RESEARCH ARTICLE

Biomechanical Comparison Between Bashti Bone Plug Technique and Biodegradable Screw for Fixation of Grafts in Ligament surgery

Kaveh Bashti, MD; Mohammad N Tahmasebi, MD; Hasan Kaseb, MD; Farzam Farahmand, PhD; Mohammad Akbar; Amir Mobini

Research performed at Tehran University of Medical Sciences and Sharif University of Technology

Received: 3 August 2014 *Accepted: 4 December 2014*

Abstract

Background: Ligament reconstruction is a common procedure in orthopedic surgery. Although several popular techniques are currently in use, new methods are proposed for secure fixation of the tendon graft into the bone tunnel.

Purposes: We sought to introduce our new technique of Bashti bone plug for fixation of soft tissue graft in anterior cruciate ligament (ACL) reconstruction and to compare its biomechanical features with conventional absorbable interference screw technique in a bovine model.

Methods: Twenty pairs of bovine knees were harvested after death. Soft tissue was removed and the Achilles tendon was harvested to be used as an ACL graft. It was secured into the bone tunnel on the tibial side via two different methods: Bashti Bone Plug technique and conventional screw method. Biomechanical strength was measured using 200 N and 300 N cyclic loading on the graft. Pull out strength was also tested until the graft fails.

Results: No graft failure was observed after 200 N and 300 N cyclic loading in either fixation methods. When testing for pull out failure, 21 tendons (53%) were torn and 19 tendons (48%) slipped out. No fixation failure occurred, which did not reveal a significant difference between the bone plug or interference screw group (*P*=0.11). The mean pull out force until failure of the graft was 496±66 N in the screw group and 503±67 N in the bone plug group (*P*=0.76).

Conclusions: Our suggested fixation technique of Bashti bone plug is a native, cheap, and feasible method that provides comparable biomechanical strength with interference screw when soft tissue fixation was attempted in bovine model.

Key words: Anterior cruciate ligament, Bashti, Biomechanical strength, Bone plug, Bovine model, Initial fixation, Interference screw, Reconstruction

Introduction

Anterior cruciate ligament (ACL) tear occurs as a common sport related injury (1). As the main stabilizer of the tibia over the femur for anterior sliding movement, ACL plays a crucial role in activities demanding counteracting rotation and valgus stress such as football, netball and hockey (2). ACL reconstruction is a popular orthopedic procedure in knee surgery which has evolved dramatically during the last years. Several donor sites have been suggested for harvesting the tendon graft for ACL reconstruction (3-5). Bone-patellar tendon-bone (BPTB) graft is a common reconstruction technique with the benefit of rapid bone-to-bone healing process (6). However, later joint instability has been observed as a serious donor site morbidity (7). Moreover, tunnel enlargement probably due to bone loss

Corresponding Author: Kaveh Bashti, Department of Orthopedics, Division of Knee Surgery, Shariati Hospital, Tehran University of Medical Sciences, Tehran, Iran.
Email: bashtikaveh@yahoo.com

THE ONLINE VERSION OF THIS ARTICLE
ABJS.MUMS.AC.IR

Figure 1. Bone transfer trochar.

and subsequent fibrosis are other concerns (8-9).

Despite multitude reconstruction techniques for ACL injuries, initial fixation of the soft tissue graft remains the main challenge (10-11). An ideal technique should provide strong fixation of the graft to withstand the resulting forces of rehabilitation and achieves postural stability (12-13). Several fixation techniques have been described including metallic and biodegradable interference screws (1, 9, 14-15) and press-fit fixation of the bony part of a tendon-bone graft (9, 16). Full extension of the knee joint by contraction of the quadriceps muscle has been shown to produce a force of up to 200 N on the ACL graft (17). To allow for adequate rehabilitation, the initial fixation strength of the graft should be strong enough to counteract with these resultant forces.

Autogenous bone plug has been increasingly advocated for initial fixation or secondary augmentation of tendon graft fixation in ACL reconstruction surgeries (9, 16). Nevertheless, to the best of our knowledge, this is the first biomechanical study on the use of bone plug technique for initial fixation of soft tissue graft into the tunnel for ACL reconstruction. Moreover, a limited number of studies have compared biomechanical properties of bone plug technique with conventional interference screw methods. Hence, we conducted the present study to introduce our new fixation method of

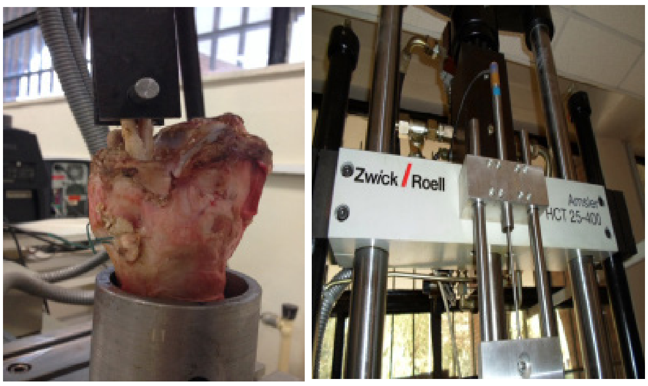

Figure 3. A. Tensioner attachment to the fatigue test machine. B. Servo-hydraulic testing machine.

Figure 2. The Achilles grafts are fixed with biodegradable interference screws and bone plug on tibia with both ends (9*30).

Bashti bone plug for initial fixation of tendon graft to the bone tunnel and compare its biomechanical strength with interference screw technique in a bovine model.

Methods and Materials

Design and Setting

This experimental study was conducted as collaboration between Biomechanics and Orthopedics Departments of two distinguished Universities in Iran between January 2013 and February 2014 investigating the biomechanical fixation strength in two different methods of ACL reconstruction in a bovine model.

Specimens and Harvesting

Twenty pairs of intact bovine knees were harvested within 4 hours of death. Soft tissues were removed and the specimens were frozen at -20ºC. Twelve hours before biomechanical testing, the specimens were thawed at room temperature and each one of every pair assigned to either the bone plug fixation or biodegradable interference screw group to make both groups comparable in terms of knee structures. Ultimately, the Achilles tendon of each bovine specimen was harvested and prepared in a loop fashion with a 10 mm diameter.

Operative Technique

Reaming a tunnel parallel to the long axis of the tibia, a cylindrical bone plug was drilled out of the tibial plateau with a length of 30 mm and diameter of 8 mm [Figure 1]. The tendon graft was secured with either screw or bone plug after pulling up into the joint.

The harvested Achilles tendon was pulled into the tunnel through the articular side. In 20 knees, it was fixed onto the tibia using bone plug through the application of bone dilator, custom made bone transfer trochar, pusher and a hammer. In the other 20 knees, it was fixed using biodegradable interference screws (8 mm*30 mm in size) through a standard technique [Figure 2]. Interference screws (DePuy Mitek, Edinburgh, United Kingdom) were inserted from the distal side of the tunnels in a rear entry/tibial type model. Operative techniques for tunnel

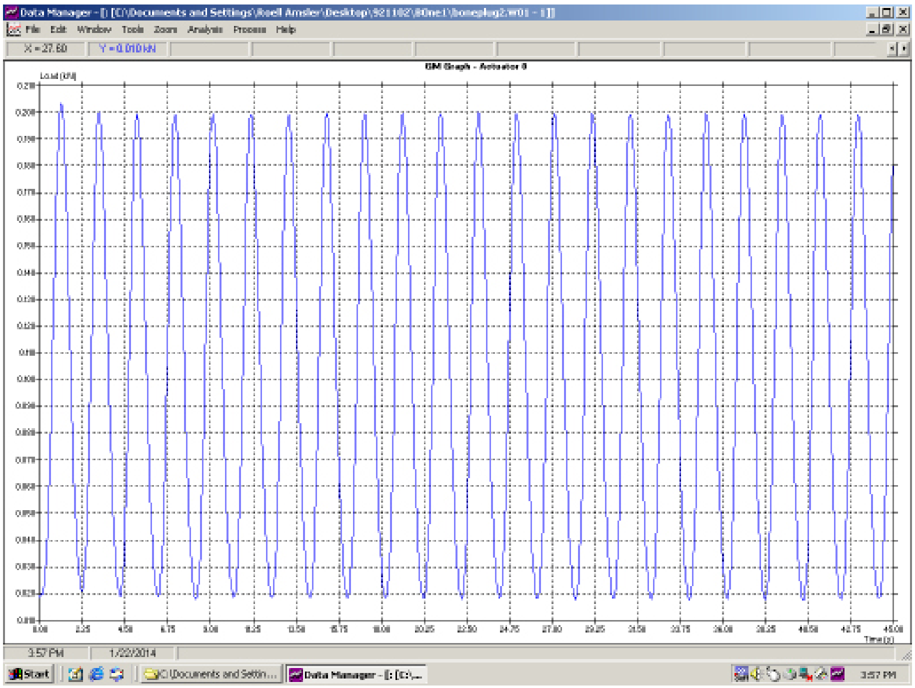

Figure 4. Cyclic-loading test.

widening and fixation of the tendon graft have been explained in details elsewhere (9, 15).

Biomechanical Testing

Tensile strength was tested using custom made apparatus, which enabled accurate positioning of the tibia for the tension to be applied along the bone tunnel [Figure 3A]. Tests were performed with a Servo-hydraulic testing machine (Amsler HCT 25-400; Zwick Roell AG, Germany) [Figure 3B]. Tibia was fixed to the apparatus using a screw passing through an 8 mm drill hole made in tibia perpendicular to its long axis. Also a metal pin was passed through the looped end of the ligament attaching the graft to the tensioner system of the testing machine [Figure 3]. Biomechanical loading was done with the following scenario:

A preload of 5 N was applied to specimens at first after which 1000 cycles of 0.5 Hz submaximal loading was applied from 0 to 200 N, and from 0 to 300 N [Figure 4]. Finally, specimens were tensioned with an increasing pulling force. Pull out force was recorded when either fixation or the graft fails, which was monitored in a real time checking for the load versus displacement [Figure 5].

Hence, cyclic loading with resulting forces up to 200 N will resemble the physiologic condition of active extension of the leg or passive motion during

Table 1. Comparison of failure mode and ultimate failure force between the two groups

	Bone Plug Group		Interference Screw Group		*P-value*
Failure at 200-N cyclic loading (n, %)	0		0		NA
Failure at 300-N cyclic loading (n, %)	0		0		NA
Ultimate Pull-out force at failure point mean± SD(N)	502.5±66.6		496 ± 65.5		0.76
Graft failure type (n, %)	N of cases	Force mean± SD(N)	N of cases	force mean± SD(N)	
Slippage	12 (60%)	497±63	7 (35%)	495±64	P value>0.1 for each paired measures
Tear	8 (40%)	505±68	13 (65%)	498±67	

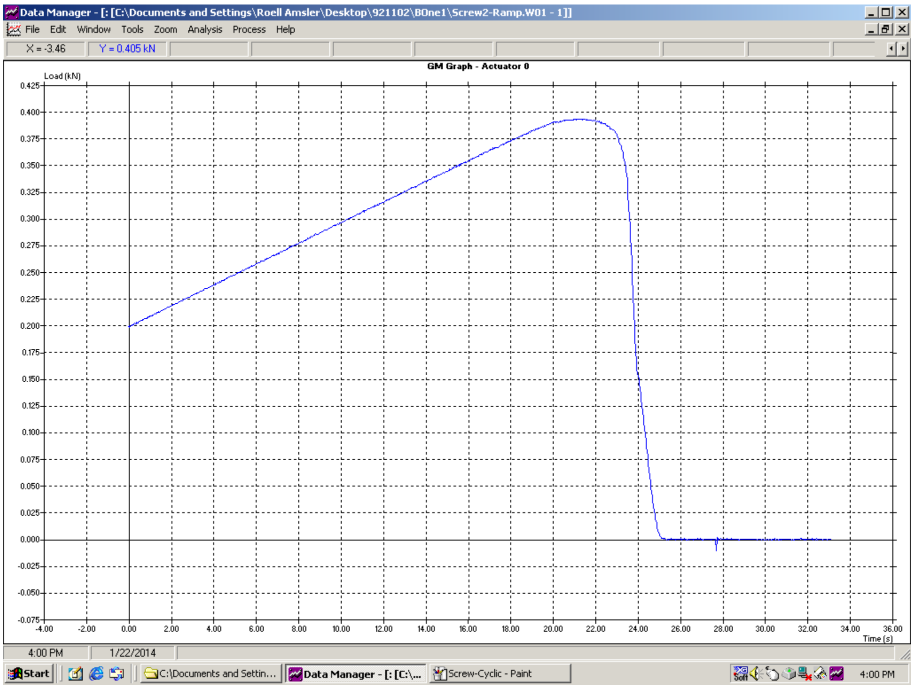

Figure 5. Pull-out test.

rehabilitation (13). Moreover, loading with the maximal strength until graft failure helps to determine the point at which the reconstructed ACL or its fixation points will tolerate disrupting forces (14).

Outcome Measures

There were two types of graft failure in relation to the strength testing. Graft slippage was defined as detachment of either the proximal or distal fixation of the tendon while graft tear was referred to the rupture of the graft along its midsubstance due to increasing pulling forces.

Statistical Analysis

Data are presented as mean (SD) and number (%). Student t-test was used to compare pull out forces and Chi-Square test was used to compare failure mode between the two groups. *P* value <0.05 was considered to be statistically significant.

Results

A total of 40 bovine knees were used and equally assigned to the interference screw group and bone plug group. The mean pull out force until graft failure was 496±66 N in the screw group and 503±67 N in the bone plug group (*P*=0.76). No graft failure was observed after 200 N and 300 N cyclic loading. On the other hand, 21 tendon tear (53%) and 19 slippage (48%) occurred, which did not reveal a significant difference between two groups (*P*=0.11) [Table 1].

Discussion

We sought to introduce our new technique of Bashti bone plug for fixation of soft tissue graft in anterior cruciate ligament (ACL) reconstruction and to compare its biomechanical features with conventional absorbable interference screw technique in a bovine model.

There was no significant difference in the mean pull out strength between groups. Also, no graft failure was observed after cyclic loading. When testing for pull out strength, fixation failure did not occur, but 21 tendon tear and 19 slippage were observed, which showed no significant difference between groups in terms of pull out strength.

Full extension of the knee by contraction of the quadriceps muscle has been shown to produce forces up to 200 N on the ACL graft (17). To allow for adequate rehabilitation, the initial fixation strength of the graft should be strong enough to counteract with these resultant forces. Our technique produces a bone plug while creating a tunnel, and then the plug is used to secure the fixation of the tendon graft into the tunnel. According to the present study, the results of bone plug technique are comparable with the interference screw method in terms of cyclic loading, maximal loading until failure, and failure mode.

There are several techniques for fixation of the graft into the bone tunnel during ACL reconstruction surgeries (1, 7, 13, 15). While graft fixation with metal interference screws has been associated with postoperative displacement under magnetic field, foreign body reaction and complicated revision surgery, bioabsorbable screws are likely to result in intra-operative breakage or incomplete absorption of the compound (18-19). However, interference screws have provided secure fixation during one-time loading with maximal strength (15). In contrast, during early rehabilitation, the reconstructed ACL is repeatedly loaded by a continuous passive motion machine.* As a biocompatible material, bone plugs have shown some advantages over conventional interference fixation of the tendon grafts with screws into the bone tunnel (9, 16, 19). There is no inflammatory reaction regarded to the bone plug while this technique is cheap and feasible owing to autogenous harvesting of the bone plug. Augmentation of BPTB with bone plug has shown improved morphological and clinical outcomes at five years (16). However, another study comparing initial fixation with interference screws and press-fit fixation technique in a porcine model showed that press-fit fixation does not provide a secure fixation in all specimens with five cases of press-fit fixation failed under cyclic loading (15). Kim et al. compared the results of secondary fixation in ACL reconstruction with Achilles tendon allograft between bioabsorbable interference screw and fixation with autogenous bone from the tibia (9). There were 14 complications (34%) in the screw group compared to six complications (15%) in the bone plug group (P=0.046) with the mean cross-sectional area of the tibial tunnel widening being significantly smaller in patients underwent bone plug technique (15% vs. 38%, P=0.017). The study failed to measure the biomechanical load-to-failure level to compare the fixation strength between two techniques. On the other hands, their patients underwent a secondary surgery due to insufficient fixation strength during initial surgery.

To the best of our knowledge, no study has yet compared biomechanical features of initial soft tissue fixation between interference screw and bone plug technique. Our new technique namely Bashti bone plug technique (BBPT) uses only autogenous bones to fixate the graft into the tunnel avoiding the use of additional interference screw or press-fit technique as for bone patellar tendon bone graft. The same technique can be applied for femoral side but obtaining the bone plug, delivering, and then impacting the graft into the tunnel is technically demanding through arthroscopy. However, the technique is relatively easier for tibial tunnel than for the femoral tunnel due to direct access to the tibial tunnel under the skin (20). Attention should be paid to keep the reamer spinning freely inside the joint and trimming the bone plug to a conical shape to allow easy passage of the bone into the tunnel. In Bashti bone Plug technique, tibial tunnel is prepared conically with a conical dilator for more secure fixation of tendon to bone and a special bone transfer trocar is used to prevent bone plug breakage [Figure 1].

Although this study lacks a follow-up component, simulation of early rehabilitation forces by performing the pull out test and cyclic loading were able to test the biomechanical strength of these two techniques, which are believed to be extremely large at early postoperative period. However, it should be noted that the animal model may be a source of variation in evaluating biomechanical forces as porcine bone is more similar to human bone and have smaller failure loads than that of a bovine model (14, 21). This may explain the larger pull out forces compared to other studies on human or porcine models and no graft failure at 200 or 300 N cyclic loading. This should be considered in human bones with less tolerability to the ultimate loading forces, especially when the age of the donated ligament and the bone density vary widely leading to variation of the results. On the other hand, as a common complication seen in the late postoperative period, tunnel widening has been reported to occur in a large number of cases after ACL reconstruction using conventional methods (8) which remains to be determined in the future studies on patients. Moreover, long-term follow-up of patients undergoing Bashti bone plug technique is needed to provide evidence on late functionality of reconstructed ACLs with this method. Further studies should be done in future on human model to investigate the effectiveness of this method in human being.

Our suggested fixation method of Bashti bone plug technique (BBPT) for secure fixation of tendon graft in ACL reconstruction is a native, cheap, and feasible method, which provides comparable biomechanical strength with interference screw in bovine model.

Kaveh Bashti MD
Mohammad N Tahmasebi MD
Department of Orthopedics, Division of Knee Surgery, Shariati Hospital, Tehran University of Medical Sciences, Tehran, Iran

Hasan Kaseb MD
Department of Orthopedics, Division of Knee Surgery, Tehran University of Medical Sciences, Tehran, Iran

Farzam Farahmand PhD
Mohammad Akbar
Amir Mobini
Biomechanics School, Sharif University of Technology, Tehran, Iran

References

1. Jomha NM, Pinczewski LA, Clingeleffer A, Otto DD. Arthroscopic reconstruction of the anterior cruciate ligament with patellar-tendon autograft and interference screw fixation. The results at seven years. J Bone Joint Surg Br. 1999; 81(5):775-9.
2. Levy IM, Torzilli PA, Warren RF. The effect of medial meniscectomy on anterior-posterior motion of the knee. J Bone Joint Surg Am. 1982; 64(6):883-8.
3. Middleton KK, Hamilton T, Irrgang JJ, Karlsson J, Harner CD, Fu FH. Anatomic anterior cruciate

ligament (ACL) reconstruction: a global perspective. Part 1. Knee Surg Sports Traumatol Arthrosc. 2014; 2(7):1467-82.

4. Asik M, Sen C, Tuncay I, Erdil M, Avci C, Taser OF. The mid- to long-term results of the anterior cruciate ligament reconstruction with hamstring tendons using Transfix technique. Knee Surg Sports Traumatol Arthrosc. 2007; 15(8):965-72.
5. Struewer J, Ziring E, Oberkircher L, Schuttler KF, Efe T. Isolated anterior cruciate ligament reconstruction in patients aged fifty years: comparison of hamstring graft versus bone-patellar tendon-bone graft. Int Orthop. 2013; 37(5):809-17.
6. Erickson BJ, Harris JD, Fillingham YA, Frank RM, Bush-Joseph CA, Bach BR Jr, et al. Anterior Cruciate Ligament Reconstruction Practice Patterns by NFL and NCAA Football Team Physicians. Arthroscopy. 2014; 30(6):731-8.
7. Angoules AG, Balakatounis K, Boutsikari EC, Mastrokalos D, Papagelopoulos PJ. Anterior-Posterior Instability of the Knee Following ACL Reconstruction with Bone-Patellar Tendon-Bone Ligament in Comparison with Four-Strand Hamstrings Autograft. Rehabil Res Pract. 2013;2013:572083.
8. Achtnich A, Stiepani H, Forkel P, Metzlaff S, Hanninen EL, Petersen W. Tunnel widening after anatomic double-bundle and mid-position single-bundle anterior cruciate ligament reconstruction. Arthroscopy. 2013; 29(9):1514-24.
9. Kim SJ, Bae JH, Song SH, Lim HC. Bone tunnel widening with autogenous bone plugs versus bioabsorbable interference screws for secondary fixation in ACL reconstruction. J Bone Joint Surg Am. 2013; 95(2):103-8.
10. Iorio R, Di Sanzo V, Vadala A, Conteduca J, Mazza D, Redler A, et al. ACL reconstruction with hamstrings: how different technique and fixation devices influence bone tunnel enlargement. Eur Rev Med Pharmacol Sci. 2013; 17(21):2956-61.
11. Kim HS, Seon JK, Jo AR. Current Trends in Anterior Cruciate Ligament Reconstruction. Knee Surg Relat Res. 2013; 25(4):165-73.
12. Dingenen B, Janssens L, Claes S, Bellemans J, Staes F. Postural stability during the transition from double-leg stance to single-leg stance in anterior cruciate ligament reconstructed subjects. Br J Sports Med. 2014; 48(7):585.
13. Lim BO, Shin HS, Lee YS. Biomechanical comparison of rotational activities between anterior cruciate ligament- and posterior cruciate ligament-reconstructed patients. Knee Surg Sports Traumatol Arthrosc. 2014 Mar 26.
14. Hulstyn M, Fadale PD, Abate J, Walsh WR. Biomechanical evaluation of interference screw fixation in a bovine patellar bone-tendon-bone autograft complex for anterior cruciate ligament reconstruction. Arthroscopy. 1993; 9(4):417-24.
15. Seil R, Rupp S, Krauss PW, Benz A, Kohn DM. Comparison of initial fixation strength between biodegradable and metallic interference screws and a press-fit fixation technique in a porcine model. Am J Sports Med. 1998; 26(6):815-9.
16. Nebelung S, Deitmer G, Gebing R, Reichwein F, Nebelung W. Improved outcomes after anterior cruciate ligament reconstruction with quadrupled hamstring autografts and additional bone plug augmentation at five year follow-up. Int Orthop. 2013; 37(3):399-405.
17. Engebretsen L, Lew WD, Lewis JL, Hunter RE. Knee mechanics after repair of the anterior cruciate ligament. A cadaver study of ligament augmentation. Acta Orthop Scand. 1989; 60(6):703-9.
18. Emond CE, Woelber EB, Kurd SK, Ciccotti MG, Cohen SB. A comparison of the results of anterior cruciate ligament reconstruction using bioabsorbable versus metal interference screws: a meta-analysis. J Bone Joint Surg Am. 2011; 93(6):572-80.
19. Kaeding C, Farr J, Kavanaugh T, Pedroza A. A prospective randomized comparison of bioabsorbable and titanium anterior cruciate ligament interference screws. Arthroscopy. 2005; 21(2):147-51.
20. Said HG, Baloch K, Green M. A new technique for femoral and tibial tunnel bone grafting using the OATS harvesters in revision anterior cruciate ligament reconstruction. Arthroscopy. 2006; 22(7):796.
21. Markolf KL, Gorek JF, Kabo JM, Shapiro MS. Direct measurement of resultant forces in the anterior cruciate ligament. An in vitro study performed with a new experimental technique. J Bone Joint Surg Am. 1990; 72(4):557-67.