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this research was to compare the results of knee stability, knee
motion and activity after anterior cruciate ligament reconstruc-
tion with single bundle hamstring tendon graft versus bone
hamstring tendon bone graft placed with different techniques.

Introduction

Anterior cruciate ligament (ACL) injury has a low
rate of prevalence among general population, but it is a
common athletic injury and one of the most com-
monly treated conditions of the knee [1]. The aim
of ACL reconstruction is to reproduce the mechani-
cal and biological properties of the original ligament.
It should restore the knee stability, maintain the ran-
ge of movement and thereby minimize injury to both the
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Material and Methods

Ninety patients who underwent ante-
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into three groups: group I patients were treated with standard
single bundle hamstring tendon graft and standard operative
technique, group II patients had modified single bundle ham-
string tendon graft with bone attachments on both ends which
was fixed with standard method, while group III patients were
operated with hybrid fixation technique at the tibial site and
modified graft was used as neoligament. Results. All surgically
treated patients had a statistically significant improvement post-
operatively in comparison with their condition before the treatment
according to the Lachman scale and International Knee Documen-
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to participate in the first competition after surgery than the athletes
from the other two groups. Conclusion. Hybrid operative technique
increased strength and stability of the graft at the tibial site which
accelerated healing process and reduced knee laxity.

Key words: Anterior Cruciate Ligament Reconstruction; Tibia;
Tendons; Range of Motion, Articular; Joint Instability; Treat-
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Sažetak

Uvod. Ruptura prednjeg ukrštenog ligamenta jedna je od najčešćih
povreda u ekipnim sportovima, a fiksacija u golenjači je najsloba-
dija karika u strukturi butna kost−hamstring−kolenjača kod rekonstruk-
cijske prednjeg ukrštenog ligamenta. Cilj ovog istraživanja bio je da se
uporedje rezultati stabilnosti kolena, pokretljivosti i aktivnosti kolena
nakan rekonstrukcije prednjeg ukrštenog ligamenta kalemom od
tetiva hamstringa (jednostruki snop) u odnosu na kalem−tetiva
hamstringa−kost, fiksirani različitim tehnikama. MATERIJAL I METO-
de. Devedeset pacijenata kojima je urađena rekonstrukcija prednjeg
ukrštenog ligamenta, metodom slučajnog izbora, raspoređeni su u
tri grupe: u prvoj grupi bili su pacijenti kod kojih je primenjen stan-
dardni kalem od tetiva hamstringa−jednostruki snop i standardna
operativna tehnika; u drugoj grupi bili su pacijenti sa modifikovanim
ekalemom od tetiva hamstringa sa koštanim gajčanjem na oba kraja,
fiksiran standardnom operativnom metodom, dok je kod pacijenata
iz treće grupe primenjena hibridna tehnika fiksacije na strane golen-
jače i modifikovani kalem je korisćen kao neoligament. REZULTATI. Svi hirurški tretirani pacijenti su imali statistički značajno postope-
rativno poboljšanje u odnosu na njihovo stanje pre operacije prema
Lahmanovoj skali i standardu International Knee Documentation
Committee. Međutim, kod pacijenata iz treće grupe postignuti su
statistički značajno bolji postoperativni rezultati prema Tegnerovoj
skali i Lisholmovom skoru u poređenju sa rezultatima postignutim kod
pacijenata iz prve i druge grupe. Vreme koje je sportistima iz
treće grupe bilo je potrebno da bi učestvovali na prvom takmičenju
posto je bilo potrebno sportistima iz preostale dve grupe pre nego su mogli
do sakupljanja i smanjio labavost kolena. ZAKLJUČAK. Hibridna operativna tehnika je
povećala čvrstinu i stabilitet kalem na strani golenjača što je
bezbednost golenjača; ishod lečenja; Lisholmov skor

Ključne reči: rekonstrukcija prednjeg ukrštenog ligamenta; tibija;
tetive; opseg pokreta zgloba; nestabilnost zgloba; ishod lečenja;

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mation Outcome; Lysholm Knee Score
Patients
The study was a randomized retrospective-prospective one. The research was performed at the Department of Orthopedic Surgery and Traumatology of the Clinical Center of Vojvodina with the approval of the Ethical Committee of Clinical Center of Vojvodina.

The study inclusion criteria were the ages of 18 to 45 years and ACL rupture diagnosis. Therefore, the patients under the age of 18 and over the age of 45 years, those with injuries of other ligaments or with comorbidities which may complicate the surgical procedure were not included in the study.

The exclusion criteria were surgical complications and patients who were operated 60 months after ACL had been injured.

Out of 92 patients included in the study, 90 patients finished it. Two patients were excluded from the study since they underwent ACL reconstruction 60 months after the ACL rupture.

Grafts
Two types of grafts were prepared for ACL reconstruction:

– Single bundle hamstring tendon graft prepared from m. semitendinosus and m. gracilis tendons. The tendons with its periosteal attachments were harvested through a small incision. Single bundle technique was used and grafts whose diameter was 8 or 9 mm.

– Single bundle hamstring tendon graft prepared from m. semitendinosus and m. gracilis tendons strengthened with fresh bone autotransplant (compressed spongy bone) on the graft end. Two 2-cm long bone cylinders of 8 mm in diameter were harvested and tied on both ends of the tendon with sutures. The bone ends were pressed, so the diameter of the prepared grafts was 8 or 9 mm.

Operative technique
The tendon grafts were fixed with standard operative procedure or with hybrid graft tibial fixation.

– The standard graft tibial fixation was fixed with interference screws in the previously prepared femoral and tibial tunnel.

– The hybrid graft tibial fixation was prepared at the Department of Orthopedic Surgery and Traumatology of the Clinical Center of Vojvodina, Faculty of Medicine, Novi Sad. The grafts were placed in the previously prepared femoral and tibial tunnels. The grafts were fixed with round cannulated interference screws, RCI (Grujic&Грјуић, Novi Sad, Serbia). When the graft was fixed in the femoral tunnel, the knee was in full flexion, at 110–120° and when it was fixed in the tibial tunnel, the knee was under the angle of 15–20°. The graft was tensioned using 80 N (Karl Storz, Tutlingen, Germany). After being fixed with round cannulated interference screws, additional fixation was performed. Bi-cortical 4.5-mm-diameter custom-made screws with modified head were placed below the tibial tunnel opening. First, the screw was tightened completely and afterwards it was loosened for half a circle. Three additional knots were tied in to provide improved graft fixation and knee stability. Finally, the screw was retightened for a quarter of a circle. For more details see reference [13].

Rehabilitation
After surgery the operated knee was fixed with the elastic immobilizer for fourteen days. Shelbour-
From day one after surgery the patients were subjected to continuous passive mobilization of the operated knee with Kinetic Performa. Two weeks after the ACL reconstruction they were able to reach 90° flexion and partial weight bearing (as tolerated), while the complete weight bearing was allowed six weeks later. The rehabilitation program consisted of series of exercises designed to restore the muscle strength.

Groups
The patients were randomly divided into three groups:

- **Group I** – Single bundle hamstring tendon graft prepared from *m. semitendinosus* and *m. gracilis tendons*, fixed with standard operative procedure (30 patients);
- **Group II** – Single bundle hamstring tendon graft prepared from *m. semitendinosus* and *m. gracilis tendons* with bone autotransplant on the graft end (bone-hamstring-bone, BHB), fixed with standard operative procedure (30 patients);
- **Group III** – Single bundle hamstring tendon graft prepared from *m. semitendinosus* and *m. gracilis tendons* with bone autotransplant on the graft end (BHB) fixed with hybrid tibial fixation procedure (30 patients).

**Evaluation and Rating Scales**
The following tests were used for objective determination of the knee function before and after ACL reconstruction:

- **Lachman test** – a reliable and sensitive test to diagnose ACL injury and knee laxity as mild: 0 to 5 mm, moderate: 6 to 10 mm laxity and severe: 11 to 15 mm. Following ACL reconstruction, laxity should be less than 3 mm compared to healthy knee results [15].
- **Tegner activity grading scale** (from 0 to 10) - a system for evaluating the degree of impairment, disability, and handicap of the patient with an ACL injury including functional score, activity grading, stability testing, and measurements of performance and strength, where 0 indicates retirement, while 10 allows professional sport activities [16].
- **Lysholm scoring scale** (to max 100) for knee ligament surgery follow-up emphasizes evaluation of symptoms of instability [17, 18]. The score is considered to be poor if it is below 66, fair if ranging from 66 to 81, good for values between 82 and 92 and excellent if it is above 93.

**Results**

**Demographic**
Ninety-two patients were enrolled in the study and two patients were excluded since the interval between the ACL injury and ACL reconstruction was over 60 months. Out of 90 patients who finished the study, 71% were men and 29% were women. The patients were between the ages of 18 and 45 years, the average age being 27.16±7.46 years. Table 1 gives the average age and the average body mass index (BMI) of the patients who underwent ACL reconstruction.

There was a statistically significant difference in age among the patients treated with standard operative technique and standard graft (group I) and those with hamstring graft tendon and standard operative technique (group II), as well as between group I patients and those with bone-hamstring tendon-bone graft and hybrid operative method (group III patients) presented as t=1.9695 and p=0.0545 and t=2.1544 and p=0.0372, respectively. No statistically significant difference was recorded between the ages of the patients who underwent ACL reconstruction with hamstring graft tendon, regardless of the operative technique i.e. between group II and group III patients (t=0.7216, p=0.4738).

Most of the patients had normal BMI. None of the women was obese and only 11% of men were obese according to the WHO classification. The patients’ weight was in range from 47 to 105 kg, while the height ranged from 157 to 200 cm. Body mass index of the patients did not differ significantly among the groups.

Out of 79 treated patients who went in for sports, 65% played it professionally and 35% for recreation. The cause for ACL rupture was landing in 35%, direction change in 30% and direct hit with other player in 25% of the cases. Hyperextension and deceleration were responsible for ACL rupture in only 10% of cases.
10% of the examined cases. Out of the study sample, 49% of the operated patients got injured while playing football, 23% handball, 15% basketball, 6% volleyball and 7% all other sports.

The patients underwent surgical treatment up to 60 months after the ACL injury. Surgery was performed in 81% of the patients within 12 months after the injury and in 52% within 4 months after the rupture was diagnosed. The first and the second injury was treated surgically in 38% and 27% of the patients, respectively and the remaining patients underwent operation after three or more injuries of the ligament.

**Lachman test results**

There was no significant difference in Lachman test before and after surgery for the healthy knee in any study group, nor was there a difference between the healthy knee and injured knee results after ACL reconstruction. However, in each operated group there were statistically significant differences between the pre and postoperative results of the injured knee as following: \( t=12.37, p<0.001 \) for group I, \( t=22.45, p<0.001 \) for group II and \( t=16.65, p<0.001 \) for group III, neither were differences of statistical significance recorded among the groups after surgery for the operated knee when Lachman test results were compared although different grafts were placed and different operative techniques were applied. The statistical results are presented below:

- Differences between group I and II \( t=-1.0881, p=0.2819 \)
- Differences between group II and III \( t=-0.3148, p=0.7541 \)
- Differences between group I and III \( t=-0.9338, p=0.355 \)

The details of the Lachman test are presented in Table 2.

**Tegner activity scale results**

According to Tegner activity scale there was a statistically significant difference \( (t=23.90, p<0.001) \) before \( (1.94 \pm 0.89) \) and after the surgery \( (7.70 \pm 1.69) \) in the patients of the observed sample. Most of the athletes (89%) returned to trainings and competition and moreover, 22% of players achieved level 10 of the Tegner activity scale while 20% and 18% of them achieved level 9 and 8, respectively. Table 3 presents Tegner activity scale results of patients in different groups depending on the graft and fixation method type.

There were no statistically significant differences in the postoperative results between the group I and group II patients \( (t=0.6196, p=0.3582) \) according to the Tegner scale. However, the patients from group III who had been operated with hybrid fixation technique and bone-hamstring tendon-bone graft achieved better results on the Tegner activity scale when compared to the group I patients who had had standard tendon graft fixed with standard technique \( (t=3.6753, p<0.001) \) and in comparison with the group II patients who had had the same bone-hamstring tendon-bone graft placed but with standard operative procedure \( (t=3.609, p<0.001) \).

**The Lysholm grading scale results**

The Lysholm scale results suggested a statistically significant postoperative improvement of knee stability.

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**Table 2.** The results of the Lachman test before and after surgery

<table>
<thead>
<tr>
<th>Group</th>
<th>Before surgery/Pre operacije</th>
<th>After surgery/Posle operacije</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>1.0-4.5 2.1 ± 1.1</td>
<td>1.0-7.0 4.2 ± 1.2</td>
</tr>
<tr>
<td>II</td>
<td>1.0-8.0 3.2 ± 1.5</td>
<td>1.0-6.0 3.8 ± 1.2</td>
</tr>
<tr>
<td>III</td>
<td>1.0-5.0 2.9 ± 1.5</td>
<td>1.0-10.5 3.0 ± 2.2</td>
</tr>
</tbody>
</table>

---

**Table 3.** The results of Tegner activity scale of patients in differently treated groups

<table>
<thead>
<tr>
<th>Group</th>
<th>Before surgery/Pre operacije</th>
<th>After surgery/Posle operacije</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>1-2 1.62 ± 0.49</td>
<td>3-10 7.13 ± 1.90</td>
</tr>
<tr>
<td>II</td>
<td>1-6 2.03 ± 0.51</td>
<td>4-10 7.43 ± 1.53</td>
</tr>
<tr>
<td>III</td>
<td>1-4 2.13 ± 0.74</td>
<td>7-10 8.8 ± 0.87</td>
</tr>
</tbody>
</table>

---
when compared with preoperative results \( (t=21.86, p<0.001) \). According to the Lysholm scale, the results were excellent in 39.50%, good in 20.25%, fair in 12.15% and poor 8.10% of the patients after ACL reconstruction.

**Table 4.** The results of the Lyshom scale before and after surgery in different groups

<table>
<thead>
<tr>
<th>Group I/Grupa I</th>
<th>Before surgery/Pre operacije</th>
<th>Interval/Interval</th>
<th>Average ± SD/Sred. vr ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>After surgery/Posle operacije</td>
<td></td>
<td>32-95</td>
<td>42.33 ± 6.34</td>
</tr>
<tr>
<td>Group II/Grupa II</td>
<td>Before surgery/Pre operacije</td>
<td>27-89</td>
<td>59 ± 3.96</td>
</tr>
<tr>
<td>After surgery/Posle operacije</td>
<td></td>
<td>72-100</td>
<td>96.33 ± 4.27</td>
</tr>
<tr>
<td>Group III/Grupa III</td>
<td>Before surgery/Pre operacije</td>
<td>27-96</td>
<td>58.12 ± 4.38</td>
</tr>
<tr>
<td>After surgery/Posle operacije</td>
<td></td>
<td>90-100</td>
<td>97.92 ± 2.54</td>
</tr>
</tbody>
</table>

No statistical significance was recorded in the postoperative results of the Lysholm scale between the group I and group II patients, nor between the group II and group III patients, \( t=-0.2447, p=0.8077 \) and \( t=1.1595, p=0.2517 \) respectively. Introducing different operative techniques and different graft type simultaneously resulted in a statistically significant increment in the knee stability in the group III patients according to the Lysholm scale in comparison with the postoperative knee stability in the group I patients, \( t=2.0259, p=0.492 \).

**IKDC scale grades**

**Table 5** summarizes the IKDC scale grades before and after ACL reconstruction in each observed group.

<table>
<thead>
<tr>
<th>Grade A/Ocena A</th>
<th>Grade B/Ocena B</th>
<th>Grade C/Ocena C</th>
<th>Grade D/Ocena D</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>%</td>
<td>n</td>
<td>%</td>
</tr>
<tr>
<td>Group I/Grupa I</td>
<td>Before surgery</td>
<td>Pre operacije</td>
<td>14</td>
</tr>
<tr>
<td>After surgery</td>
<td>21</td>
<td>70.0</td>
<td>7</td>
</tr>
<tr>
<td>Posle operacije</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group II/Grupa II</td>
<td>Before surgery</td>
<td>Pre operacije</td>
<td>22</td>
</tr>
<tr>
<td>After surgery</td>
<td>22</td>
<td>73.3</td>
<td>5</td>
</tr>
<tr>
<td>Posle operacije</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group III/Grupa III</td>
<td>Before surgery</td>
<td>Pre operacije</td>
<td>24</td>
</tr>
<tr>
<td>After surgery</td>
<td>26</td>
<td>86.6</td>
<td>3</td>
</tr>
<tr>
<td>Posle operacije</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Discussion**

ACL injuries are common in team sports. Football (soccer) is the most popular sport worldwide with more than 270 million active players (www.fifa.com) and based on data from a sampling of college men’s football teams, there were an estimated 69 ACL injuries nationwide in a single season [20] or incidence rates of ACL injury ranged from 0.15% to 3.67% in soccer players of various age and competition levels per year [21]. These findings correspond with 49% injuries in football players compared to all other athletes in our sample.

Graft fixation, function, and integration ultimately determine the outcome of ACL reconstruction [22, 23]. The knee stability improved after ACL reconstruction in the 90 observed patients regardless of the graft type and surgical technique performed. The comparison of the pre and postoperative results of the Lachman test confirmed the postoperative improvement of knee laxity. There were no differences in the knee laxity after surgery between groups. When the operated knee has been compared with the healthy knee the results are considered excellent if the arthrometric measurement of knee laxity is between 0 and 3 mm and good if it is up to 5 mm [24]. The obtained results in this study can be considered good/excellent. Freedman and al. [25] have analyzed 34 studies of ACL reconstruction, 21 with patellar tendon graft and 13 with hamstring tendon graft in over 1,300 patients. The literature data are in accordance with our study since 73.8% of the obta-
ined results after hamstring tendon graft placement according to the Lachman test were excellent (<3 mm) and 19.4% were classified as good (3-5 mm), while 79% were excellent and 15.4% were good when patellar tendon graft was used for reconstruction. In the review study of Lewis and al. [26], in which 1024 single-bundle anterior cruciate ligament reconstructions were analyzed from 11 studies, it was found that the results were good/excellent (<5 mm) according to Lachman test in 86%. Hence, when the Lachman test results after ACL reconstruction in this study are adequately interpreted, they are comparable to literature data.

Furthermore, the results of the Tegner activity scale and Lysholm scoring scale define more precisely the postoperative quality of life of the patients with ACL reconstruction. Both Tegner scale and Lysholm scale confirm a significant improvement of the possibility for everyday and professional sport activity in our patients after surgery as expected [27–29]. The average values for Tegner scale were improved from 1.94 after the injury to 7.70 after ACL reconstruction. Moreover, the Lysholm scale confirmed these findings, so the preoperative values ranged from 27 to 89, the average value being 54.03, and they were improved to as much as 72 to 100, the average postoperative value being 96.9. However, more careful observation of the results of both Tegner and Lysholm scale suggest that postoperative activity of the patients is affected by the operative method and the graft type applied. The statistically significant difference in the postoperative Tegner activity scale results of the group III compared with the postoperative results of the group II and group I indicates the more pronounced knee stability in the group III patients and greater possibility for unimpeded and painless physical activity after surgery. The postoperative results obtained with the Lysholm grading scale confirm the statistically significant differences in knee stability and its influence on the patients’ quality of life after surgery between the group I and group III patients. However, no statistically significant differences were recorded in the postoperative results of the Lysholm scale between the group II and group III patients. The postoperative results of the Tegner activity scale and of the Lysholm grading scale presented in this paper for the group I and II patients correspond to the results reported in the literature, no matter whether hamstring tendon graft with single bundle or double bundle technique was performed [30], quadrupled hamstring graft was placed [31] or quadruple-stranded semitendinosus tendon was used [32] for ACL reconstruction or whether interference screw or a press-fit fixation was applied [33]. When Tegner and Lysholm scales were applied, the results obtained after operative treatment in the group III patients (hamstring graft tendon with bone attachment fixed with hybrid surgical technique) are even more favorable compared to the literature data [30–33].

Most of the players (89%) who were followed up after surgery have returned to their professional sport activities. There was a difference in time, although not statistically significant, it took the athletes from group I and group III to resume training and it depended on the operative technique and graft type (it took the group III athletes the least time from surgery to their first training). It took the operated athletes from group III statistically significantly less time to enter the first sport competition when compared with the group II and group I patients, which further corroborates these statements. Normally, there are no sites in the human body where tendon enters the bone tunnel, while in the fixation process the tendinous portion of the hamstring graft usually extends into the upper part of the tibial tunnel [34]. The bone attached to both sides of the tendon graft (in group II) reduces the healing time when compared to group I in which standard single bundle hamstring graft was placed, while hybrid fixation which was performed in group III reduced slippage of the soft tissue and additionally decreased the time required for recovery.

The IKDC scale reported in this paper showed grade A/B (normal/nearly normal) after the surgery in 93.4% patients from group I, 89.9% from group II and 96.6% from group III compared to 0% before the ACL reconstruction. Normal/nearly normal (A/B) grade usually ranges between 78 and 92% after surgical treatment of ACL rupture [30, 35–38], hence the obtained results in this study can be considered quite satisfactory.

Conclusion

The surgical treatment of anterior cruciate ligament rupture improves subjective experience of knee motility and objective stability of the treated knee. Placing bone-hamstring tendon-bone graft allows a biological approach since no artificial fixation devices, i.e. implants, are utilized and it diminishes the risk of postoperative bone tunnel enlargement because tibial tunnel diameter is filled with the tibial bone cylinder and hence reduced. Finally, additional fixation guarantees the knee stability, increases the graft fixation strength and secures the improvement of life quality which includes not only everyday activity but professional sport trainings and competition.
References


