Aus der Klinik für Orthopädie und Unfallchirurgie des Martin-Luther-Krankenhauses Berlin, Akademisches Lehrkrankenhaus der Medizinischen Fakultät Charité – Universitätsmedizin Berlin

DISSERTATION

# Anterior Cruciate Ligament Revision Surgery: Ipsilateral Quadriceps Versus Contralateral Semitendinosus-Gracilis Autografts

zur Erlangung des akademischen Grades
Doctor medicinae (Dr. med.)

vorgelegt der Medizinischen Fakultät
Charité – Universitätsmedizin Berlin

von

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aus Berlin

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Inhaltsverzeichnis

# 1. Abstract

Englisch:

**Purpose:** To evaluate the subjective outcomes, knee stability, and donor-site morbidity after revision ACL reconstruction using either autologous ipsilateral quadriceps tendon or contralateral semitendinosus-gracilis tendon.

**Methods:** A sample-size calculation suggested that we needed 25 patients in each group to detect equality between both groups. Therefore, we evaluated 30 consecutive patients who underwent an ACL revision surgery with ipsilateral bone-quadriceps tendon grafts and 30 consecutive patients with the contralateral semitendinosus-gracilis grafts between January 2010 and December 2012. Because of follow-up and exclusion criteria, finally 51 patients were evaluated. All patients were followed prospectively for at least 2 years with KT1000 arthrometer testing and the International Knee Documentation Committee (IKDC) objective grading. At the 24-month follow-up, additional clinical scores were evaluated: the Knee Injury Osteoarthritis Outcome Score (KOOS), the Lysholm score, assessing pain during kneeling and anterior knee pain.

**Results:** The KT1000 postoperatively arthrometer side-to-side difference was 2.0 ± 1.2 mm for the quadriceps group and 3.0 ± 2.9 mm for the semitendinosus-gracilis group. The difference was not statistically significant ($P$ = 0.461). There was also no difference in the rate of positive pivot-shift tests between groups ($P$ = 0.661). The Lysholm score was 82.5 ± 18 in the quadriceps group and 73.8 ± 19 in the semitendinosus-gracilis group. The difference was not statistically significant ($P$ = 0.060). There was also no significant difference in the single KOOS subscores, assessing pain while kneeling and anterior knee pain (included in the KOOS score). No rerupture occurred during follow-up.

**Conclusion:** Revision ACL reconstruction using the quadriceps tendon graft showed clinical outcomes similar to those of the contralateral semitendinosus-gracilis graft in terms of knee stability and function. Thus, the bone–quadriceps tendon graft may be a good alternative to the contralateral semitendinosus-gracilis tendon graft for revision ACL reconstruction.

Deutsch:

**Ziel**: Vergleich der subjektiven Beurteilung des Knies, der Kniestabilität, der Entnahmemorbidität nach einer Revisionsrekonstruktion des vorderen Kreuzbandes (VKB) mit autologer ipsilateraler Quadrizepssehne oder kontralateraler Semitendinosus-Gracilissehne.

**Methodik:** Eine Schätzung der Stichprobengröße hat angezeigt, dass 25 Patienten je Gruppe benötigt werden, um Gleichwertigkeit zwischen beiden Gruppen zu erkennen. Deshalb wurden 30 aufeinanderfolgende Patienten, die ein ipsilaterales Quadrizepssehnentransplantat und weitere 30 aufeinanderfolgende Patienen, die ein kontralaterales Semitendinosus-Gracilissehnentransplantat zwischen Januar 2010 und Dezember 2012 erhalten haben, untersucht. Aufgrund von Ein- und Ausschlusskriterien wurden 51 Patienten in die Studie eingeschlossen. Alle Patienten wurden prospektiv für mindestens 2 Jahre mit dem KT1000 Arthrometer und dem Formblatt des “International Knee Documentation Committee” (IKDC) untersucht. Außerdem wurden nach 24 Monaten folgende Tests hinzugezogen: der “Knee Injury Osteoarthritis Outcome Score” (KOOS), der Lysholm-Score, die Bemessung des Schmerzes während des Hockens und der vordere Knieschmerz.

**Ergebnisse:** Die postoperative KT1000 Arthrometer Messung hat eine Seitendifferenz von 2.0 ± 1.2 mm für die Quadrizepsgruppe und 3.0 ± 2.9 mm für die Semitendinosus-Gracilis-Gruppe ergeben. Der Unterschied war statistisch nicht signifikant ($P$ = 0.461). Es gab weiterhin keine signifikante Differenz bei der Anzahl positiver Pivot-Shift-Tests ($P$ = 0.661). Der Lysholm-Score ergab in der Quadrizepsgruppe einen Wert von 82.5 ± 18 und in der Semitendinosus-Gracilis-Gruppe einen Wert von 73.8 ± 19. Auch dieser Unterschied war statistisch nicht signifikant ($P$ = 0.060). Des Weiterem gab es keine signifikante Differenz bei den einzelnen KOOS Untergruppen, bei der Bemessung des Schmerzes während des Hockens und beim vorderen Knieschmerz (ermittelt durch den KOOS Score). Während der 24-monatigen Untersuchungszeit trat keine Reruptur auf.

**Schlussfolgerung:** Die Revisionsrekonstruktion des VKB mit dem Quadrizepssehentransplantat zeigt zum kontralateralen Semitendinosus-Gracilissehnentransplantat in Bezug auf Kniestabilität und Funktion vergleichbare Ergebnisse. Deshalb ist die Quadrizepssehne eine gute Alternative zur Semitendinosus-Gracilissehne bei Revisionsrekonstruktionen des VKB.

2. Eidesstattliche Versicherung und Anteilserklärung

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Ausführliche Anteilserklärung an der erfolgten Publikation

Publikation : Häner M, Bierke S, Petersen W. Anterior Cruciate Ligament Revision Surgery: Ipsilateral Quadriceps Versus Contralateral Semitendinosus-Gracilis Autografts. *Arthroscopy.* 2016.

Beitrag im Einzelnen:

- Durchführung der Stichprobengrößenkalkulation

- Aufstellen von Einschluss- und Ausschlusskriterien

- Erstellen des Flussdiagramms für die 24-monatige Untersuchungszeit

- Statistische Analyse des Formblattes des „International Knee Documentation Commitee“ (IKDC)

- Verfassen der Einleitung, des Methodenteils und der Beschreibung der OP-Technik

- Auswertung der Daten für die KT1000 Arthrometer Messung, den Pivot-Shift-Test, den Lysholm-Score, der KOOS Untergruppen, des Formblattes des „International Knee Documentation Commitee“ (IKDC) und des vorderen Knieschmerzes im Ergebnisteil

- Verfassen der Diskussion mit Bezugnahme auf andere Publikationen

- Erstellen und Verfassen der Einschränkungen der Arbeit

- Schlussfolgerung aus der Auswertung der Ergebnisse/Daten und der Diskussion

Unterschrift des Doktoranden/der Doktorandin

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# 3. Auszug aus der Journal Summary List



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| Mark | Rank | Abbreviated Journal Title (linked to journal information) | ISSN | JCR Data | | | | | | *Eigenfactor*® Metrics | |
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| | | | | Total Cites | Impact Factor | 5-Year Impact Factor | Immediacy Index | Articles | Cited Half-life | *Eigenfactor*® Score | *Article Influence*® Score |
| | 1 | J BONE JOINT SURG AM | 0021-9355 | 38618 | 5.163 | 5.372 | 0.424 | 255 | >10.0 | 0.05086 | 2.089 |
| | 2 | OSTEOARTHR CARTILAGE | 1063-4584 | 11842 | 4.535 | 5.093 | 0.913 | 254 | 6.3 | 0.02612 | 1.634 |
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| | 5 | ARTHROSCOPY | 0749-8063 | 11993 | 3.724 | 3.865 | 1.533 | 276 | 7.8 | 0.02051 | 1.208 |
| | 6 | CLIN ORTHOP RELAT R | 0009-921X | 33080 | 3.127 | 3.477 | 0.782 | 386 | >10.0 | 0.04084 | 1.258 |
| | 7 | KNEE SURG SPORT TR A | 0942-2056 | 9184 | 3.097 | 3.083 | 0.356 | 495 | 4.7 | 0.02426 | 0.903 |
| | 8 | J AM ACAD ORTHOP SUR | 1067-151X | 3852 | 3.055 | 3.207 | 0.393 | 107 | 7.7 | 0.00830 | 1.265 |
| | 9 | J ORTHOP RES | 0736-0266 | 13276 | 2.807 | 3.151 | 0.489 | 235 | 9.1 | 0.01988 | 0.996 |
| | 10 | PHYS THER | 0031-9023 | 9933 | 2.799 | 3.680 | 0.802 | 131 | >10.0 | 0.01172 | 1.174 |
| | 11 | BONE JOINT J | 2049-4394 | 1722 | 2.660 | 2.662 | 0.463 | 272 | 2.1 | 0.00845 | 0.940 |
| | 11 | SPINE J | 1529-9430 | 5887 | 2.660 | 3.008 | 0.586 | 324 | 5.3 | 0.01729 | 1.113 |
| | 13 | ACTA ORTHOP | 1745-3674 | 7101 | 2.617 | 3.089 | 0.647 | 116 | >10.0 | 0.00920 | 1.089 |
| | 14 | J ORTHOP SPORT PHYS | 0190-6011 | 5130 | 2.551 | 3.538 | 0.677 | 99 | 8.8 | 0.00740 | 1.092 |
| | 15 | J ARTHROPLASTY | 0883-5403 | 11117 | 2.515 | 2.640 | 0.314 | 477 | 7.1 | 0.02254 | 0.857 |
| | 16 | SPINE | 0362-2436 | 38769 | 2.439 | 2.786 | 0.334 | 437 | >10.0 | 0.03969 | 0.909 |
| | 17 | BONE JOINT RES | 2046-3758 | 345 | 2.425 | 2.515 | 0.500 | 26 | 2.6 | 0.00177 | 0.885 |
| | 18 | J SHOULDER ELB SURG | 1058-2746 | 8827 | 2.412 | 2.967 | 0.370 | 322 | 6.8 | 0.01816 | 0.930 |
| | 19 | ARCH OSTEOPOROS | 1862-3522 | 462 | 2.387 | | 0.474 | 19 | 2.8 | 0.00217 | |
| | 19 | INT ORTHOP | 0341-2695 | 6578 | 2.387 | 2.481 | 0.462 | 331 | 4.8 | 0.01665 | 0.728 |

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# Anterior Cruciate Ligament Revision Surgery: Ipsilateral Quadriceps Versus Contralateral Semitendinosus-Gracilis Autografts

Martin Häner, Sebastian Bierke, and Wolf Petersen, M.D.

**Purpose:** To evaluate the subjective outcomes, knee stability, and donor-site morbidity after revision ACL reconstruction using either autologous ipsilateral quadriceps tendon or contralateral semitendinosus-gracilis tendon. **Methods:** A sample size calculation suggested that we needed 25 patients in each group to detect equality between both groups. Therefore, we evaluated 30 consecutive patients who underwent an ACL revision surgery with ipsilateral bone−quadriceps tendon grafts and 30 consecutive patients with the contralateral semitendinosus-gracilis grafts between January 2010 and December 2012. Because of follow-up and exclusion criteria, finally 51 patients were evaluated. All patients were followed prospectively for at least 2 years with KT1000 arthrometer testing and the International Knee Documentation Committee (IKDC) objective grading. At the 24-month follow-up, additional clinical scores were evaluated: the Knee Injury Osteoarthritis Outcome Score (KOOS), the Lysholm score, assessing pain during kneeling, and anterior knee pain. **Results:** The KT1000 postoperative arthrometer side-to-side difference was 2.0 ± 1.2 mm for the quadriceps group and 3.0 ± 2.9 mm for the semitendinosus-gracilis group. The difference was not statistically significant ($P = .461$). There was also no difference in the rate of positive pivot-shift tests between groups ($P = .661$). The Lysholm score was 82.5 ± 18 in the quadriceps group and 73.8 ± 19 in the semitendinosus-gracilis group. The difference was not statistically significant ($P = .060$). There was also no significant difference in the single KOOS subscores, assessing pain while kneeling and anterior knee pain (included in the KOOS score). No rerupture occurred during follow-up. **Conclusion:** Revision ACL reconstruction using the quadriceps tendon graft showed clinical outcomes similar to those of the contralateral semitendinosus-gracilis graft in terms of knee stability and function. Thus, the bone−quadriceps tendon graft may be a good alternative to the contralateral semitendinosus-gracilis tendon graft for revision ACL reconstruction. **Level of Evidence:** Level II, prospective comparative study.

Choosing the proper graft material is an important technical issue for primary anterior cruciate ligament (ACL) revision because graft options for revision may be limited because of the previously used grafts.[1] Several grafts have been recommended for revision ACL surgery, including allografts and autografts. A recent registry study showed that better sports function and patient-reported outcome measures were obtained when an autograft, instead of an allograft, was used.[1] Ipsilateral or contralateral semitendinosus-gracilis grafts or bone−patellar tendon−bone (BPTB) grafts are the most popular autograft options.[2] However, there is no consensus about the optimal choice of autograft tissue for ACL revision surgery.[1,3] In contrast to many studies of primary ACL reconstruction, there is little information about the outcome of the various grafts used for ACL revision surgery. A recent registry study showed that there was no difference in outcomes between patellar tendon and semitendinosus-gracilis grafts using autograft and allograft for revision surgery.[1] Currently, the semitendinosus-gracilis graft is probably the most common graft used for primary ACL reconstruction in Europe.[2,4] If a semitendinosus-gracilis graft was used for the primary ACL reconstruction, it

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*The Medical Ethics Committee of the Medical Faculty of the Charité Hospital, University Medicine Berlin, approved the study design.*

*The study protocol is registered with the Deutsches Register Klinischer Studien (German Clinical Trials Register) as DRKS-ID number DRKS00006770.*

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**Table 1.** Inclusion and Exclusion Criteria

| Inclusion Criteria | Exclusion Criteria |
|---|---|
| Recurrent subjective and objective instability after ACL reconstruction | Varus malalignment (Mikulicz line intersecting the knee baseline more than 4 mm medial of the center) |
| Anatomic tunnel positions | Partial anatomic tunnel positions (if one part of the tunnel is outside of the original insertion of the ACL) |
| Nonanatomic tunnel positions | Tunnel diameter of more than 11 mm |
| ACL revision surgery with autologous semitendinosus-gracilis or quadriceps tendon graft | Additional ligamentous instability − MCL > ++, LCL > ++, PCL > + |
| Primary ACL reconstruction with ipsilateral autologous semitendinosus-gracilis tendon | Previous revision ACL reconstruction |
| − | Combination with an HTO |
| − | Primary ACL reconstruction with allograft |
| − | ACL revision surgery with bone−patellar tendon−bone graft |

ACL, anterior cruciate ligament; HTO, high tibial osteotomy; LCL, lateral collateral ligament; MCL, medial collateral ligament; PCL, posterior cruciate ligament.

can be challenging to convince the patient to allow graft harvesting from the contralateral, uninjured knee. Another downside of the autologous semitendinosus-gracilis graft is that recent registry data show a higher prevalence of primary ACL graft failure in patients with an autologous semitendinosus-gracilis graft than patients with a BPTB graft.[5,6]

Another autologous graft choice for ACL revision surgery is the central quadriceps tendon.[7] This graft option has received little attention in the past, although the tendon has the morphologic and biomechanical characteristics to produce a suitable graft for ACL reconstruction.[8-10] A recent systematic review showed that the use of the quadriceps tendon−bone graft for primary ACL reconstruction resulted in knee stability and subjective outcomes similar to those achieved with BPTB grafts but with less donor-site morbidity.[11] In contrast to the many studies on the use of the quadriceps tendon−bone graft for primary ACL reconstruction,[7,12-15] there is little information about its use in ACL revision surgery.

The purpose of this study was to evaluate the subjective outcomes, knee stability, and donor-site morbidity after revision ACL reconstruction using either autologous ipsilateral quadriceps tendon or contralateral semitendinosus-gracilis tendon. Our hypothesis was that use of the quadriceps tendon−bone graft would result in knee stability, good subjective outcomes, and donor-site morbidity similar to that achieved with contralateral semitendinosus-gracilis grafts.

## Methods

### Patients and Entry Criteria

The Medical Ethics Committee of the Medical Faculty of the Charité Hospital, University Medicine Berlin, approved the study design. All patients provided written informed consent. Patient recruitment (n = 64) and baseline data collection for this prospective, comparative study were done at our hospital between January 1, 2010, and December 31, 2012.

Inclusion and exclusion criteria are summarized in Table 1. The preoperative ligamentous status was evaluated with the International Knee Documentation Committee (IKDC) objective form. The KT1000 arthrometer (MEDmetric Corporation, San Diego, CA) was used for the Lachman test. Malalignment was measured on whole-leg radiographs. The tunnel position was checked on 3-dimensional computed tomographic scans (Fig 1). The tunnel position was classified into anatomic, partially anatomic (if one part of the tunnel is outside of the original insertion of the ACL), and nonanatomic via 3-dimensional computed tomographic scans.

According to our sample size calculation, we needed 25 patients in each group to detect equality between both groups providing 80% power. The probability of committing type I error was chosen as 0.05. Therefore, we evaluated 30 consecutive patients who underwent an ACL revision surgery with ipsilateral bone−quadriceps tendon grafts and 30 consecutive patients who underwent ACL revision surgery with the contralateral semitendinosus-gracilis grafts between January 2010 and December 2012. Once we met our target of participating subjects (30 in each group), we stopped the enrollment. Randomization was not done. The indications for the 2 different tendons are the same, which are the inclusion criteria. Therefore, the decision for either tendon was made by the patients. The patients' demographic data are presented in Table 2. Two patients of each group regret to participate before surgery. Three patients in the semitendinosus-gracilis tendon group were excluded because of the need for additional surgery (1 required posterolateral reconstruction, 2 had a tunnel diameter >11 mm). Equally, 3 patients in the quadriceps tendon group were excluded (2 required high tibial osteotomies and 1 had a tunnel diameter >11 mm). Thus, 54 patients were included in the study, although 3 were lost to follow-up

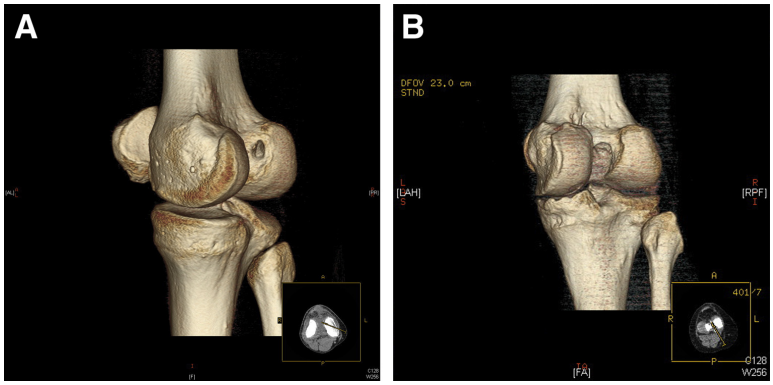


**Fig 1.** (A) Computed tomographic scan of the right knee of an anatomic tunnel position. (B) Computed tomographic scan of the right knee of a nonanatomic tunnel position (so-called high noon position). Both cases were included in the present study.

(2 from the quadriceps tendon group and 1 from the semitendinosus-gracilis tendon group). At a mean 24-month follow-up, 51 patients remained, with 25 patients in the quadriceps tendon group (93% follow-up rate) and 26 in the semitendinosus-gracilis tendon group (96% follow-up rate) (Fig 2).

## Surgical Technique

### Arthroscopy and Hardware

The senior surgeon (W.P.) performed all of the revision ACL reconstructions using general or spinal anesthesia. After examining the anesthetized knee, arthroscopy was performed to evaluate the knee for any associated injuries. The intraoperative status of the cartilage and menisci were documented according to the IKDC documentation form. The International Cartilage Research Society classification was used to grade the cartilage lesions.

Torn menisci were partially removed or repaired.

Old metallic fixation devices were removed only if they would have compromised new tunnel creation or graft fixation or if the fixation devices caused discomfort or local pain. If the 3-dimensional computed tomographic scan (before surgery) showed that the tunnel diameter would be >11 mm after hardware removal, the patient was excluded from the study.

### Tunnel Preparation

Tunnel preparation was the same for the 2 treatment groups. On the tibial side, the old anatomic tunnel was used in all cases (Fig 3). After hardware removal (buttons, clamps) at the proximal tibia, the tunnel aperture was identified and a guidewire was drilled through the tunnel into the joint The old graft material was then removed using drills with increasing diameters (Fig 3). Drilling was stopped when the bony tunnel wall was visible.

On the femoral side, a new anatomic tunnel was created via the medial portal in patients with a nonanatomic tunnel (Fig 4). For medial portal drilling, the knee was flexed more than 110°. An anteromedial portal aimer (Karl Storz, Tuttlingen, Germany) was used to place the Kirschner (K)-wire in the center of the ACL insertion.[7] The K-wire's position was always checked via the anteromedial portal. The landmarks for femoral tunnel placement were the intercondylar line and the cartilage border.[16] When the K-wire was placed centrally in the femoral insertion, the femoral tunnel was drilled stepwise according to the diameter of the graft. The last 1 mm of the tunnel was dilated with a dilator (Karl Storz) to make sure that the bridge between the old tunnel was not destroyed. In patients with a very narrow bridge, the old nonanatomic tunnel was augmented with an appropriately sized interference screw (PDLLA, Mega Fix-P; Karl Storz). In each case, the positions of the tunnels were controlled and documented using arthroscopy in the anteromedial portal.[17,18] In patients with an anatomic femoral tunnel, the same technique as that for the tibial tunnel was used to remove the old graft and prepare the femoral tunnel.

### Semitendinosus-Gracilis Tendon Harvesting and Femoral Fixation

Semitendinosus-gracilis tendons were harvested via a 3-cm oblique incision medial to the tibial tuberosity.[19]

**Table 2.** Age and Gender Distribution

| | Semitendinosus-gracilis Tendon | Quadriceps Tendon |
|---|---|---|
| Age, yr (± standard deviation) | 35.8 (± 13.1) | 35.9 (± 10.4) |
| Gender | | |
| Female | 8 | 8 |
| Male | 18 | 17 |

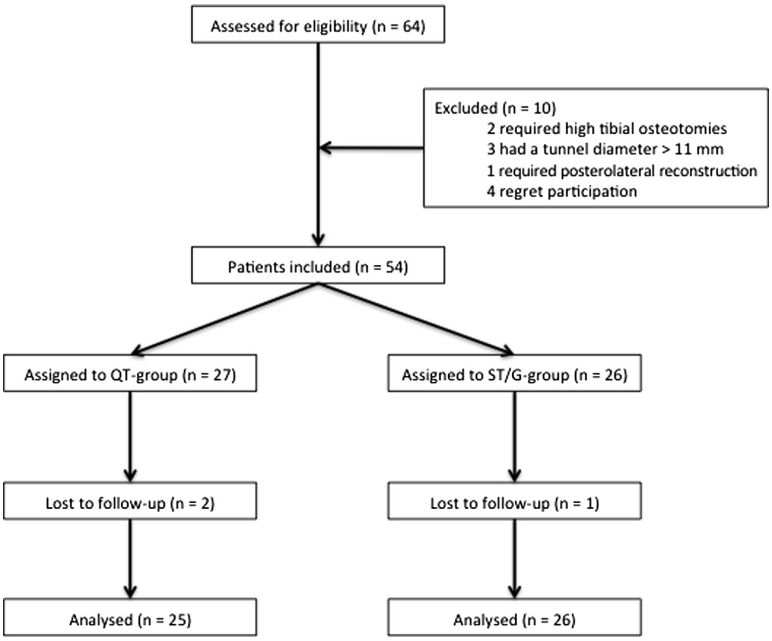


**Fig 2.** Flowchart showing the patient enrollment and the subsequent exclusion (QT, quadriceps tendon; ST/G, semitendinous-gracilis tendon.)

After incision of the sartorius fascia, the gracilis and semitendinosus tendons were identified. In most cases, the semitendinosus and the gracilis tendon were harvested with a tendon stripper. The decision about whether only the semitendinosus tendon or both tendons were to be harvested was based on the tunnel diameter. After harvesting the tendons, they were looped over a Flipptack (Karl Storz) for femoral fixation. The other end of the graft was secured with a baseball stitch and connected to a button (Endotack; Karl Storz).[17]

### Quadriceps Tendon Harvesting and Femoral Fixation

The quadriceps tendon graft was harvested via a 4-cm incision. A 10 × 65-mm graft was excised from the

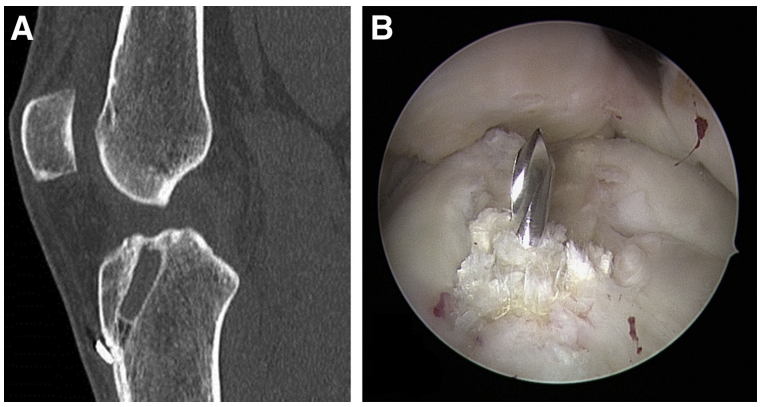


**Fig 3.** (A) Computed tomographic scan of the right knee showing an anatomic tibial tunnel position. (B) In these cases a guidewire was drilled into the left knee from the tibial aperture through the old tunnel.

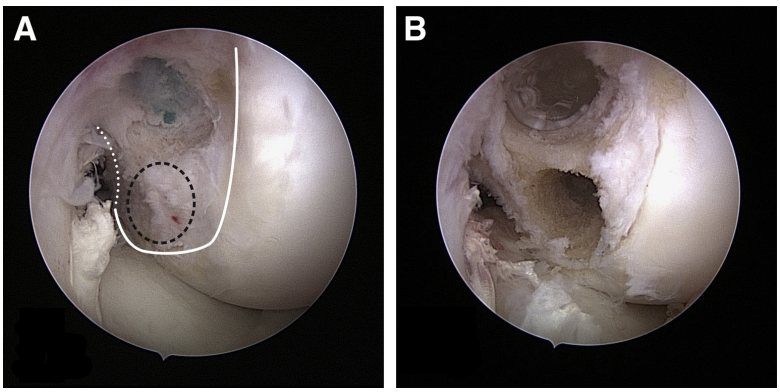


**Fig 4.** (A) Arthroscopic view from the medial portal on the lateral femoral condyle of the left knee. The tunnel from previous anterior cruciate ligament reconstruction is in a nonanatomic position. The white dotted line shows the intercondylar line; the white line shows the cartilage border. The planned tunnel is indicated by the black dotted line. (B) To prevent breakage of the bridge between the new and the nonanatomic tunnel of the left knee, the nonanatomic tunnel was augmented with a resorbable interference screw (PDLLA, Mega Fix, Karl Storz).

central quadriceps tendon together with a 15-mm bone block (Fig 5). The bone block was removed with an oscillating saw and was shaped in a conical manner for femoral press-fit fixation, which was achieved in all cases.[20] The free end of the graft was secured with a baseball stitch and connected to a button (Endotack).

### Tibial Fixation

On the tibial side, hybrid fixation was used in all of the patients. The grafts were first fixed with an interference screw of 23 mm length (PDLLA screw, Mega Fix-P). The diameter of the screw was 1 mm smaller than the diameter of the tunnel. After fixation, the grafts were secured distally with 4 nonresorbable No. 3 polyester sutures (Johnson & Johnson, Neuss, Germany) that were tied over a button (Endotack).

### Concomitant Surgery

Suture repair was required at 2 medial and 3 lateral menisci in each group. Also, 4 meniscal lesions in the semitendinosus-gracilis group and 6 meniscal lesions in the quadriceps group underwent partial resection. Microfracture procedures for treating chondral lesions of the medial femoral condyle were performed in 2 patients in the quadriceps group and in 3 patients in the semitendinosus-gracilis group.

### Rehabilitation

The rehabilitation protocol was the same for both groups. Partial weight bearing and full range of motion were permitted. Crutches were used for 4 weeks. A rehabilitation brace was used for 6 weeks. Closed-chain exercises were started after 2 weeks. If meniscal repair

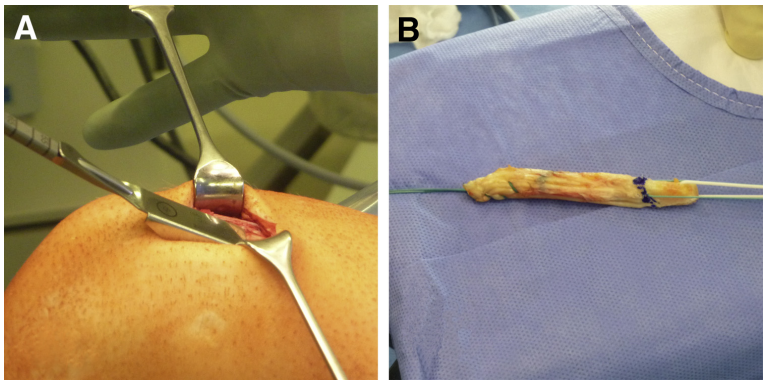


**Fig 5.** (A) The quadriceps tendon of the left knee was harvested via a small suprapatellar approach with a special double-bladed knife. (B) Preparation of the autologous quadriceps tendon graft.

was performed during the same operation, 0° to 60° range of motion of the knee was allowed for the first 6 weeks.

### Follow-up Evaluation

All patients were examined before surgery and at a minimum follow-up of 24 months postoperatively, at which times they underwent a clinical examination. Patients were evaluated using the IKDC objective score. For the final IKDC results, additional parameters—effusion, passive motion deficit, ligament examination—were included according to the 2000 IKDC Knee Examination Form. Laxity was measured by comparing the knee that underwent revision surgery with the healthy knee using the KT1000 arthrometer at maximum manual tension and at a knee flexion angle of 20°.[21] Two examiners graded pivot shift according to the IKDC 2000 examination form, where grade A described equal laxity in the 2 knees, grade B described gliding, grade C described clunking, and grade D described gross laxity.

At the 24-month follow-up, 2 additional clinical scores were evaluated: the Lysholm score[22] and the Knee Osteoarthritis Outcome Score (KOOS).[23] The Lysholm score is a commonly used scoring system to rate knee instability. It has been validated for the German language,[22] as has the KOOS.[24] The KOOS is self-explanatory and consists of 5 subscales: pain, symptoms, sports/recreational activities, activities of daily living, and function.[23] Standardized answer options are given (5 Likert boxes), and each question is assigned a score from 0 to 4. A normalized score (100 indicating no symptoms and 0 indicating extreme symptoms) is calculated for each subscale.[23] A total score has not been validated and is not recommended.[23]

Kneeling pain was evaluated with the following question: How severe is the pain when you are kneeling (0, none; 1, mild; 2, moderate; 3, severe; 4, extreme)? Anterior knee pain was evaluated on a scale of 0 to 4 (0, none; 1, mild; 2, moderate; 3, severe; 4, extreme) with the questions: (1) What difficulty did you experience last week when ascending stairs? (2) What difficulty did you experience last week trying to squat? All patients with scores of 2 to 4 were counted. Kneeling pain and anterior knee pain were dichotomized to pain (Likert box 2 to 4) or no pain (Likert box 0 to 1).

### Statistical Analyses

The Kolmogorov-Smirnov and Shapiro-Wilk tests were used to test the parameters (i.e., KT1000 score, pivot-shift, Lysholm score, KOOS) for normal distribution. The Mann-Whitney *U* test was used to analyze the results of the postoperative KT1000 arthrometer-determined side-to-side difference, Lysholm score, and KOOS subscales. A *t* test was used for KOOS to assess quality of life, anterior knee pain (squatting and ascending stairs), and the preoperative KT1000 (AP) posterior displacement measurement. The $\chi^2$ test was used to examine the extent of kneeling pain. Fisher exact test was used to assess the results of the pivot-shift tests. The significance level was set at $P \leq .05$ for all tests.

Before the examination was initiated, a sample size calculation on the basis of a non-inferiority power analysis for a continuous parameter was performed. For it, anterior-posterior laxity measured with the KT1000 arthrometer was our primary end point. The following assumptions affected our analysis. According to the literature, side to-side difference in anterior-posterior knee laxity after semitendinosus-gracilis tendon ACL reconstruction is about 2.5 mm, with a standard deviation of 1.25 mm. Furthermore, we decided that 1.0 mm increased laxity for the bone−quadriceps tendon group would show a clinically significant inferior outcome. According to these assumptions, a sample size calculation suggested that we needed 25 patients in each group to detect equality between both groups, providing 80% power. The probability of committing type I error was chosen as 0.05. Therefore, we decided to include 30 patients in each group into the study.

## Results

### Age and Gender

There were no significant differences between the 2 groups in regard to age and gender distributions (Table 2).

### Cartilage Damage and Loss of Menisci at the Time of Revision

Four patients in each group experienced medial meniscus deficiency because of prior partial meniscectomy. Deficiency of the lateral meniscus was found in none of the patients in the semitendinosus-gracilis group and in 1 patient in the quadriceps group. Also, 4 meniscal lesions in the semitendinous-gracilis group and 6 meniscal lesions in the quadriceps group underwent partial resection. There was no difference in the magnitude of meniscal deficiency between the 2 groups.

Articular cartilage damage was present at the time of the revision in 24 patients. According to the International Cartilage Research Society classification, the cartilage damage was grade 1 in 3 patients, grade 2 in 15 patients, grade 3 in 6 patients, and grade 4 in zero patients. There was no difference in the incidence of cartilage damage in the groups. The medial compartment was involved in 22 patients, the lateral compartment in 14 patients, and the patellofemoral compartment in 18 patients.

### IKDC Objective Grading and KT1000 Measurement

The objective IKDC grading scale indicated that both groups improved significantly indicated by the objective IKDC grading scale. No significant difference could be measured between both groups preoperatively ($P = .506$) or postoperatively ($P = .296$) (Table 3).

**Table 3.** Preoperative and Postoperative Objective International Knee Documentation Committee Grading

| | Grade | | | | |
|---|---|---|---|---|---|
| | A Normal | B Nearly Normal | C Abnormal | D Severely Abnormal | *P* Value |
| Preoperatively | | | | | |
| Semitendinosus-gracilis tendon | 0 | 5 | 14 | 0 | .506 |
| Quadriceps tendon | 0 | 5 | 13 | 2 | |
| Postoperatively | | | | | |
| Semitendinosus-gracilis tendon | 10 | 6 | 4 | 0 | .296 |
| Quadriceps tendon | 13 | 5 | 2 | 0 | |

The mean preoperative AP laxity measured with the KT1000 arthrometer was 6.4 ± 2.5 mm for the quadriceps group and 5.9 ± 1.6 mm for the semitendinosus-gracilis group. This value decreased to 2.0 ± 1.2 mm postoperatively for the quadriceps group and 3.0 ± 2.9 mm for the semitendinosus-gracilis group. There were no significant differences in AP laxity between the semitendinosus-gracilis and quadriceps groups preoperatively ($P = .455$) or postoperatively ($P = .461$) (Fig 6). There was also no significant difference in the rate of positive pivot-shift tests ($P = .661$).

### Lysholm Score, KOOS Subscales, Kneeling Pain, Anterior Knee Pain

At the 24-month follow-up, the overall Lysholm score was 78.1, with no significant differences in the Lysholm scores for the 2 treatment groups (Fig 7). There was also no significant difference in any of the KOOS subscales between the quadriceps and semitendinosus-gracilis groups (Fig 8).

In all, 7 patients in the quadriceps group experienced pain while kneeling, as did 11 patients in the semitendinosus-gracilis group. Also, 7 patients in the quadriceps group experienced pain while squatting and 4 patients while ascending stairs. Eight patients in the semitendinosus-gracilis group experienced pain while squatting and 4 while ascending stairs.

### Complications

No rerupture occurred during postoperative follow-up. Also, no early superficial infection or meniscal injury was found in both groups.

## Discussion

The results of the study support our hypothesis that ACL revision surgery with bone–quadriceps tendon grafts provide clinical results similar to those achieved with semitendinosus-gracilis tendon grafts. A previous biomechanical study using a robotic/universal force-moment sensor testing system showed that reconstruction of the ACL with a quadriceps tendon graft restored AP translation and simulated rotatory loads to levels similar to those achieved with a semitendinosus-gracilis graft for reconstruction.[8] Several studies have evaluated the outcomes of ACL reconstruction using the quadriceps tendon in primary ACL reconstruction. Retrospective studies comparing the central quadriceps tendon graft with BPTB grafts reported equal subjective outcome scores and equal knee stability for the 2 graft options.[12-14] A prospective randomized study also found equal knee stability and functional scores as well as less donor-side morbidity (e.g., anterior knee pain) in the quadriceps tendon group than in the BPTB group.[15] In the present study, there was no difference between the quadriceps and semitendinosus-gracilis groups in terms of kneeling pain or pain while stair climbing.

Published studies of ACL revision surgery often lack a control group, and patient collectives often lack homogeneity because different surgical techniques were used within autograft or allograft groups (1-step or 2-step procedures, different graft types) or patients were enrolled by different surgeons.[1] Also, weak inclusion and exclusion criteria (e.g., different concomitant injuries, tunnel malplacement, tunnel enlargement, malalignment) could be a problem.[3,5,25-29] Thus, in regard to other issues relating to ACL reconstruction, the level of evidence among reports on ACL revision surgery is low. Homogeneity is definitely a strength of the present study design because we applied strict inclusion and exclusion criteria, which negatively influence the number of included patients (Table 1). There was also no difference in age and gender distribution between the 2 study groups because of the matching procedure (Table 2).

A recent registry study, in which 1,205 patients from 52 centers were enrolled, found that the use of an autograft instead of an allograft predicted an improved subjective IKDC scale and improved KOOS sports and quality of life subscales. Also, use of an allograft resulted in a higher risk of rerupture.[1] That study found no difference in patient-reported outcomes and rerupture rates between BPTB grafts and semitendinosus-gracilis grafts. The absolute values of the KOOS subscales were comparable to the outcomes in the various KOOS subscales (symptoms 79, pain 89, activities of daily living 97, sports 75, quality of life 56) found in the present study.[1] The minimum clinically important difference is 8 to 10 points for the KOOS.[30]

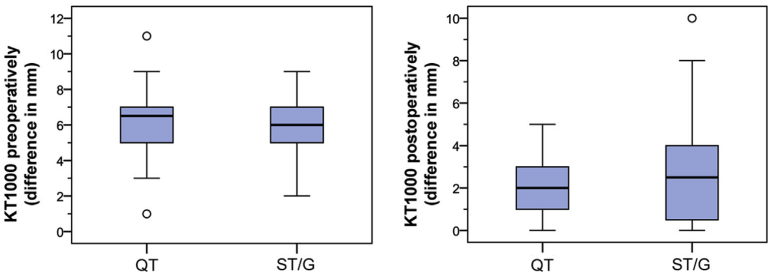


**Fig 6.** Box-plot of AP displacement as measured with the KT 1000 (MEDmetric, San Diego, CA). Pre- and postoperatively, there was no significant difference in AP laxity between the semitendinosus-gracilis (ST/G) and quadriceps group (QT) (Mann-Whitney *U* test 0.46). (AP, anteroposterior.)

In the present study, the overall Lysholm score after 2 years of follow-up was 78.1. This value is comparable to the Lysholm score of 82.1 found in a meta-analysis of 491 patients.[29] The minimal detectable change is between 8.9 and 10.1 for knee injuries.[31]

The overall AP translation side-to-side difference measured with the KT1000 arthrometer was 2.5 ± 2.1 mm. This side-to-side difference was also comparable to that found in other studies of patients after ACL revision surgery.[3,26,27] Weiler et al.[3] reported AP translation of 2.1 ± 1.6 mm in a group of 50 ACL revision patients using the semitendinosus-gracilis graft compared with 2.2 ± 1.1 mm in the primary reconstruction group.[3] Noyes and Barber-Westin[27] reported results of revision ACL surgery using a patellar tendon autograft and found a mean postoperative AP translation of 2.2 ± 4.9 mm.[27] These comparisons show that the functional outcome and knee stability results in the quadriceps tendon or semitendinosus-gracilis tendon group of the present study are comparable to those of other studies of 1-stage revision ACL reconstruction.

The results of the subjective, patient-reported outcome scores of the present study, however, are inferior to published results after primary ACL reconstruction.[1,3,27,29] There is general agreement in the literature that patient-reported outcome scores after ACL revision surgery are inferior to published results after primary ACL reconstruction.[1,3,27,29] The higher prevalence of cartilage and meniscal damage, muscle atrophy, and lax secondary stabilizers at the time of ACL revision surgery could be an explanation.[1,3,27,29] The prevalence of cartilage and meniscus damage found in the present study is similar to that found in a recent systematic review of ACL revision studies.[29] It is well known that meniscal status is one of the most important predictors of functional outcome after ACL surgery.[32] The use of validated outcome measures was the greatest strength of the present study.

### Limitations

This study has several limitations. First, the study design did not include prospective randomization, which minimizes selection bias. However, such a trial design is difficult to be implemented for the inhomogeneous group of patients who are scheduled for ACL revision surgery. Thus, the level of evidence gained from reports on ACL revision surgery is lower than that for other issues regarding ACL reconstruction.[3] Most published clinical studies are of a retrospective nature and lack control groups.[3]

Second, this study has only a small number of patients in each treatment group, although the number of patients is comparable to that of other studies on ACL revision surgery.[3,9,26,27,33] It is also comparable to the group sizes of several prospective randomized trials on primary ACL reconstruction.

The small number of patients could be the reason for the rerupture rate being nonexistent in the present study—none of the patients experienced rerupture. In the MARS study, the rerupture rate for the 1,205 patients who underwent revision surgery was 3.3%. Furthermore, the preoperative scores of the KOOS score and Lysholm score are missing.

## Conclusions

Revision ACL reconstruction using the quadriceps tendon graft showed clinical outcomes similar to those of the contralateral semitendinosus-gracilis graft in

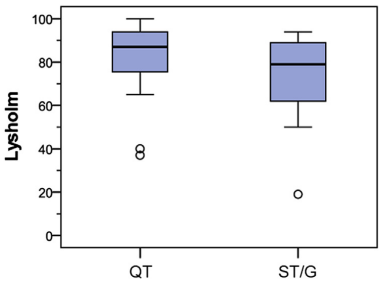


**Fig 7.** Box-plot of the postoperative Lysholm score of the semitendinosus-gracilis (ST/G) and quadriceps (QT) group. At the 24-month follow-up, there was no significant difference in the Lysholm score between both treatment groups ($P = .06$).

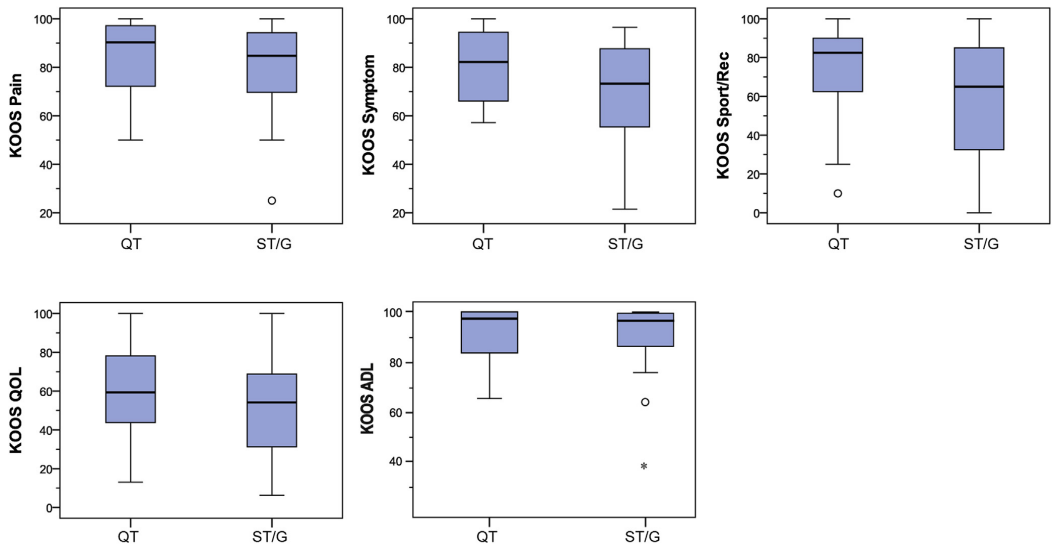


**Fig 8.** Box-plot of the Knee Injury Osteoarthritis Outcome Score (KOOS) subscales of pain, symptoms, activity of daily living (ADL), sports/recreation, and quality of life (QOL). There was also no significant difference in any of the KOOS subscales between the quadriceps (QT) and semitendinosus-gracilis (ST/G) group (pain: $P = .39$, symptoms: $P = .1$, ADL: $P = .46$, sports/recreation: $P = .14$, QOL: $P = .36$).

terms of knee stability and function. Thus, the bone–quadriceps tendon graft may be a good alternative to the contralateral semitendinosus-gracilis tendon graft for revision ACL reconstruction.

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## 5. Lebenslauf

„Mein Lebenslauf wird aus datenschutzrechtlichen Gründen in der elektronischen Version meiner Arbeit nicht veröffentlicht.“

## 6. Publikationsliste

Bierke S, Häner M, Petersen W. Influence of somatization and depressive symptoms on the course of pain within the first year after uncomplicated total knee replacement: a prospective study. *International orthopaedics.* 2016;40:1353-1360.

Häner M, Bierke S, Petersen W. Anterior Cruciate Ligament Revision Surgery: Ipsilateral Quadriceps Versus Contralateral Semitendinosus-Gracilis Autografts. *Arthroscopy.* 2016.

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