Injury, Int. J. Care Injured 46S (2015) S14–S17

Contents lists available at ScienceDirect

Injury

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

Analysis of biomechanical properties of patellar ligament graft and quadruple hamstring tendon graft

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ARTICLE INFO

Keywords:
Patellar ligament
Quadruple tendons
Biomechanical
Anterior cruciate ligament

ABSTRACT

Introduction: Two types of transplant are commonly used in the surgical management of anterior cruciate ligament lesions: the central part of the patellar ligament and quadruple tendons of the gracilis muscle and semitendinosus muscle.
Aims: The aim of this study was to determine the biomechanical characteristics of patellar ligament transplants and transplants of the quadruple tendons of the hamstring muscles under tensile force in the laboratory, and to compare the results in each group of samples.
Materials and methods: The study comprised 160 specimens: 40 specimens of gracilis muscle tendons, 40 of semitendinosus muscle tendons, 40 of quadruple tendons and 40 of the patellar ligament, approximately equally distributed according to sex, age (50–70 years) and the side of the body from which the specimen had been taken.
Results: The working curve analysis of the specimens under tensile load of a maximum force of 30 N showed the least elongation (0.31%) in the quadruple tendon, followed by the gracilis muscle tendon (1.48%) and patellar ligament tendon (3.91%).
Conclusions: The quadruple tendon specimen showed greater strength and higher elasticity compared with the patellar ligament specimen, which proved the starting hypothesis.

Introduction

Tendons, ligaments, aponeuroses and other similar connective tissue structures are composed of dense bundles of collagenous fibres ordered in parallel, slightly wavy or curved arrays. About 20% of the mass of both tendons and ligaments is made up of cellular component, mostly fibrocytes and fibroblasts, and about 80% is extracellular component. Between 60% and 80% of their total mass is made up of water; the remaining 20–40% is solid material. Collagen fibres make up between 65% and 80% of the dry mass of tendons and ligaments and are mostly type 1 collagen with much less type 3 collagen; however, collagen content is higher in tendons than in ligaments. There is also a difference in the ratio of collagen type 1 to type 3, which varies between 95%:5% and 99%:1% in tendons, and is 90%:10% in ligaments. Both tendons and ligaments in the extremities contain little elastin (around 3%) [1,2].

Cruciate and collateral ligaments are fundamental parts of the knee joint. The two collateral ligaments, the lateral collateral ligament (LCL) and the medial collateral ligament (MCL), control knee movements during flexion and extension around the transverse axis. The two cruciate ligaments, the anterior cruciate ligament (ACL) and the posterior cruciate ligament (PCL), provide stability to the knee joint during these movements, and during rotation movements around the tibial axis [3,4].

The ACL is an average of 38 mm long (range 25–41 mm) and 10 mm wide (range 7–12 mm). It is composed of multiple collagen bundles, which, on a microscopic level, consist of fibrils of 150–250 nm in diameter that make up fibres of 1–20 μm in diameter, and is covered by synovial membrane [5,6].

The biomechanics of the ACL are based on maximum graft strength of 2160 $\pm$ 157 N and graft stiffness of 242 $\pm$ 28 N/m (force–elasticity curve) [7]. Passive knee extension produces forces along the

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http://dx.doi.org/10.1016/j.injury.2015.10.040

ACL during only the last 10° of knee extension. The ACL is subjected to much higher force than the PCL in knee hyperextension. The knee with uninjured ACL in full extension has anterior tibial translation with laxity of 2–5 mm, whereas in flexion of 30° laxity is 5–8 mm. Anterior translation decreases as the angle of flexion increases. In knee flexion at 90°, the ACL accounts for approximately 85% of resistance to anterior tibial translation. In the knee with injured ACL, laxity increases with the angle of knee flexion.

The primary functional role of the ACL is to resist anterior tibial translation. The ACL does not remain a constant length as the knee is flexed and extended.

ACL reconstruction is commonly performed using an autologous graft, such as the middle third of the patellar ligament with bone plugs, or hamstring tendons, usually quadruple tendons of the semitendinosus and gracilis muscles [6,8]. However, there has been much discussion regarding the choice of a more suitable autologous graft in ACL reconstruction. According to Noyes et al. [9], the strength of a 14-mm-wide patellar ligament graft is approximately 170% the strength of normal ACL, whereas hamstring tendons have much less strength, but much better elasticity [9]. This fact was not taken into account in the past, so the patellar ligament graft was the most common choice for years, mainly due to its more secure fixation in the bone tunnel [10–12]. It has become clear that ACL reconstruction is better when the graft has similar elasticity and its force-elasticity curve resembles ACL [13]. Also, Hamner et al. [7] showed that doubled semitendinosus or gracilis tendons or even their combination can replace the strength of normal ACL. Moreover, hamstring tendons contain more collagen than the bone–tendon–bone (BTB) graft. The maximum strength of the middle third of the 10-mm-wide patellar ligament is 1080 N, and of the quadruple hamstring tendon is 1160 N. In laboratory conditions, the strength of the quadruple hamstring tendon is up to 250% that of a healthy ACL [7,14]. Steiner et al. reported that mechanical testing of ACL reconstruction on cadavers showed better results in patellar ligament grafts [15]. The difference in stiffness between patellar ligament graft and uninjured ACL was not significant ($p > 0.05$), whereas all reconstructions with hamstring tendons were significantly less stiff ($p < 0.01$). According to Cooper et al. [16], the structural strength of a 10-mm-wide patellar ligament is 2977 N, and according to Hamner et al. [7], the strength of quadruple hamstring tendons is 4590 N.

Previous studies have compared grafts that were fixed to the bone in different ways, which probably led to contradictory results [17,18]. Taking into account existing diversity in research on biomechanical properties of patellar ligament and quadruple tendon samples, the aim of the present study was to investigate the difference between these two types of grafts while simulating initial strains in the knee joint. The working hypothesis was that the quadruple tendon sample has greater elasticity than the patellar ligament sample and a lower level of elongation at initial knee strains, as stated by Hamner et al. and Noyes et al. in their studies [7,9].

Materials and methods

This study included 40 samples each of patellar ligament, quadruple hamstring tendon, semitendinosus tendon and gracilis tendon obtained from the Department of Anatomy and Neuroscience collection of anatomical preparations at the Faculty of Medicine, J.J. Strossmayer University of Osijek. Samples were preserved with 1% formaldehyde for 6–10 months. All samples were obtained from individuals aged from 50 to 70 years. Patellar ligament graft was harvested from the middle part of the patella ligament and was 10 mm in width, with a 10 mm wide and 25 mm long patellar bone plug and a 10 mm wide and 30 mm long tibial bone plug [16]. Bone plugs were formed by passing through a cylinder of 10 mm in diameter and fixing both ends with sutures through holes in the bone (Fig. 1). Quadruple hamstring tendon graft consisted of doubled over semitendinosus tendon and gracilis tendon (Fig. 2). This research was conducted in accordance with the opinion of the ethics committee of Medical Faculty Osijek (July 20, 2014).

Biomechanical research was conducted using a specially designed device created in the Faculty of Electrical Engineering, Osijek. Both grafts were subjected to tensile forces during a stress test under laboratory conditions (Fig. 3). The device consists of an 8.5-bar air compressor, a microscrew for pressure (force) intensity regulation on a cylinder with a metal jaw and a metre to measure the piston shift inside the cylinder [19,20]. A built-in analogue-to-digital converter enabled the device to register the size of

Fig. 1. Patellar ligament graft with bone plugs.

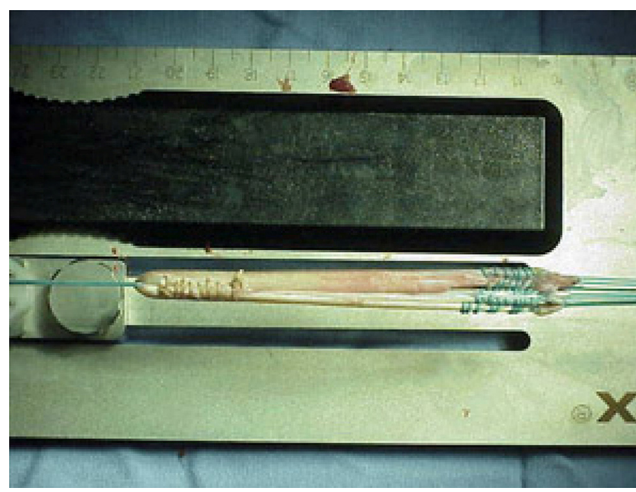

Fig. 2. Quadruple hamstring tendon graft.

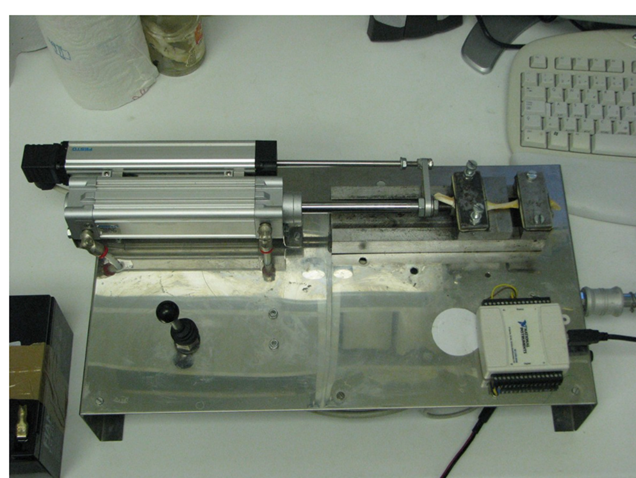

Fig. 3. Specially designed device for biomechanical research on anterior cruciate ligament (ACL) grafts.