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Arthroscopic optical coherence tomography provides detailed information on articular cartilage lesions in horses

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ABSTRACT

Arthroscopy enables direct inspection of the articular surface, but provides no information on deeper cartilage layers. Optical coherence tomography (OCT), based on measurement of reflection and backscattering of light, is a diagnostic technique used in cardiovascular surgery and ophthalmology. It provides cross-sectional images at resolutions comparable to that of low-power microscopy. The aim of this study was to determine if OCT is feasible for advanced clinical assessment of lesions in equine articular cartilage during diagnostic arthroscopy.

Diagnostic arthroscopy of 36 metacarpophalangeal joints was carried out ex vivo. Of these, 18 joints with varying degrees of cartilage damage were selected, wherein OCT arthroscopy was conducted using an OCT catheter (diameter 0.9 mm) inserted through standard instrument portals. Five sites of interest, occasionally supplemented with other locations where defects were encountered, were arthroscopically graded according to the International Cartilage Repair Society (ICRS) classification system. The same sites were evaluated qualitatively (ICRS classification and morphological description of the lesions) and quantitatively (measurement of cartilage thickness) on OCT images.

OCT provided high resolution images of cartilage enabling determination of cartilage thickness. Comparing ICRS grades determined by both arthroscopy and OCT revealed poor agreement. Furthermore, OCT visualised a spectrum of lesions, including cavitation, fibrillation, superficial and deep clefts, erosion, ulceration and fragmentation. In addition, with OCT the arthroscopically inaccessible area between the dorsal MC3 and P1 was reachable in some cases. Arthroscopically-guided OCT provided more detailed and quantitative information on the morphology of articular cartilage lesions than conventional arthroscopy. OCT could therefore improve the diagnostic value of arthroscopy in equine orthopaedic surgery.

Introduction

Arthroscopy is widely used for the detection of articular cartilage lesions in human as well as in equine healthcare and is considered the clinical gold standard for in vivo assessment of the status of articular cartilage. It enables direct visual inspection and mechanical probing of the cartilage surface and adjacent structures. Arthroscopic evaluation of articular cartilage has been reported to correlate well with histopathological scoring systems (Oakley et al., 2005; Acebes et al., 2009) and to be consistent with most clinical characteristics in human knee osteoarthritis (Kuzmanova et al., 2000).

Arthroscopic scoring of the status of articular cartilage, however, does have certain shortcomings. Grading of cartilage lesions depends on the surgeon's subjective interpretation of what is seen. This limits the quantitativeness of the evaluation and makes the inter-observer reliability poor (Oakley and Lassere, 2003; Spahn et al., 2011). In particular, the differentiation between intact and softened cartilage, as well as the differentiation between superficial and deep cartilage lesions are major obstacles (Spahn et al., 2011).

A second limitation is the insensitivity of arthroscopic assessment for pathological changes below a seemingly intact cartilage surface. Consequently, small lesions that do not yet reach the surface may be overlooked. A third limitation is the restricted area of the joint surface that can be visualised mainly due to joint geometry and limited lighting conditions at certain areas (Vanderperren et al., 2009). This limits access to the articular surface of the

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proximal phalanx (P1). In the forelimb, only the dorsal margin of P1 can be visualised but this area is often not representative of the status of the entire articular surface. In an earlier study using equine joints, arthroscopic grading of lesions located at the visible area of the proximal phalanx (P1) in the metacarpophalangeal (MCP) joint resulted in an underestimation of the total damage in joints with mild cartilage damage and an overestimation in joints with severe lesions (Brommer et al., 2004).

To overcome the subjective aspect of visual assessment, different arthroscope-guided mechanical probing techniques have been introduced in recent years. Measuring cartilage stiffness with arthroscopic indentation devices provides quantitative information on alterations in mechanical properties of the articular cartilage, which may be indicative for early degeneration (Lane et al., 1979; Lyyra et al., 1995; Brama et al., 2001; Bae et al., 2003). The integration of a miniature ultrasound transducer at the tip of the indentation instrument enables simultaneous determination of the cartilage thickness at the tested location that is necessary for accurate determination of the mechanical characteristics (Laasanen et al., 2002; Saarakkala et al., 2003; Kiviranta et al., 2008).

Additionally, quantitative ultrasound imaging may provide information on intrinsic structural properties of the cartilage (Saarakkala et al., 2006; Virén et al., 2009). Quantitative ultrasound arthroscopy has already been successfully applied for characterization of cartilage injuries and degeneration in human joints in vivo (Kaleva et al., 2011). However, with this technique the speed of sound is usually assumed to be constant, which is not the case in pathologically altered cartilage. This may affect the reliability of the measurements (Töyräs et al., 2003). Moreover, the visual information on cartilage structure is restricted by the limited resolution of ultrasound images.

A quantitative diagnostic technique that could potentially overcome the limitations of conventional arthroscopy and provide a better resolution than ultrasound arthroscopy is optical coherence tomography (OCT). This imaging technique is based on the measurement of reflection and backscattering of near infra-red light from tissues probed with a beam of near infra-red light. From a series of laterally adjacent depth-scans cross-sectional digital images are produced at resolutions comparable to that of low-power microscopy, thereby providing non-destructive near real-time 'optical biopsies' of the investigated tissue (Brezinski et al., 1998; Fercher et al., 2003; Marschall et al., 2011). OCT has been widely investigated for its application in different medical fields, including dermatology and gastroenterology and it is already being clinically used in cardiovascular surgery and ophthalmology (Fercher, 2010). Its feasibility for articular cartilage diagnostics has been evaluated with good results in an in vitro setting using bovine cartilage (Huang et al., 2011) and in situ and ex vivo using human knee cartilage (Chu et al., 2004). In an ex vivo setting the sensitivities of OCT and ultrasound were compared using equine cartilage (Virén et al., 2012). Furthermore, OCT has been applied to porcine and human joints during arthroscopy in vivo (Pan et al., 2003; Chu et al., 2007, 2010). The latter studies showed the potential value of OCT for clinical use in human joints as an adjunct to arthroscopy for (early) detection of cartilage lesions and degeneration. The OCT-generated high-resolution cross-sectional images, in combination with the small size of the optical catheter that allows access to joint areas that cannot be reached by other arthroscopic techniques, make OCT a potential solution to overcome the limitations of conventional arthroscopy.

The aim of the present study was to test whether OCT would be helpful in the advanced clinical assessment of lesions in equine articular cartilage in the MCP joint during arthroscopy. This was done by assessing cartilage thickness and various morphological characteristics of articular cartilage defects using OCT in an ex vivo setting representative to clinical diagnostic arthroscopy and comparing the outcome with conventional visual assessment by means of arthroscopy.

Materials and methods

Sample collection

Thirty-six fresh distal forelimbs of adult horses (age >2 years) were obtained from a slaughterhouse and stored at 7 °C until arthroscopy was performed 2–3 days later. To select a range of joints representing different stages of cartilage degeneration, standard diagnostic arthroscopy of the dorsal aspect of the MCP joint was performed (McIlwraith et al., 2005a) using a 4 mm, 30° arthroscope (Storz). Occurrence and severity of cartilage lesions at the dorsal eminences of the proximal phalanx (P1) and at the dorsoproximal area of the condyles and sagittal ridge of the third metacarpal bone (MC3) were scored using the SFA (Société Française d'Arthroscopie) scoring system (Dougados et al., 1994; Ayral, 1996). Briefly, the depth of the cartilage lesions was classified on a 0–4 scale and the size of the lesion was estimated as a percentage of the visible cartilage surface. An SFA score was then calculated using a specific formula resulting in a continuous variable ranging from 0% to 100% indicating the stage of cartilage degeneration (Ayral, 1996).

Eighteen joints were selected for OCT arthroscopy. This selection represented a range of degeneration with increasing severity (SFA scoring ranging from 0.70% to 33.25%). After completing conventional arthroscopy, the selected joints were stored at −20 °C until performing OCT arthroscopy.

OCT arthroscopy

The standard portal at the dorsal aspect of the joint (McIlwraith et al., 2005a) was used for the arthroscope and dorsomedial or dorsolateral portals were used for the OCT catheter (C7 Dragonfly Intravascular Imaging Catheter). The OCT catheter (diameter 0.9 mm) was guided into the joint through a custom made hollow instrument under arthroscopic control (Fig. 1). The OCT imaging and measurements of cartilage lesions were performed using the Ilumien PCI Optimisation System (St. Jude Medical; wavelength 1305 ± 55 nm, in plane pixel size of 10 × 10 μm^2, slice thickness 100 μm, frame rate 100 frames/s).

Five sites of interest (SOIs) for each joint were defined: the medial and lateral dorsal eminences of P1 (P1M and P1L), known to be often involved in early OA (Brommer et al., 2003), the opposing sites at the medial and lateral condyles of MC3 (MC3M and MC3L) at a joint angle position of 180°, and the central aspect of the sagittal ridge of MC3, in between the locations on the medial and lateral condyles (Fig. 2). Apart from the SOIs, lesions on other locations of the visible cartilage surface, found by arthroscopy or accidently found by randomly scanning the surface with the OCT catheter were also imaged. Lastly, it was tried to increase the visible area of P1 by manoeuvring the OCT catheter in between the surfaces of P1 and MC3 (P1-MC3), abaxial (lateral or medial) to the sagittal ridge. Whenever this was successful, this area was also scanned with OCT.

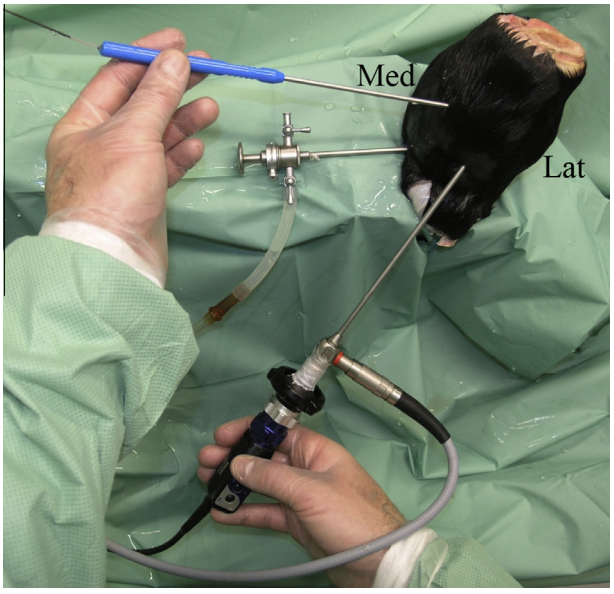

Fig. 1. OCT arthroscopy imaging of an equine MCP joint. A standard portal is used for the arthroscope and a dorsomedial portal is used for the OCT catheter.