Medical Engineering & Physics 36 (2014) 1156–1161

Contents lists available at ScienceDirect

Medical Engineering & Physics

journal homepage: www.elsevier.com/locate/medengphy

Changes in dissipated energy and contact pressure after osteochondral graft transplantation

Evgenij Bobrowitsch, Andrea Lorenz, Johanna Jörg, Ulf G. Leichtle*, Nikolaus Wülker, Christian Walter

University Hospital Tübingen, Department of Orthopaedic Surgery, Biomechanics Laboratory, 72076 Tübingen, Germany

ARTICLE INFO

Article history:
Received 19 July 2013
Received in revised form 10 June 2014
Accepted 28 June 2014

Keywords:
Biomechanics
Cartilage
Defect reconstruction
Osteochondral mosaicplasty
Graft
Autologous
transplantation
Dissipated energy
Friction
Contact pressure
Contact area
In vitro

ABSTRACT

Osteochondral autologous transplantation is frequently used to repair small cartilage defects. Incongruence between the osteochondral graft surface and the adjacent cartilage leads to changed friction and contact pressure. The present study wanted to analyze the differences between intact and surgically treated cartilage surface in respect to contact pressure and frictional characteristic (dissipated energy). Six ovine carpometacarpal joints were used in the present study. Dissipated energy during instrumentally controlled joint movement as well as static contact pressure were measured in different cartilage states (intact, defect, deep-, flush-, high-implanted osteochondral graft and cartilage failure simulation on a high-implanted graft). The best contact area restoration was observed after the flush implantation. However, the dissipated energy measurements did not reveal an advantage of the flush implantation compared to the defect and deep-implanted graft states. The high-implanted graft was associated with a significant increase of the mean contact pressure and decrease of the contact area but the dissipated energy was on the level of intact cartilage in contrast to other treatments where the dissipated energy was significantly higher as in the intact state. However the cartilage failure simulation on the high-implanted graft showed the highest increase of the dissipated energy.

1. Introduction

Articular cartilage lesions are observed with increasing frequency in the athletic population and, due to limited intrinsic healing capacity, can lead to progressive pain and functional limitation over time [1]. Cartilage defects sizes measuring less than 2 cm^2 are usually treated with either microfracturing or mosaic osteochondral grafting [2]. Mosaic osteochondral grafting is also known as osteochondral autologous transplantation (OAT) technique [3–5]. According to some studies the patients treated with this technique maintained a superior level of athletic activity compared to those treated with microfracturing [6,7]. Additionally, the OAT remains to be more cost effective than other promising techniques such as autologous chondrocyte transplantation [8].

Joint cartilage surface and synovial fluid provide low-friction movement in a healthy joint. It is obvious that cartilage surface congruence during OAT is pivotal to maintain low-friction movement. Incongruence between the graft surface and the adjacent cartilage results in increased contact pressures and poorer outcomes [9]. The increased local pressure can induce chondrocyte apoptosis [10,11].

Some study groups focused on analysis of pressure distribution in OAT treated joints. Latt et al. found that the pressure distribution after OAT has to be considered not only at the graft site [12,13] but also within the entire joint [14]. Regarding previous pressure distribution research the authors suggest to implant the osteochondral graft flush or if that is not possible then slightly sunk [12,14].

The questions remains what a surgeon should do when the osteochondral graft is slightly too long and therefore cannot be implanted flush. One option could probably be the use of a higher insertion force, thus maintaining flush implantation but risking cartilage damage.

Other researcher groups focused on measurement of friction coefficients in OAT treated joints. Lane et al. revealed that OAT led to a significant friction increase in the joints when the osteochondral graft was implanted with different heights. The highest level of friction was found in a highly implanted osteochondral graft [15].

---

* Corresponding author. Tel.: +49 (0) 7071/29 86691.
E-mail addresses: Evgenij.Bobrowitsch@med.uni-tuebingen.de (E. Bobrowitsch), andrea.lorenz@med.uni-tuebingen.de (A. Lorenz), johanna.m.joerg@gmail.com (J. Jörg), ulf.leichtle@med.uni-tuebingen.de (U.G. Leichtle), nikolaus.wuelker@med.uni-tuebingen.de (N. Wülker), christian.walter@med.uni-tuebingen.de (C. Walter).

http://dx.doi.org/10.1016/j.medengphy.2014.06.015
1350-4533/

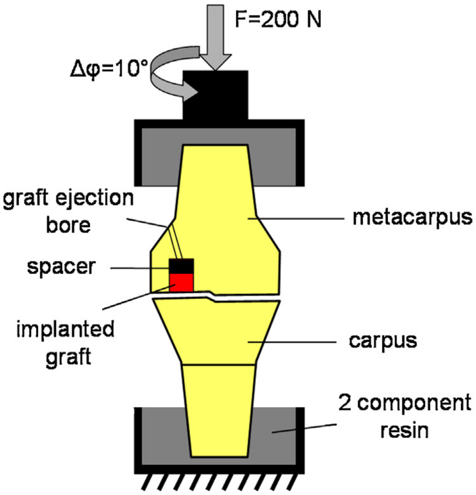

Fig. 1. Schematic diagram of the measurement set up on the material testing machine.

The purpose of the present study was to perform a complex analysis of OAT treated joints for different cartilage states (intact, defect, deep-, flush-, high-implanted osteochondral graft and cartilage failure simulation on a high-implanted graft. We considered not only the pressure distribution in the entire joint but we also measured frictional characteristics of the joint according to the dissipated energy method described by Walter et al. [16]. This method is an alternative approach to characterize the friction properties in complete animal joints with the potential to differentiate between varying cartilage damage conditions. We hypothesized that the highest dissipated energy levels will occur in high-implanted graft.

2. Methods and material

2.1. Specimen preparation

Fourteen fresh frozen ovine carpometacarpal joints were directly obtained post mortem. The averaged weight of sheep was about 40 kg. Eight joints were assigned for mechanical testing and cut 8 cm distal and proximal from the joint gap and dissected from the skin, musculature and connective tissue. Subsequently, the ends of the radius shaft and metacarpal bone were embedded in a custom made metal frame with a two component resin (Technovit Universal Fluid and Pouder 2060, Heraeus Kulzer GmbH, Wehrheim, Germany). The carpal joints were fixed with screws to prevent residual movements. The specimens were stored in plastic bags at −20 °C. Prior to testing, the specimens were thawed 12 h at room temperature. Right before testing, the joints were completely opened along the carpometacarpal joint gap and sprayed with isotonic saline solution (154 mmol/l Na^+ and 154 mmol/l Cl^- in H_2O). The isotonic saline solution was used as a substitute for the synovial fluid. The remaining six joints were used for harvesting of osteochondral grafts.

2.2. Dissipated energy measurement during a torsion test

We measured the dissipated energy on eight specimens. Six specimens were surgically treated and the cartilage surface of another two specimens remained intact to perform control measurements. The specimens were mounted to a material testing machine (MTS 858 Mini Bionix, Eden Prairie, 25 kN load cell) with the specimen longitudinal axis aligned to the MTS piston axis (Fig. 1). An angle controlled torsional motion of 10° range was applied with a triangularly shaped target value and a frequency of 0.1 Hz [16] with constant axial preload of 200 N for 9 cycles. The rotation angle and the torque around the long axis were recorded to calculate the dissipated energy.

2.3. Measurement of contact area and pressure

Prior to the torsion test, the contact pressure of the entire joint was measured by means of a pressure sensitive film (Tekscan 4000 sensor, measurement area of $28 \times 33\,mm^2$, resolution of 62 sensor elements per cm^2, saturation pressure of 10.3 MPa, Tekscan, Inc., South Boston, MA, USA) under 100 N of axial load at a 0° and 10° torsion position (without movement). Before use, each sensor was equilibrated and linearly calibrated [17] with the known load of 100 N using IScan software (IScan version 5.83, TekScan, Boston, MA, USA). After the pressure measurement, the pressure sensitive film was removed from the articular gap. Two minutes before the torsion test the cartilage surface was sprayed with the isotonic saline solution for cartilage hydrorecovery.

2.4. Surgical treatment of the joint surface

Surgical treatment was performed after the specimen with intact cartilage (Fig. 2a) was mechanically examined during the torsion test. The metacarpal joint part was demounted from the MTS material testing machine and treated. The carpal joint part remained there wrapped into thin polyethylene film to preserve the cartilage from drying. First, a defined cartilage defect of 8 mm in diameter was notched comprising full thickness of the cartilage (approximately 1 mm). The defect was placed lateral to the specimen's longitudinal axis fitted in the lateral articular surface in para-central location on the proximal articular part of the fourth metacarpal bone (Fig. 2b) [18]. The defect was created using a round window of 8 mm diameter in a thin aluminium plate and a multi-purpose drilling tool (2 mm drill bit, Dremel 300, Dremel Europe, Konijnenberg, Netherlands). Then an osteochondral graft of 8 mm diameter harvested from the equivalent part of a donor carpometacarpal joint was implanted using the osteochondral autograft transfer system (Aesculap AG, Tuttlingen, Germany). The same graft was used to fill the cartilage defect in three different heights to the host joint cartilage surface: deep (1 mm below, Fig. 2e), flush (Fig. 2c) and high (1 mm above, Fig. 2d). The different height of the implanted graft was achieved using thin (0.5 mm) round (7 mm diameter) metallic spacers under the graft bottom. To remove the implanted graft from the bone, a thin bore of 2 mm diameter was drilled from bottom of the transplantation site to the lateral corticalis (Fig. 1). Thus it was possible to eject the implanted graft with a thin pin through the bore [19]; the graft was then reimplanted with different height to perform the permutation of the three graft heights "deep, flush and high". The permutation of three elements resulted in six possible sequences. Therefore six specimens were used. In order to simulate a cartilage failure on the high-implanted graft the osteochondral graft was reimplanted high. The cartilage of the high-implanted graft was then damaged (Fig. 2f) similar to the defect placement in the first treatment (Fig. 2b) using the standard reaming instrument. A total of tested cartilage states were six (Fig. 2).

2.5. Control measurements

During the tests, cartilage characteristics like form or quality could be changed by e.g. drying or mechanical influence. This could affect pressure and dissipated energy measurements. Therefore control pressure and dissipated energy measurements of two specimens were performed under the same measurement conditions but without defect creation or surgical treatment. During these control measurements the metacarpal joint parts were exposed for