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Cartilage health in high tibial osteotomy using dGEMRIC: Relationships with joint kinematics

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ABSTRACT

Purpose: The aims of this study are to determine how opening-wedge high tibial osteotomy (HTO) affects cartilage health in the tibiofemoral (TF) joint and patella, and to explore relationships between TF and patellofemoral (PF) joint kinematics and cartilage health in HTO.
Methods: 14 knees (13 subjects) with medial TF osteoarthritis (OA) were examined before HTO and 6 and 12 months after HTO using delayed gadolinium-enhanced MRI of cartilage (dGEMRIC) to evaluate cartilage health at the TF joint and patella. They were also examined using a validated 3D MR knee kinematics measurement to obtain 11 rotations and translations at both TF and PF joints.
Results: No statistically significant differences in overall TF or patellar dGEMRIC score were found at 6 or 12 months after HTO. However three subjects had large decreases (mean 105 ms) in TF dGEMRIC at 6 months that recovered at 12 months. Kinematics for these subjects were compared to subjects who did not have decreases in TF dGEMRIC at 6 months ($n = 5$). Differences were observed between groups with HTO in anterior and proximal tibial translation (mean differences 3.05 mm and 1.35 mm), and patellar flexion (mean difference 3.65°). These changes were consistent between 6 and 12 months, despite recovery of TF dGEMRIC values.
Conclusions: We did not find significant differences in TF or patellar dGEMRIC before and after HTO with all subjects, however there were differences in kinematics between subjects who had a decrease in TF dGEMRIC at 6 months and those who did not. This suggests a link between joint kinematics and cartilage health in HTO.
Clinical relevance: The effect of opening-wedge high tibial osteotomy on cartilage GAG concentration may be linked to specific changes in knee kinematics following surgery

1. Introduction

Opening-wedge high tibial osteotomy (HTO) is a procedure used to treat medial tibiofemoral (TF) osteoarthritis (OA) in knees with varus malalignment. This procedure is performed to change the alignment of the lower limb in an effort to shift load from the diseased medial compartment of the tibiofemoral joint to the lateral compartment. Young, active individuals with medial compartment osteoarthritis are not good candidates for total or unicompartmental knee arthroplasty and the most accepted surgical treatment option in this group is an HTO.

While there are clear guidelines for leg alignment correction in the literature, the correlation between correcting leg alignment to a specific target range and clinical outcome in HTO is not clear. Some studies have found a correlation between correcting leg alignment to a specified range and clinical success [1,2], and others have not [3,4]. Some authors report medial compartment cartilage repair following HTO [5–9], but evidence of further cartilage degeneration in the lateral TF compartment and on the patella has also been found by others [5,6]. It is not clear why cartilage may be protected, or restored, in some cases while in others it is not.

One potential reason that leg alignment is an inconsistent predictor of HTO outcome is that HTO changes many of the three-dimensional components of knee kinematics of the TF and patellofemoral (PF) joints [10]. The single two-dimensional measure used to quantify

Abbreviations: dGEMRIC, delayed gadolinium-enhanced MRI of cartilage; HTO, high tibial osteotomy; TF, tibiofemoral; PF, patellofemoral; GAG, glycosaminoglycans; IR, inversion recovery; SR, saturation recovery; TSE, turbo spin echo; UNCHGD, unchanged group (subjects with small decrease or increase in TF dGEMRIC score at 6 months); DECRES, decreased group (subjects with large decrease in TF dGEMRIC score at 6 months).

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leg alignment and guide surgery does not capture the complex three-dimensional change to the movement of the knee in HTO [10].

A further limitation to understanding the links between cartilage health and joint mechanics (both in HTO and in OA in general) is that most techniques for assessing in vivo cartilage health require direct access to the cartilage through arthroscopic surgery or biopsy, which is invasive. Low glycosaminoglycan (GAG) content assessed with dGEMRIC is associated with early osteoarthritis (OA) [11]. Delayed gadolinium-enhanced magnetic resonance imaging, MRI of cartilage (dGEMRIC), a validated method for estimating GAG content of cartilage, *in vivo*, using T_1 mapping [12], represents a minimally invasive method to assess articular cartilage. Recent studies of cartilage health in HTO have applied dGEMRIC to TF cartilage before and after surgery [13,14], but have not been applied to the patella. In each case, they found no significant difference in overall TF dGEMRIC score with HTO and found no correlation between changes in dGEMRIC score and changes in two dimensional (2D) leg alignment [13,14]. However, it is not clear whether there is a relationship between changes in cartilage health as assessed with dGEMRIC and changes in three dimensional (3D) knee kinematics following surgery. This is because, to our knowledge, there has been no simultaneous application of advanced measures of both cartilage health (dGEMRIC) and three-dimensional kinematics, in HTO or in any other population or joint.

Our research questions were: how does opening-wedge HTO affect cartilage GAG content in the tibiofemoral joint and patella, and is there a relationship between tibiofemoral and patellofemoral joint kinematics and cartilage GAG content in HTO?

2. Methods

A cohort of 14 knees in 13 male subjects (mean age 48.3, standard deviation, SD 7.2) undergoing opening-wedge HTO for medial compartment osteoarthritis participated in this study (Table 1). All subjects gave informed consent and UBC Clinical Research Ethics Board approval was granted. Each subject was scanned using a 3 T Philips Achieva scanner at three time points: within the month before surgery, six months after surgery, and 12 months after surgery. With some subjects unable to complete all scans, our final subject numbers were 13 at pre-operative baseline, nine at six months, and 10 at 12 months.

The primary participant inclusion criterion was that they were a patient undergoing opening-wedge high tibial osteotomy for treatment of medial tibiofemoral osteoarthritis. Exclusion criteria included previous surgery beyond arthroscopic lavage or debridement, and injury or disorder beyond varus deformity and medial tibiofemoral osteoarthritis (such as ligament rupture or insufficiency). This sample represents consecutive consenting participants available for recruitment in the authors' practices.

Table 1
Description of HTO subjects, including which group they were included in (if any) based on TF dGEMRIC change between pre-op and six months. * Indicates same subject.

Subject	Age	HTO knee	Dominant knee	Height (cm)	Weight (kg)	BMI	Surgeon	Group
1	35.8	R	R	193	112	30.0	SH	–
2	41.8	L	R	174	83	27.4	SH	UNCHGD
3	54.0	L	R	176	84	27.1	SH	UNCHGD
4	38.8	L	L	172	77	26.1	SH	–
5	43.9	L	R	173	66	22.0	RM	DECRES
6	59.8	R	L	160	88	34.6	TS	DECRES
7	51.3	R	R	185	107	31.1	TS	UNCHGD
8	50.4	L	R	177	100	31.9	RM	UNCHGD
9	50.2	L	R	177	80	25.6	TS	–
10	57.4	R	R	173	86	28.6	TS	DECRES
11	53.4	L	R	162	65	24.7	TS	–
12	55.1	R	R	175	83	27.1	RM	–
13*	40.8	R	R	180	107	32.9	RM	–
14*	42.3	L	R	180	109	33.6	RM	UNCHGD

2.1. Surgical procedure

Pre-operative planning (using weight-bearing and flexed radiographs) was performed to change the mechanical axis to pass through the 62.5% width point on the tibial plateau. Using a medial approach, the osteotomy plane, proximal to the tibial tubercle, was marked with two k-wires, and the osteotomy was performed with osteotomes and a sagittal saw, leaving the lateral cortex intact. Alignment was checked with a three-foot rod, and fixation was performed with titanium hardware to minimize MR artifacts (plate and four locking screws, Puddu, Arthrex). The osteotomy was filled with autograft or calcium triphosphate wedges, and post-operative protocol consisted of no weight-bearing for six to eight weeks followed by partial weight-bearing for two to four weeks.

2.2. MR imaging

We performed dGEMRIC scans on the tibiofemoral and patellofemoral joints of the operated knee of each subject to quantify cartilage GAG concentration. Each subject was first injected with an intravenous double dose (0.2 mmol/kg) of gadopentatate dimeglumine (Gd-DTPA^{2-}, Magnevist, Bayer). Subjects then performed 10 min of brisk walking following the injection and scanning began 90 min post-injection.

For each subject, we first obtained a dGEMRIC scan series of the tibiofemoral joint of the operated knee (coronal plane). Because the metal osteotomy plate near the cartilage can cause artifact that disrupts the T_1 map in the tibiofemoral cartilage [15], we used saturation recovery (SR) instead of inversion recovery (IR) to reduce metal artifact for scans of the tibiofemoral joint, as described in previous work [15]. We obtained a series of single-slice coronal plane saturation recovery turbo spin-echo (TSE) scans (Table 2) with two surface coils (SENSE Flex-M, Philips, Best, Netherlands) positioned one on either side of the joint.

For each subject, we then obtained a dGEMRIC scan of the patella of the operated knee. This scan was started about two hours post-injection. The scan series consisted of a series of single-slice inversion recovery (IR) turbo spin-echo (TSE) scans in the axial plane (Table 2). We used the inversion recovery sequence at the patellofemoral joint because the metal implant was sufficiently distant and the inversion recovery sequence has a higher signal to noise ratio than the saturation recovery sequence. The inversion preparation was achieved with a commercially available hyperbolic secant adiabatic pulse (amplitude and frequency modulated) which was designed to produce accurate inversion pulses even in presence of radiofrequency field (B_1) inhomogeneities [16].

We also collected three-dimensional knee kinematic data for these same subjects using a validated MR method [10]. Briefly, we obtained one high-resolution scan of the knee in a relaxed position, and six rapid scans of the knee loaded in simulated squats at flexion angles

Table 2
MR sequence parameters for dGEMRIC.

	SR (TF)	IR (patellar)
Repetition time (TR)	2200, 1800, 1200, 700, 400, 300, 200, 150, 100 ms	2200 ms
Inversion time (TI)	–	1800, 1200, 700, 400, 200, 150, 100, 50 ms
Echo time (TE)	15 ms	15 ms
TSE factor	2	9
Field of view (FOV)	100 mm	100 mm
Slice thickness	3 mm	3 mm
Matrix size (scanned)	256 × 256	256 × 256
Matrix size (reconstructed)	256 × 256	256 × 256
In-plane resolution	0.39 × 0.39 mm	0.39 × 0.39 mm
Number of slices	1	1
Scan time (total)	12:53	16:25