Muscle function after endoprosthetic replacement of the proximal tibia

Different techniques for extensor reconstruction in 17 tumor patients

Renate Petschnig[1], Ramon Baron[2], Rainer Kotz[3], Peter Ritschl[4] and Alfred Engel[3]

We analyzed in 17 patients the outcome of various surgical techniques for reconstruction of the extension apparatus after resection of the proximal tibia and tumor prosthesis implantation. The mean follow-up period was 5 (1.5–11) years. Knee extension and flexion strength were measured isokinetically by dynamometer and muscle activities of the vastus medialis, the vastus lateralis and the rectus femoris muscles determined by means of EMG. Muscle function of the operated leg was compared to that of the contralateral extremity by using various surgical techniques: fibula transposition, transposition of the gastrocnemius muscle, and combination technique. The results concerning the operated leg were compared within the 3 groups and the activity and strength of both legs were compared to those of a control group of healthy subjects matched for age and weight.

The strength of extensor muscles of the healthy leg was greater than that of the control group in flexion position (60°–90°); the hamstring strength values were within the normal range. The strength of extensor muscles of the operated leg differed between groups II and III at 90° in favor of group II ($p < 0.01$) and at 60° to 20° ($p < 0.001$) in favor of group III. Expressed in percentage ranges (nonoperated leg set at 100 percent) the flexor muscles averaged 30 percent, the extensor muscles represented on average 12 percent (9–17 percent) in group I, 9 percent (5–18 percent) in group II and 16 percent (6–26 percent) in group III, depending on the knee angle. In all 3 groups the EMG of the nonoperated leg indicated the highest activity in the vastus medialis or in the vastus lateralis muscle and the lowest activity in the rectus femoris muscle. In contrast, the highest EMG activity was registered in the rectus femoris muscle and the lowest in the vastus medialis muscle of the operated leg in all patients of all 3 groups.

[1]Department of Physical Medicine and Rehabilitation Donauspital, [2]Institute of Sport Science, Dept. of Prevention and Recreation, University of Vienna, [3]Department of Orthopedics, University of Vienna, [4]Department of Orthopedics, Gersthof Correspondence: Dr. Ramon Baron, Department of Prevention and Recreation, University of Vienna, Institute of Sport Science, Auf der Schmelz 6, A-1150 Vienna, Austria. Tel +43 1-9822661/172. Fax -9822661/198
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Reconstruction of the extensor apparatus is a problem after endoprosthetic replacement of the upper tibia and the knee joint. Up to now there are no reports on quantitative measurements of muscle strength and muscle activity related to different surgical techniques. In a pilot study on 5 patients with osteosarcoma, dynamometry and electromyography revealed in all subjects a marked reduction in force production, as well as in innervation of the involved muscle groups (Petschnig et al. 1993a). An alteration in the EMG-recruitment pattern for all heads of the quadriceps femoris muscle was also recorded. The deficits were substantially higher than one would expect from results obtained by clinical examination.

We analyzed in 17 patients the outcome of various surgical techniques for the reconstruction of the extensor apparatus, after resection and endoprosthetic replacement of the upper tibia.

Patients and methods

Between May 1979 and July 1990 we treated 36 patients with primary malignant bone tumor with resection of the proximal tibia and endoprosthesis implantation (6 custom-made prostheses and 30 modular uncemented prostheses KMFTR = Kotz modular femoral-tibial reconstruction system, manufactured by Howmedica, U.S.A.). At the time of the study, 7 patients had died and 9 patients were living abroad and could not participate in the study. Another 3 patients were also excluded as they were not able to lift their leg against gravitational force. All 17 remaining patients (15 men and 2 women) had no sign of metastasis at the time of investigation. In 12 patients, the original prostheses were in place. 5 patients had had reoperations with partial replacement of the prosthesis. The reason for the replace-

Table 1. Patient data

	Group[a]		
	I	II	III
Sex m/f	5/1	4/1	6/0
Tumor type			
osteosarcoma	5	4	3
chondrosarcoma	1	1	
MFH			3
Follow-up, yr	8 (2–11)	5 (1.5–7)	2.5 (1.5–3.5)

[a] See text

ment was in 1 patient septic loosening and in 2 patients aseptic loosening. 2 other patients had a fracture of the femur stem. Time lapse since primary surgery averaged 5 (1.5–11) years (Table 1). A modular cementless prosthesis was used in 14 patients and a custom-made tumor prosthesis in 3 patients. We used 3 methods to reconstruct the ligamentum patellae.

I. Fibula transposition. After 2–3 subperiostal osteotomies, the proximal fibula was ventralized and medialized and the ligamentum patellae was sutured to the tendon of the biceps femoris muscle and the collateral ligament (Kotz and Engel 1983, Kotz et al. 1986).

II. Transposition of the gastrocnemius muscle. An extensor apparatus was created by reconstruction of the patellar ligament by a strap of fascia and transfer of the femoral insertion of one or both heads of the gastrocnemius muscle (Malawer 1983).

III. Combination of fibula transposition and gastrocnemius shift. The extensor apparatus was reconstructed by ventralization and medialization of the proximal fibula and the medial gastrocnemius head. The tendons of the gastrocnemius muscle and of the tendons of the apex of the fibula were connected to the ligamentum patellae (Figure 1).

The mean age was 24 (20–27) years in group I, 28 (21–38) yers in group II and 35 (27–47) years in group III. Postoperatively, the patients were immobilized in a plaster splint for about a week. They were then mobilized with no weight bearing for 6 weeks. All patients were fitted with a brace having a mobile knee and ankle joint. Partial weight-bearing was allowed after 6 weeks and full weight-bearing after 3 months.

The functional results were rated according to the old Enneking classification (Enneking 1983, 1987) and to the new functional Enneking classification (Enneking et al. 1993).

Dynamometry

The dynamometric measurements of the hamstrings and the quadriceps muscle were performed on a Dynamatic device (Wintersteiger, Austria) with the subject sitting upright. The axis of rotation of the lever arm and the center of rotation of the knee joint were coordinated by adjusting the seat and the backrest. The patient was fixed with belts and was asked to size the grips at both sides of the seat in order to minimize the influence of other muscle groups on the movement. An acoustic and an optical signal told the patient when to press against the lever arm with maximal effort. The chosen velocity was maintained constant over the whole range of motion by means of hydraulics. Simultaneously, the angle was measured by a potentiometer and the torque of the lever by a strain gauge. The torque of the angles between 20° and 90° (all values were calculated at every 10 degrees throughout the range of motion, not only the peak torque, 0° maximum extension) and the total work (area under the torque-angle curve) were recorded at a constant angular velocity of 10° per second for knee extensor and flexor muscles. After a warming up with 3 repetitions at an intermediate speed (90°/sec), each patient performed 3 submaximal test runs to become accustomed to the measuring procedure and a 3-min rest period before measuring the maximal leg extension and flexion. The nonoperated limb was tested first. The results from both legs were compared to an age- and weight-matched control group of 50 untrained subjects (Baron et al. 1991,

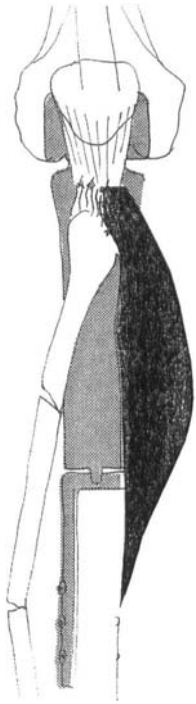

Figure 1. Ventralization and medialization of both the proximal fibula and the medial gastrocnemius head.

Table 2. Non-operated leg: Knee extension strength in relation to an age- and weight-matched control group. Nm/kg

Angular position (°)	Control group I	Group I	Group II	Control group II	Group III
90	1.97	2.02	2.00	1.84	2.03
80	2.05	2.40	2.09	1.99	2.57 $p < 0.05$
70	2.33	2.60	2.36	2.21	2.70 $p < 0.05$
60	2.67	2.82	2.30	2.50	2.64
50	2.74	2.50	2.07 $p < 0.05$	2.44	2.33
40	2.46	2.11	1.75 $p < 0.05$	2.21	2.06
30	2.09	1.62 $p < 0.05$	1.41 $p < 0.01$	1.93	1.66
20	1.92	1.36 $p < 0.05$	1.14 $p < 0.01$	1.70	1.43

Control group I 20–30 years of age. Control group II 30–40 years of age.

Petschnig et al. 1993b) and the data concerning the operated leg were compared within the three groups. The results from the healthy leg were compared with those from the operated one and expressed in percentage ranges (nonoperated leg set at 100 percent).

Integrated electromyography

The electromyographic examination was performed with Myosystem 2000 (Noraxon, Finland). The skin was prepared with sandpaper and alcohol to reduce skin resistance. Surface electrodes Medi Trace (Graphic Controls, Canada) were attached to the muscle bellies of the vastus medialis, the vastus lateralis and the rectus femoris muscles. We standardized the position of the surface electrodes for the examination according to Chomiak (Petschnig et al. 1991). In 5 patients the position was checked by means of concentric needle electrodes. A 500 Hz sampling rate was used to collect the data. The raw EMG signal was fully rectified. The statistical analysis used the area under the EMG curve for each head of the quadriceps muscle during dynamometric measurement and the total electric activity of the whole muscle. The results from the healthy leg were compared with those from the injured one.

Results

Functional results

Passive motion of the knee ranged from full extension to flexion over 100°. While sitting on a table, all 17 patients were able to extend the leg. Active extension was best in group III, with a median extension defect of 2° (0°–5°). Group I had a median extension defect of 12.5° (3°–15°). The largest deficit in active extension was seen in group II with 32.5° (18°–36°).

According to the old Enneking's classification, function in group I was excellent in 3 patients and good in 3 patients; in group II excellent in 1, good in 2 and fair in 2 patients; and in group III excellent in 4 patients and good in 2 patients. The mean results using the new Enneking's classification were 24 (21–28) points in group I, 23 (19–27) points in group II and 26 (24–29) points in group III.

Muscle strength

Nonoperated leg. The strength of the extensor muscles was greater than those of the control group in the range from 90° to 60° for groups I and III and in the range from 90° to 70° for group II. In the range from 50° to 20° (groups I and III) and from 60° to 20° (group II) the torques of the extensor muscles were lower than those of the control group (Table 2). The hamstring strength of the healthy leg was within normal range in all 3 groups.

Operated leg. There was a difference ($p < 0.001$) in total work and in strength at all angles between the operated and nonoperated leg in all 3 groups. This applied to both flexor and extensor muscles of the knee. The strength of extensor muscles in the operated leg differed between groups II and III (Table 3). There was no difference in strength of extensor muscles between groups I and III. Compared to the healthy leg the strength of the operated leg was on average 12 (9–17) percent in group I, 9 (5–18) percent in group II and 16 (6–26) percent in group III, depending on the knee angle.

Untrained healthy persons reach dynamic peak torque of knee extensor muscles at an angle of 40°–60°. In our patients the peak torque on the nonoperated leg was found at 60° in group I and at 70° in groups II and III and shifted further to flexion as compared to the control subjects. The peak torque of the operated leg in group II was 90°. The strength at this angle was higher in groups I and II than in group III (Table 3). Groups I and III achieved peak torque of the operated leg at 50°, i.e., within the normal range.

The strength of flexor muscles in all 3 groups differed at all measured angles from the nonoperated leg ($p < 0.001$). However, no intergroup differences were detected. Compared to the nonoperated leg, the flex-

Table 3. Operated leg: Knee extension strength between reconstruction groups I / II / III. Nm/kg

Angular position (°)	I	II	III	p-value
90	0.20	0.34	0.11	< 0.01
80	0.22	0.26	0.16	n.s.
70	0.27	0.22	0.30	n.s.
60	0.27	0.18	0.37	< 0.001
50	0.29	0.14	0.46	< 0.001
40	0.27	0.11	0.44	< 0.001
30	0.26	0.08	0.44	< 0.001
20	0.23	0.05	0.36	< 0.001

Significant differences only between group II and group III.

Table 4. Operated leg: EMG activities of different heads of the quadriceps femoris muscle related to the overall EMG activity, percentages

Group	Rectus	Medialis	Lateralis
I	49**	24	27
II	48**	19	33
III	41**	19	40**

The activities of rectus femoris and vastus medialis muscle differed ($p < 0.01$) in all groups.
In group III the activities of vastus lateralis and vastus medialis muscles also differed ($p < 0.01$).

or muscles averaged 30 (6–42) percent in group I, 30 (8–47) percent in group II and 33 (9–51) percent in group III. Dynamic peak torque of flexor muscles of the operated as well as the nonoperated leg was the same as in controls at 30°.

Hamstring/quadriceps ratio. Whereas the extensor muscles of the nonoperated leg in all groups were stronger ($p < 0.01$) than the flexor muscles, a reversed ratio, i.e., greater strength of flexors than extensors ($p < 0.05$) was recorded from the operated leg.

Muscle activity/EMG

The EMG activities of particular heads of the quadriceps femoris muscle and the overall EMG activities were similar in all groups in the operated and the nonoperated leg. However, the EMG activities differed between the operated and the nonoperated legs. In all 3 groups the EMG of the nonoperated leg indicated the highest activity in the vastus medialis muscle or in the vastus lateralis muscle and the lowest activity in the rectus femoris muscle. However, the highest EMG activities of the operated leg in all patients of all 3 groups were recorded from the rectus femoris muscle and the lowest from the vastus medialis muscle (Table 4). The activities of the rectus femoris muscle and the vastus medialis muscle differed in all groups. In group III also, the activity of the vastus lateralis muscle was higher than that recorded from the vastus medialis muscle. The activity of the vastus medialis muscle of the operated leg was lower than that of the nonoperated leg.

Discussion

Our findings favor the combined technique used in group III (gastrocnemius shift plus transposition of fibula), as compared to group II (sole gastrocnemius shift). Patients operated by the combined technique reached substantially higher strength at angle positions between 60° and 20°, as well as better functional results. The soft low elastic musculo-ligamental connection in group II is not able to produce sufficient pre-stretch which is essential for any muscle contraction. In addition, the connection does not imitate the exact pull direction of the extensor muscles. These patients had the highest force at 90° and they also showed the highest extension deficit.

The reconstruction using transposition of the fibula (group I) creates a ligamento-ligamental connection, but it entails the risk of lateralization of the patella. The reconstruction of the extensor apparatus by means of a combination of 2 techniques (group III) seems to be more favorable than transposition of the fibula alone (group I). The combined technique, which includes a medial dynamic stabilization by the medial gastrocnemius head, permits an extensor pull in the best central position. This is evident by higher, though not significant, mean strength values and the better functional results in this group than in the group with fibula transposition alone. The centralization of the patella represents an important part of the extension (Watkins et al. 1983). Normally this happens by interplay between the vastus medialis muscle and the vastus lateralis muscle (Pockock 1963, Brault et al. 1975, Petschnig et al. 1991, 1993a). In the last 15° of final extension the vastus medialis muscle is primarily responsible for the medialization of the patella (Brault 1975, Strobel and Stedtfeld 1990). One possibility for medial stabilization is represented by an additional shift of the gastrocnemius. Patella dislocation impairs the patient's ability to extend the leg from the sitting position. The 3 excluded patients who could not extend the stretched leg against gravity could not center the patella. After surgical centralization of the patella 1 patient could perform an antigravitational lift of the stretched leg.

Surgery also leads to adaptation changes in the nonoperated leg. One is a shift of peak torque further to flexion. These changes allow a sort of compensa-

tion helping the patient to cope with the requirements of everyday life. For example, a patient with a tumor prosthesis standing up from the sitting position has to flex the opposite knee more than a healthy person to relieve the operated leg. This means that he must shift his whole body weight onto the healthy leg; we found a higher strength in all 3 groups in flexion of 90°–60°.

The altered EMG activity patterns point to the vastus medialis muscle in all 3 groups as the most affected muscle. It is not clear to what extent this alteration is a consequence of massive resection of proprioceptors and muscles. The combined reconstruction includes a transposition of muscle insertion points which leads not only to a change in the direction of pull but also to an alteration of muscular pre-stretch and better activation of the vastus lateralis muscle. This may explain the better extension strength after this procedure.

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