissimus dorsi muscle has been published previously [23], these data were obtained at slaughter. To our knowledge, MFI in ovine spinal musculature has not been reported or compared to MRI quantification methods used in humans. Therefore, the aim of this study was to quantify and compare MFI in the ovine lumbar spine musculature using a T1-weighted and three-dimensional two-point Dixon sequence, as these sequences are commonly used to quantify muscle fat in humans. Additionally, two locations for fat calculation from the T1-weighted sequences were evaluated, as both methods have been used in previously published research [12,24].

Materials and methods

Study population

Seventeen healthy male and female Austrian mountain sheep were included in the study. A range of young and older sheep were included in order to identify the effect of age on MFI. The female sheep underwent an ultrasound investigation to exclude pregnancy. All sheep were assessed by an experienced orthopaedic veterinarian and were deemed medically fit to undergo anaesthesia for the imaging procedure of computed tomography (CT) and MRI. Ethical approval was obtained from the Austrian Federal Ministry of Science and Research (13/10/97/2011), and the guidelines for animal care and use were followed.

Data collection

Latero-lateral radiographs (Computed Radiography, Imaging plate Fuji) of the thoracic and lumbar spine were obtained (70 kV, 2.1 mAs; Super 100 CP; Philips, Eindhoven, The Netherlands) in unsedated sheep to identify the presence of any spinal pathology.

Prior to MRI, CT (Siemens Somatom Emotion 16; Siemens, Erlangen, Germany) was performed to ensure that the sheep did not have any metal in their bodies (i.e., ingested foreign objects) that could move when introduced to the magnetic field environment. The sheep were anaesthetised and placed in dorsal recumbency for CT and MRI data collection. Premedication for anaesthesia consisted of intravenous butorphanol (0.1 mg/kg) and xylazine (0.15 mg/kg). After obvious sedation was achieved, general anaesthesia was induced with ketamine (5 mg/mL) and maintained with inhalation of vaporised sevoflurane. For CT, dorsoventral images (80 kV, 25 mA, tilt 0.0, inversion time (TI) 10.6 seconds, slice thickness 0.6 mm, Display Field of View (DFOV) 153.3 cm × 153.3 cm) were obtained to determine the number of lumbar vertebrae and identify any potential foreign objects, and transverse images (130 kV, 200 mA, tilt 0.0 m TI 1.0 seconds, slice thickness 1.2 mm, DFOV 25.0 cm × 25.0 cm) were obtained to assess the presence of spinal pathology. For MRI data collection, lumbar spine T1-weighted and Dixon sequences were collected using a 1.5-T MRI (Siemens Magnetom Esprit; Siemens). T1-weighted images were obtained using a 4-mm slice thickness, 2-mm gap space, DFOV 450 mm × 450 mm, repetition time (TR) 448 ms, and echo time (TE) 11 ms. Dixon images were obtained using a 1.5-mm slice thickness, 1—5 mm gap space, DFOV 450 × 450 mm, TR 7.2 ms, TE 2.4 ms (oppose-phase), and TE 4.8 (in-phase). Axial images of the entire lumbar spine were obtained in up to three acquisitions. Attempts were made to obtain the entire lumbar spine in one acquisition, but in some sheep this was not possible owing to a risk of temperature increase because of a proportionally large fluid-filled rumen. In these cases, the lumbar spine was imaged in either two acquisitions (cranial and caudal lumbar spine) or in three acquisitions (cranial, middle, and caudal lumbar spine). A ventral to dorsal phase direction was used, and where this