Osteoarthritis and Cartilage xxx (2014) 1–11

Osteoarthritis and Cartilage

OARSI OSTEOARTHRITIS RESEARCH SOCIETY INTERNATIONAL

Severity mapping of the proximal femur: a new method for assessing hip osteoarthritis with computed tomography

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ARTICLE INFO

Article history:
Received 3 January 2014
Accepted 4 March 2014

Keywords:
Osteoarthritis
Hip joint
Computed tomography
Phenotyping

SUMMARY

Objective: Plain radiography has been the mainstay of imaging assessment in osteoarthritis for over 50 years, but it does have limitations. Here we present the methodology and results of a new technique for identifying, grading, and mapping the severity and spatial distribution of osteoarthritic disease features at the hip in 3D with clinical computed tomography (CT).

Design: CT imaging of 456 hips from 230 adult female volunteers (mean age 66 ± 17 years) was reviewed using 3D multiplanar reformatting to identify bone-related radiological features of osteoarthritis, namely osteophytes, subchondral cysts and joint space narrowing. Scoresheets dividing up the femoral head, head-neck region and the joint space were used to register the location and severity of each feature (scored from 0 to 3). Novel 3D cumulative feature severity maps were then created to display where the most severe disease features from each individual were anatomically located across the cohort.

Results: Feature severity maps showed a propensity for osteophytes at the inferoposterior and superolateral femoral head–neck junction. Subchondral cysts were a less common and less localised phenomenon. Joint space narrowing <1.5 mm was recorded in at least one sector of 83% of hips, but most frequently in the posterolateral joint space.

Conclusions: This is the first description of hip osteoarthritis using unenhanced clinical CT in which we describe the co-localisation of posterior osteophytes and joint space narrowing for the first time. We believe this technique can perform several important roles in future osteoarthritis research, including phenotyping and sensitive disease assessment in 3D.

Introduction

Plain radiographs have been used to diagnose and grade the severity of hip osteoarthritis for more than half a century. Radiographic joint space width (JSW) is currently the only accepted quantitative endpoint measure in early disease modification therapy trials[1], while Kellgren & Lawrence's (K&L) grading has been the preferred method for the assessment of radiological osteoarthritis severity, particularly in clinical and epidemiological research[2–5].

Radiographs are the frontline imaging modality in clinical practice, but they have also allowed researchers to discover patterns of disease in hip osteoarthritis, such as the relationship between osteophyte distribution and femoral head migration[6,7]. Although minimum JSW and K&L grading are associated with an increased risk of total hip replacement (THR)[8], associations between K&L grade and symptomatic osteoarthritis are less clear. Furthermore, K&L grading is based on 2D radiographs that not only introduce geometric distortion but are also unable to fully reflect 3D structure of the hip. This, among other factors, means that interpretation and application of K&L grading can be inconsistent[9], making it a sub-optimal biomarker for disease evaluation.

From a 3D perspective, full topographic representation of the hip can be achieved with cross-sectional magnetic resonance imaging (MRI) and computed tomography (CT). Hayashi *et al.* (2012) have shown that tomosynthesis (a form of radiography that encompasses aspects of 3D information) has better sensitivity for detecting subchondral cysts and osteophytes than plain radiography[10]. The importance of 3D hip and knee assessment in osteoarthritis has been reflected in the development of several semi-quantitative MRI scoring systems. These have most frequently been applied to the knee[11–14], but one has been created for the hip,

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http://dx.doi.org/10.1016/j.joca.2014.03.007
1063-4584/

called the hip osteoarthritis MRI scoring system (HOAMS)[15]. The HOAMS study showed that MRI is a reliable modality for imaging soft tissue structures such as cartilage, synovium, ligaments and bone marrow lesions. However mineralised features such as osteophytes, subchondral cysts, subchondral bone density are clearly represented in CT on account of excellent definition with this modality[16–18]. This is very much in line with previous rationales that have considered how CT may not only enhance visualisation of such "cardinal signs" of osteoarthritis, but also how it may contribute to our understanding of the disease[19,20]. Arden *et al.* (2009) have also recommended that researchers consider femoral osteophytes and JSW when defining incident radiographic hip osteoarthritis[21], both features that can be visualised and recorded with CT in detail.

This is the first of two papers that considers the assessment of hip osteoarthritis with unenhanced clinical CT. Here we present a new descriptive technique for mapping the severity and spatial distribution of features associated with hip osteoarthritis in 3D from multiplanar reformats of clinically acquired CT data. We present the cumulative results from our cohort of female volunteers using novel 3D-based feature severity maps.

Methods

Demographics

This study was performed using clinical CT examinations acquired from female volunteers acting as control participants in existing Cambridge trials investigating hip fracture risk from cortical bone thickness measurements. All participants were free of hip fracture, metastatic bone disease, and unilateral metabolic bone disease. Each had given informed consent for analysis of their hip and pelvic imaging data. No clinical information was recorded on the clinical assessment of osteoarthritis or related symptoms such as hip pain or reduced mobility. CT examinations were reported by a consultant radiologist as part of the routine clinical care of patients involved in Cambridge studies (FEMCO: LREC 07-H0305-61; MRC-Hip fx and MRC-Ageing: LREC 06/Q0108/180; MRC-Stroke: LREC 01/245; ACCT-1: LREC 04/Q0108/257). Imaging of 247 female volunteer control participants was available for review. Seventeen of these were excluded on account of: unilateral hip metalwork causing imaging artefact ($n = 9$); lack of complete demographic data ($n = 5$); excessive image noise ($n = 1$); no image files for a registered trial attendant ($n = 1$); or corrupt imaging data files ($n = 1$). The final combined cohort of 230 females had a mean ± standard deviation age of 66 ± 17 years, ranging from 20 to 95 years. Mean weight of the participants was 69.3 ± 14.2 kg. Imaging of only one hip was available in four individuals, so a total of 456 hips were included in the analysis.

Image acquisition and review

Imaging was acquired helically in the supine position on a range of clinical whole-body multidetector CT machines (Siemens SOMATOM Sensation 16, Siemens SOMATOM Sensation 64, Siemens SOMATOM Definition Flash, Siemens SOMATOM Definition AS+, GE Medical Systems Discovery 690). Reconstructed axial slice thickness ranged from 0.75 to 1.5 mm. Peak kV was 120 kV. When available from the anonymised metadata, recorded exposure ranged from 67 to 274 mAs, varying due to routine use of dose limiting. All acquisitions were processed with a standard smooth-edge body reconstruction kernel. No record of symptoms or clinical assessment of hip osteoarthritis was taken at the time of scanning.

Imaging review was performed on a workstation (Osirix v4.0 32-bit, http://www.osirix-viewer.com/, on a v5, 2 iMac, Apple, Cupertino, http://www.apple.com/) using the 3D MPR function with 200% screen zoom, and fixed window level (1800 HU) and width (500 HU). Axial oblique, sagittal oblique and coronal oblique planes were set to the patient's vertical axis and the axis from the centre of the femoral head to the centre of the femoral neck, with the reviewer free to move around the hip joint in these planes (SI Figs. 1 and 2).

Imaging review was performed by a single radiologist who had completed UK specialist training with musculoskeletal subspecialisation (TT). Imaging data were anonymised for all patient identifiers apart from their trial ID number. All distance measurements were made using electronic callipers provided in the Osirix software.

Scoresheet development

In developing HOAMS, Roemer *et al.* (2011) recognised that the structure of the hip joint and its sector of near spherical articular surface posed significant topographic challenges[15]. Our scoresheet [Fig. 1] was created to record the distribution and severity of disease features around the hip joint with sector divisions of the acetabulum, femoral head, and femoral head−neck junction. Radial divisions every 30° (resulting in 12 subdivisions) were inspired by Stelzeneder *et al.* (2012)[22], circumferential divisions by Alvarez *et al.* (2005)[23]. This provided 24 acetabular sectors (12 medial, 12 lateral); 26 femoral head sectors (12 medial, 12 lateral, 2 foveal); and 24 femoral head−neck junction sectors (12 medial, 12 lateral). Acetabular sectors were grouped into seven relevant joint space zones: superolateral, superomedial, anterior, medial, posteromedial, posterolateral, and inferoposterior. Fig. 2 shows how the scoresheet sectors correlate with 3D location on the acetabulum and femoral head/neck.

While the division of axial oblique, sagittal oblique and coronal oblique planes was consistently represented by fixed MPR tool crosshairs for each hip, subsequent sector divisions in these MPR images were subjectively assessed by the reviewer.

Feature assessment

Imaging assessment focused on three bone-related features of osteoarthritis: (1) osteophytes, (2) subchondral cysts, and (3) JSW. Although a recognised radiographic feature of hip osteoarthritis, subchondral bone sclerosis was not assessed because it was considered too unreliable for subjective assessment based on preliminary study. The full guide for assessing features is included in the Supplementary Information (Si).

(1). Osteophytes

No CT definition for an osteophyte exists and so, based on the characterisation of different stages of osteophyte development by Gelse *et al.* (2003)[24], we derived the following definition:

> *"An osteocartilagenous outgrowth or spur with a bony base and cartilaginous cap arising from the periosteum at the junction between articular cartilage and bone, excluding enthesophytes at the point of ligamentous insertion."*

Osteophyte severity was scored as: 0 = none; 1 = possible; 2 = definite osteophyte ≤5 mm from base to tip; 3 = definite osteophyte >5 mm from base to tip. This score was registered in the appropriate sector. If an osteophyte appeared to occupy more than one sector, then sectors were marked as containing it if >50% occupied (see osteophyte assessment − SI Fig. 3 & Table 1).

Please cite this article in press as: Turmezei TD, et al., Severity mapping of the proximal femur: a new method for assessing hip osteoarthritis with computed tomography, Osteoarthritis and Cartilage (2014), http://dx.doi.org/10.1016/j.joca.2014.03.007