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RESTORING NORMAL GAIT AFTER LIMB SALVAGE PROCEDURES IN MALIGNANT BONE TUMOURS OF THE KNEE

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ABSTRACT. Eleven patients exhibiting decreased strength of knee extension following wide resection and prosthetic reconstruction for malignant bone tumors of the knee performed gait exercises with compensatory muscle training. Two patients whose knee extension strength was assessed as manual muscle test (MMT) grade 4 were able to develop a gait with double knee action and to maneuver stairs, step-by-step, due to compensation by the gluteus maximus, biceps femoris, and gastrocnemius muscles. Four patients whose knee extension strength was less than MMT grade 4, and whose ankle dorsal and plantar flexion was MMT grade 4 or higher, acquired the ability to go up and down stairs step-by-step, although their gait pattern was a knee-extended gait. Electromyographic studies demonstrated continuous discharges of the gluteus maximus, biceps femoris, and gastrocnemius muscles during the stance phase as compensation for decreased strength in knee extension.

INTRODUCTION

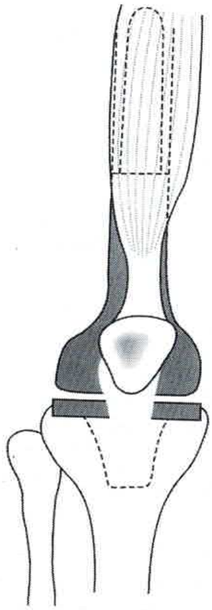
Limb salvage surgery for malignant bone tumors of the knee tends to be accompanied by a marked decrease in knee extensor muscle power. In many patients with osteosarcomas of the distal femur, for example, the femoral vastus muscles, with the exception of the rectus femoris, are removed with the tumor in order to obtain a safe surgical margin (wide resection) (1, 2). The patellar tendon is sacrificed and cannot be functionally reattached to the prosthesis after wide resection in nearly all patients with a proximal tibial malignancy, although the quadriceps muscles are preserved. In both cases, without any expectation of significant improvement in knee extension torque, patients will walk with the knee in an extended position during the stance phase.

Patients are taught to maneuver stairs step-by-step, since maximum function of the knee extensor muscles is required for weight support during contact of the foot with the ground. However, if flexion and extension of the knee can be obtained in the stance phase of a limb that has been subjected to limb-saving surgery, the patient's gait will be closer to normal. The other muscles of the lower extremity compensate for quadriceps function, so physical therapy treatment should be designed to strengthen and achieve compensatory muscle function in patients with functional loss of the quadriceps, the prime mover of the knee extensor muscles (4, 6). In this paper, exercise procedures for achieving compensation for loss of knee extension strength with other muscles in the lower extremity and their effects on patients who have undergone limb-saving operations for malignant bone tumors of the knee are discussed.

MATERIALS AND METHODS

Patients

Eleven patients (7 males, 4 females, age range 8–20 years, average 15.3 years) undergoing limb-saving surgery for the treatment of osteosarcoma in the distal femur and proximal tibia participated in this study. All the patients exhibited knee extension strength on manual muscle testing (MMT) of grade 3 or less, or marked extension lag of 30° or more for those with MMT grade 4. The effect of exercise was measured by assessing gait capacity, lower extremity muscle strength, and surface electromyography. Gait was evaluated at a self-selected speed on a 6-m walkway. Two force platforms and two video cameras were used to record the gait pattern. Gait capacity was also estimated when going up and down stairs. Muscle strength was estimated with the manual muscle test. Gait analysis and the muscle manual test were investigated by three examiners. Three muscular activities, the gluteus maximus, the hamstrings, and gastrocnemius muscles, were recorded by a surface electromyograph. Miniature silver-silver chloride electrodes, measuring 8 mm in diameter, were attached to the patient's skin, in line with the muscle fibers. By bipolar recording using these electrodes, rectified filtered electromyograms were obtained. A common ground electrode was positioned over the external ear. The stability of the myograms was also checked.



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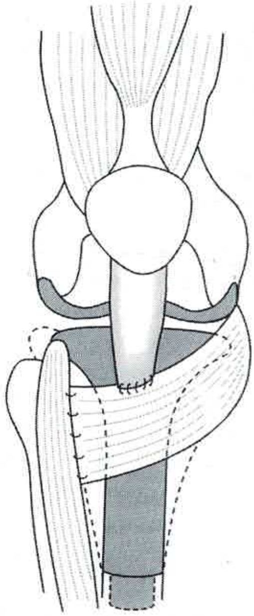

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Fig. 1. Illustration of operative procedure in the distal femur. The rectus femoris muscle was preserved, but the medial and lateral vastus muscles were resected with the tumor. The origin of the gastrocnemius muscle was reattached to the adjacent tissues.

Fig. 2. Illustration of operative procedure in the proximal tibia. The insertion of the patellar ligament into the tibia was resected with the tumor and reconstructed by medial gastrocnemius muscle rotated anteriorly. The hamstrings were resutured to the adjacent tissues.

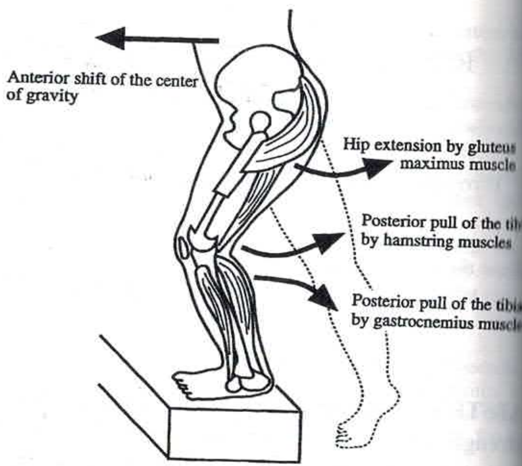

Fig. 3. Compensation for knee extension as a result of a deficiency in the strength of the quadriceps muscle.

Operative procedures

General operative procedures are described briefly, although they differed slightly in each case. In nearly all patients with malignant bone tumors in the distal femur, the rectus femoris muscle was preserved with resection of the other extensor muscles of the knee with tumor. The hamstrings were usually preserved, and the gastrocnemius muscle was sutured to the adjacent soft tissues after cutting at the level of origin (Fig. 1). In resecting tumors of the proximal tibia, the anterior tibial and soleus muscles were resected partially with the tumor, and the insertions of the hamstrings and patellar tendon were cut. The resected patellar tendon was reattached to the medial gastrocnemius muscle which was rotated anteriorly to cover the prosthesis, and the hamstrings were reattached to the adjacent soft tissue (Fig. 2). Osteoarticular defects were replaced using a tumor prosthesis with a hinge or rotating hinge mechanism.

Exercise

The theoretical background for the exercise came from observing patients with idiopathic quadriceps paralysis who exhibited no giving way in the stance phase of gait despite complete lack of strength in the quadriceps muscles. These patients could go up and down stairs slowly with the support of the affected limb without an abnormal gait pattern. However,

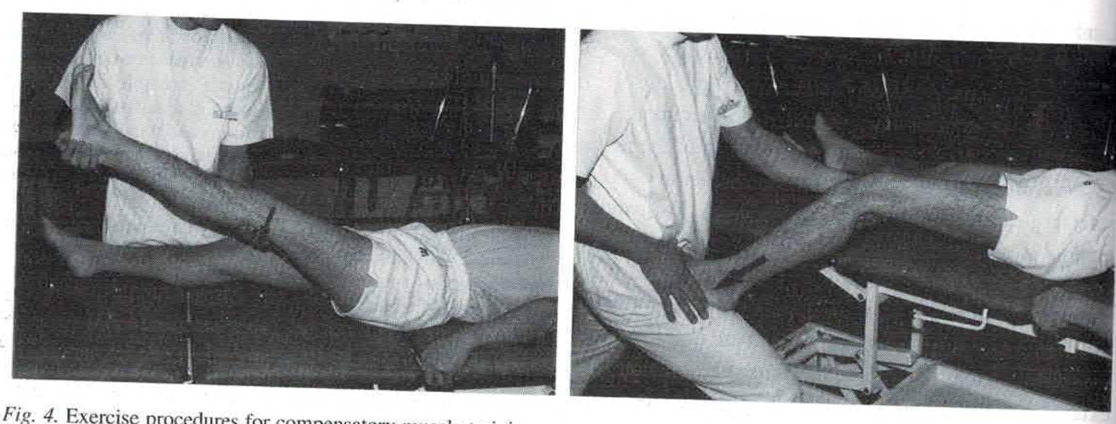

Fig. 4. Exercise procedures for compensatory muscle training.

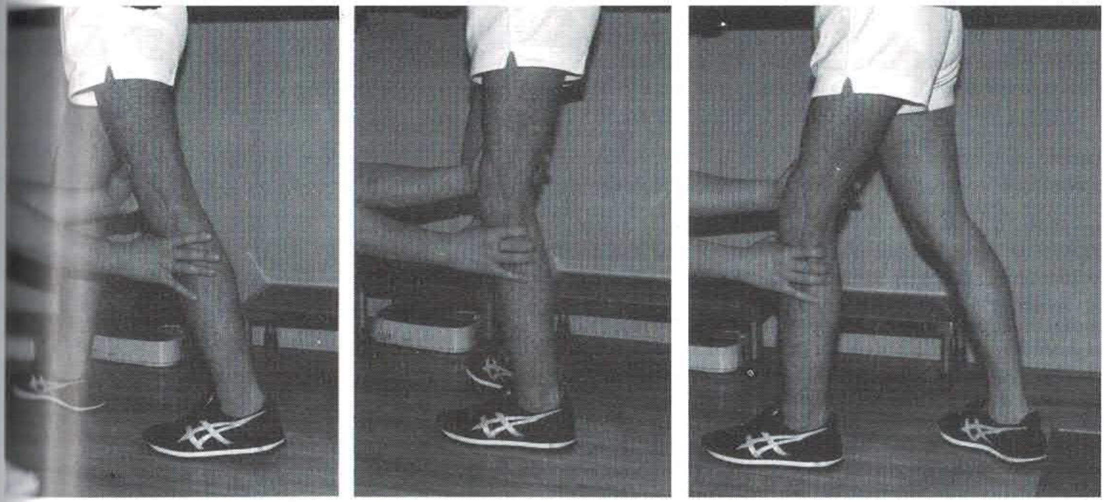

Fig. 5. Gait exercise in parallel bar.

they could not extend the knee at all in the sitting position, and knee extension on swing phase was achieved by performing a pendulum movement of the lower extremity, as is the case for artificial limb gait. The findings in these cases suggest that muscles other than the quadriceps play a significant role in extension of the knee joint during contact of the affected foot with the ground, even in the case of patients having undergone limb-saving operations for bone tumors of the knee. The knee extensor muscles in closed kinetic chain during foot contact with the ground include the gluteus maximus, hamstring,

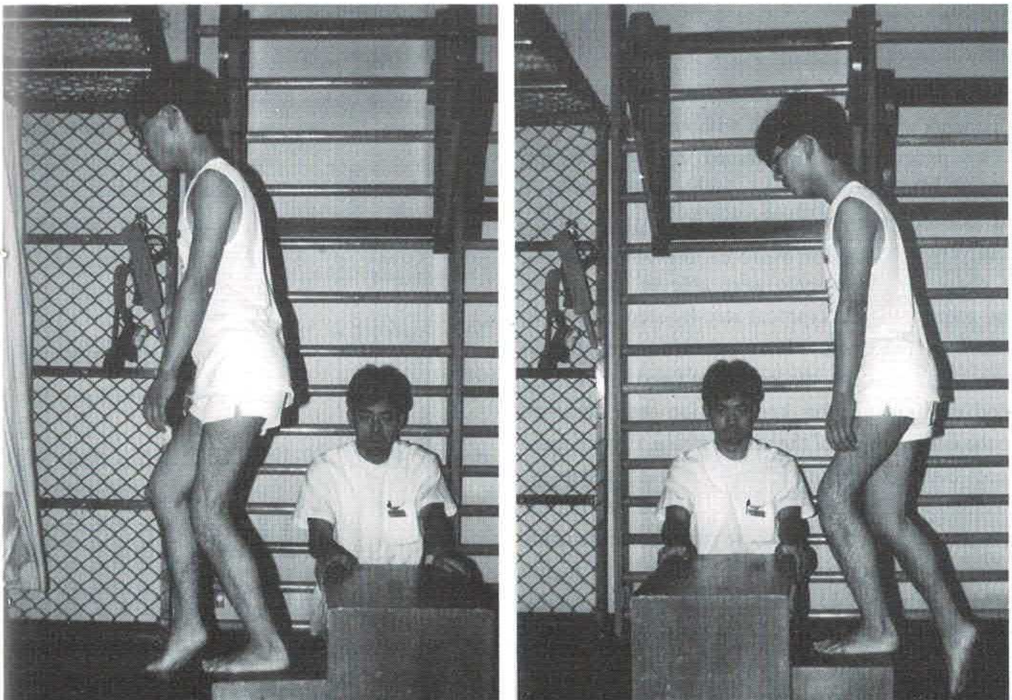

Fig. 6. Ascending and descending stairs, step by step, after compensatory muscle training in a 20-year-old male with a wide resection of the tumor in the distal femur (case 5).

gastrocnemius, and soleus muscles in addition to the quadriceps muscle (5, 6). When the foot is firmly planted on the ground, the gluteal, gastrocnemius, and soleus muscles pull the femur and tibia backward, and, as a consequence, the knee joint is extended. It thus seems possible that to extend the knee patients could learn the timing of muscle contraction and centroid metakinesis (Fig. 3).

Based upon the exercise theory, the gluteus maximus, hamstring, gastrocnemius, and soleus muscles were reinforced in patients with limb-saving operations of the knee. Patients learned the timing of muscle contractions as well as a method for transferring the center of gravity of locomotion. During non-full weight bearing in the early stage, post-surgery, the gluteus maximus and hamstring muscles were reinforced by resistance to extension of the hip with the knee fixed in an extended position (Fig. 4). Many patients were able to walk with ease with the fixed extension position of the knee in the stance phase upon full weight bearing. Patients learned to contract the muscles that compensate for loss of knee extension and learned how to transfer the center of gravity through the exercise program. After stability was obtained in the knee-extended gait, the exercise for knee extension by simultaneous contraction of the gluteus maximus and gastrosoleus muscles was begun in the supine position and then progressed to standing with the affected limb alone. As a result of these exercises, the patients were able to maneuver stairs, step-by-step, and could walk with a double knee action. After learning the appropriate knee action with weight bearing, the height of the stairs could be increased (6). Once the patient mastered knee control in weight bearing, he could learn the double knee action in the stance phase (Figs. 5, 6).

RESULTS

The results of this study are summarized in Table I. All of the patients were able to walk without any supportive aids. Two patients who maintained a knee extension strength of MMT grade 4 had double knee action, a normal phenomenon in which the knee joint moves consecutively in extension–flexion–extension during the stance phase. These patients were able to ascend and descend stairs using a reciprocal step-by-step pattern. In the other 9 patients, whose knee extension strength was less than MMT grade 4, the knee was fixed in the fully extended position and no knee flexion was observed during the entire period of the stance phase. Five of these 9 patients could go up and down stairs using a step-by-step technique. This finding was related to muscle strength around the ankle, i.e. those patients whose ankle extension and flexion strength evaluation was higher than MMT grade 4 could achieve a step-by-step pattern, while those with strength lower than MMT grade 3 could not.

On surface electromyography, a continuous discharge pattern of the gluteus maximus, the hamstrings, and gastrocnemius muscles was observed during the total period of the stance phase in earlier gait training. The

Table I. *Results after gait exercises of patients with decreased strength of knee extension*

Case	Age/Sex	Site of tumor	Hip		Knee		Ankle		Gait profile of the knee	Stairs	
			Extension	Flexion	Extension	Flexion	Dorsi flexion	Plantar flexion	(stance phase)	Going up	Going down
1.	8/F	Distal femur	4−	4	1+	4	4	4	Fixed extension	Step-by-step	Step-by-step
2.	14/F	Distal femur	4−	4	1+	3+	4	4−	Fixed extension	Step-by-step	Step-by-step
3.	20/F	Distal femur	4	4	4	4	4	4	With double knee action	Step-by-step	Step-by-step
4.	15/M	Distal femur	4	4	2+	4	4+	4	Fixed extension	Step-by-step	Step-by-step
5.	17/M	Distal femur	4	4	1+	4−	4	3+	Fixed extension	Step-by-step	Step-by-step
6.	14/F	Proximal tibia	3+	3−	2+	2	0	2	Fixed extension With AFO	Step-to-step	Step-to-step
7.	15/M	Proximal tibia	4	4−	2	4	0	4	Fixed extension With AFO	Step-to-step	Step-to-step
8.	16/M	Proximal tibia	4+	3+	3	4	5	4	Fixed extension	Step-by-step	Step-by-step
9.	16/M	Proximal tibia	5	5	3	4	0	4	Fixed extension	Step-to-step	Step-by-step
10.	19/M	Proximal tibia	3+	4+	1+	2	0	3+	Fixed extension With AFO	Step-to-step	Step-to-step
11.	15/M	Proximal tibia	5	4	4	4	4	5	With double knee action	Step-by-step	Step-by-step

Step-to-step: Stepping up with the sound leg or down with the affected leg, and placing the other leg next to it.
Step-by-step: stepping up or down with one leg, and placing the other leg next through it.
AFO: Shoe-horn-type Ankle Foot Orthosis.

discharge pattern subsequently changed with time, and the discharge of the gluteus maximus and hamstring muscles became limited during the early period of the stance phase. However, the discharge of the gastrocnemius muscle was not observed during the early period of the stance phase, and was detected during and after the middle period of the stance phase. These findings suggest that the gluteus maximus and hamstring muscles compensate for knee extension in the early period of the stance phase and that continuous contraction of the calf muscles prevents any giving way during the middle period of the stance phase.

DISCUSSION

This study demonstrated that patients whose knee extension strength was MMT grade 3 retained a basic capability for locomotion, including walking and ascending and descending stairs. These patients also exhibited strenuous propelling force on each side, identical to that of normal subjects, if ankle extension and flexion strength were preserved at an MMT level of more than grade 4. Generally speaking, a slight decrease in the strength of knee extension causes difficulty in motion due to eccentric muscle contraction such as when descending stairs. Patients with weakness of knee extension due to limb-saving operations for malignant tumors of the knee rapidly develop knee flexion while descending stairs. They therefore descend stairs in a step-to-step fashion.

Currently, it is difficult sufficiently to restore the knee extensor mechanism surgically, and therefore compensatory muscle training is becoming increasingly important. A gait with double knee action, in which vertical and forward components of a floor reaction force are diminished, may prevent loosening and breakage of prostheses, since the impact on the prosthesis is decreased. The provision of compensatory muscle training for these patients, most of whom are young, appears to be highly beneficial. These results demonstrate the significance of postoperative rehabilitation exercise in patients with limb salvage surgery.

REFERENCES

1. Enneking, W. F.: Musculoskeletal tumor surgery. Vols. I & II. Churchill Livingstone, 1983.
2. Enneking, W. F.: A system of staging musculoskeletal neoplasms. Clin Orthop *204:* 9–24, 1986.
3. Uchida, A., Myoui, A., Araki, N., Yoshikawa, H., Shinto, Y. & Ueda, A.: Neoadjuvant chemotherapy for pediatric osteosarcoma patients. Cancer *79:* 411–415, 1996.
4. Kawamura, H., Yoneda, T., Hayashi, Y., Uchida, A., Kuratsu, S., Hiroshima, K. & Ono, K.: Gait analysis and significance in patients with total knee prosthesis after wide resection of malignant tumor. *In* Recent Advances in Musculoskeletal Oncology (eds A. Uchida & K. Ono), pp. 269–277. Springer-Verlag, 1992.
5. Sutherland, D. H.: An electromyographic study of the plantar flexors of the ankle in normal walking on the level. J Bone Joint Surg *48A:* 66–71, 1966.
6. Winter, D. A.: Biomechanics and motor control of human movement. 2nd ed. Wiley Interscience, 1990.

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