UNIVERSITY OF SOUTHAMPTON

QUANTITATIVE MUSCULAR PERFORMANCE AND TRAINING IN PATIENTS WITH OSTEOARTHRITIS OF THE KNEE

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Doctor of Philosophy

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ABSTRACT

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Osteoarthritis (OA) of the knee is a disabling condition characterized by pain, stiffness, and muscle weakness leading to reduction in normal functional activities. A variety of exercise programmes are used in order to reduce clinical symptoms in patients with OA of the knee, but there is little evidence to determine the most effective exercise programme in the conservative treatment of this condition. This dissertation is divided into four major parts. The first part reviews the literature relating to OA of the knee, the strength of quadriceps and hamstring muscles, functional activities, and the effects of training programmes. It then describes previous experimental studies. The second part outlines methods used in assessment and their reliability and validity. The third part describes the differences in torque and myoelectrical activity between healthy subjects and patients with OA of the knee. This part also details a pilot study which determines the feasibility and acceptability of Squat Closed Kinetic Chain Training (Squat Closed KCT) in these patients. The fourth part describes a prospective trial.

In the prospective trial, the effects of Squat Closed KCT compared with traditional Open Kinetic Chain Training (Open KCT) and progress in a control group. Outcomes include maximum isometric knee extension and flexion torques and agonist and antagonist myoelectrical activity. The study also investigates intensity of pain and functional activity using a Self-reported Pain and Functional Knee Assessment (SPFKA). The assessments were undertaken before treatment (initial baseline), at three and six weeks during training, and at fifty weeks from baseline.

Maximum isometric knee extension and flexion torques and agonist myoelectrical activity significantly increased in both exercise groups compared with the control group at three and six weeks during the training. There was a relative reduction in the antagonist coactivation index during maximum isometric knee extension. The increases in torques and agonist myoelectrical activity were accompanied by improvements in functional activities and reduction in knee pain. These gains had declined at fifty weeks. There was a trend for Squat Closed KCT to produce greater torque and myoelectrical activity than Open KCT, but this trend was not statistically significant. The differences in pain and walking disability scores were significantly less in Squat Closed KCT compared with Open KCT at fifty weeks, but the number of patients was too small and subjects were too highly selected to draw a firm conclusion about the longer term results.

The results of this study suggest that Squat Closed KCT, using a modified tilting table (MTT) and painful squat angle, is safe and is probably more appropriate than traditional Open KCT in providing clinical benefits, and improving functional activities.

ABBREVIATIONS

a-	Cincinnati Rating System	:	(CRS)
b-	Closed Kinetic Chain Training	:	(Closed KCT)
c-	Functional Index Questionnaire	:	(FIQ)
d-	General Practitioner	:	(GP)
e-	Hamstring	:	(Hs)
f-	Maximum isometric knee extension	:	(MKE)
g-	Maximum isometric knee flexion	:	(MKF)
h-	Isotonic Knee Extension	:	(TKE)
I-	Lateral Hamstring	:	(HL)
j-	Medial Hamstring	:	(HM)
k-	Myoelectrical activity	:	(EMG)
l-	Open Kinetic Chain Training	:	(Open KCT)
m-	Osteoarthritis	:	(OA)
n-	Quadriceps	:	(Qs)
o-	Rectus Femoris Muscle	:	(RF)
p-	Self-report Pain and Function Knee Assessment:		(SPFKA)
q-	Maximum static quadriceps contraction	:	(SQC)
r-	Straight leg raise	:	(SLR)
s-	Vastus Lateralis Muscle	:	(VL)
t-	Vastus Medialis Muscle	:	(VM)
u-	Visual Analogue Scale	:	(VAS)

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PRESENTATIONS AND SCIENTIFIC MEETINGS

Comparison of Torque and Myelectrical Activity in Quadriceps and Hamstrings Muscles Between health Subjects and Patients with Osteoarthritis of the Knee During Isometric and Isotonic Exercises (chapter three). Rustam A, McLellan LD. **The 13th International Congress of Word Confederation for Physical Therapy**. May 1999, Yokohama, Japan. (Accepted).

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VOLUME TWO

PART FOUR

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CHAPTER TEN: DISCUSSION OF THE PROSPECTIVE STUDY

CHAPTER EIGHT
METHODS USED IN THE PROSPECTIVE STUDY COMPARING SQUAT CLOSED KCT, OPEN KCT, AND THE CONTROL GROUPS IN PATIENTS WITH OSTEOARTHRITIS OF THE KNEE

8.1. INTRODUCTION

The pilot study (chapter seven) suggested that Squat Closed KCT is acceptable to be used in patients with OA of the knee in the hope of improving torque, agonist myoelectrical activity, some functional activities, and reducing pain. In the pilot study, the investigator and the participants were satisfied with the preliminary results. Squat Closed KCT was performed smoothly on those patients with knee OA without exacerbation of the symptoms. A six week period proved reasonable to allow a provisional estimate of effectiveness. The main study was designed:

1- to compare the effectiveness of Squat Closed KCT with that of Open KCT in increasing muscular torque in a larger group of subjects.
2- to find out whether any associated increase in torque is associated with reduced antagonist muscle coactivation.
3- to find out whether improvement of torque and myoelectrical activity is associated with a reduction in pain, and an improvement in functional activity in patients with OA of the knee.
4- to investigate the relationship between the severity of pain and the myoelectrical activity in agonist and antagonist muscles acting at the knee during voluntary activation.

8.2. ETHICAL CONSIDERATIONS

These issues were described previously in the pilot study (chapter seven, page 171).

8.3. METHODS

8.3.1. Plan of Study

The prospective study was designed to select patients with OA of the knee from the Physiotherapy Departments at Southampton General Hospital and the Royal South Hants Hospital. The patients were randomly allocated to one of the three groups (Closed KCT, Open KCT, and control) before the baseline assessment. In each group, some subjects had one affected knee which in others both knees were affected.

As a result of lack information on possible effect sizes for each variable, a large effect size was employed as a factor for determining sample size.

Patients with bilateral OA were accepted into the study. Both knees were tested separately throughout the study, but the data were only analysed on the bases of the most painful knee using VAS. Such patients were instructed to disregard the opposite knee while performing the test procedures or filling in the SPFKA.

8.3.1.1. Recruitment and Selection of Subjects

Patients referred to the Physiotherapy Departments at Southampton General and the Royal South Hants Hospitals were identified from their records as meeting the study criteria for referral for physiotherapy because of OA of the knee (see chapter seven, page 172).

The investigator contacted each patient by telephone after having verbal or written permission from patient's physiotherapist and doctor. The investigator explained to all subjects the purposes of the study and measurement conditions, and asked them to sign the consent form (Appendix 4). The patients were then assigned to one of the three groups using a pseudo random technique by placing three playing cards (faced down) on a table. Each card was assigned for one of the three groups by

the investigator. The playing cards were shuffled three times before the investigator asked patients to select one card. Each patient was asked to pick one card only.

The investigator explained to each patient the process and sequence of each set of procedures. All patients were instructed to take their usual medication, and not to involve themselves in any new sport or other strenuous exercise activity during the period of the study.

Patients in both exercise groups were asked to undertake supervised exercises twice per week for six weeks. All groups were to be tested at baseline and thereafter at three, six, and fifty weeks. The outcomes included torque, myoelectrical activity in the thigh muscles during four seconds MKE and MKF, intensity of pain, and lower limb functional activities.

8.3.1.2. Techniques of Measurement

a- Modified Chair . This was described in chapter four page 94 (Figure 4.1, page 113).

b- EMG Recordings. This system was described in chapter three pages 94 and 95 (Figures 4.3, page 115).

c- Pain and Functional Assessment Tool. The level of pain, and functional disability were measured in all patients by the Self-reported Pain and Function Knee Assessment (SPFKA) (Appendix 3). The SPFKA reliability and validity tests were described in chapter five (pages 122 and 123). The SPFKA was given to each patient immediately before the testing procedure at baseline and three, six, and fifty weeks.

d- X-Ray. All X-rays were obtained in standing position. Antero-posterior and lateral views of the knee joints were taken between one week to six months prior to

the study. The classification of OA of the knee was graded from 0 (no features of knee OA) to 4 (joint space greatly impaired) (see chapter seven, page 173).

e- Modified tilting Table (MTT). This was described in the pilot study, chapter seven, page 174 and illustrated in Figure 7.1 (page 201).

f- Other Measurement Tools. These were described in the pilot study, chapter seven (page 174).

8.3.2. Treatment Protocol

The exercise therapy was undertaken individually by each patient in the Squat Closed KCT and Open KCT groups in twice-weekly sessions each lasting 30 minutes. In order to maintain patients' compliance, all patients performed exercises under the close supervision of the investigator in the Gait Laboratory of the University Rehabilitation Research Unit, Southampton General Hospital. No such exercise was undertaken by the control group during the first six weeks period of the study.

8.3.2.1. Squat Closed KCT (Description of Given Exercise):

This exercise protocol was described in the pilot study, chapter seven (pages 175 to 178).

8.3.2.2. Open KCT (Description of Given Exercise):

The position to be adopted by patients during these exercises incorporated those used most frequently in practice by physiotherapists for patients with OA of the knee. Each exercise was adapted individually to the patient's activity level as regards of the number of repetitions and resistance used. Open KCT consisted of exercises of relevance to the knee joint including: 1) dorsi and plantar flexion of the ankle, 2) static

quadriceps contraction (quadriceps drill), 3) free knee flexion and extension, 4) straight leg raise, and 5) isometric knee extension and flexion. All these exercises were performed on the treatment table. Every patient undertook five components of the programme. Each exercise was carried out in three sets with a two minute rest period in between each set in order to avoid muscular fatigue. The investigator stopped the exercise when the patient experienced increase in pain, discomfort, or fatigue. The exercises are described in more detail below:.

1- Dorsi and plantar flexion of the ankle.

- Position.

  The patient adopted the long sitting position with each hand supported on the treatment table.

- Procedure.

  - The investigator asked the patient to straighten both legs and perform 3 seconds of dorsi flexion and 3 seconds of plantar flexion, repeated 10 times.

2- Static quadriceps contraction.

- Position.

  Same position as in dorsi and plantar flexion of the ankle.

- Procedure.

  - The investigator asked the patient to dorsiflex the ankle and tighten the quadriceps muscle maximally for 5 seconds followed by 5 seconds rest. This procedure was repeated 20 times.

3- Free knee flexion and extension.

- Position.

  The patient was positioned in supine lying with one leg (unexercised) flexed at the knee and hip. The heel was placed parallel to the knee joint line of the other (exercised) leg.

- Procedure.

  - The patient was asked to perform flexion and extension throughout the available ranges at the knee. The procedure was undertaken every 5 seconds and repeated 10 times.

4- Straight Leg Raise.

- Position.

  Same position as in free knee flexion and extension.

- Procedure.

  - The patient was asked to dorsiflex the ankle, tighten the quadriceps muscle, and raise the leg up to the level of the opposite flexed thigh. This exercise was carried out over 5 seconds for each repetition. The number of repetitions was determined individually for each patient. The first set in the first session consisted of the greatest number of repetitions in which the patient's optimal leg movements could be maintained (i.e. performance was not noticeably affected for example by fatigue). The second set consisted of half the number of the first set of repetitions. The third set followed the same rules as the first set. In subsequent sessions, the initial (first) set of exercises employed the same number of repetitions as had been advised in the third set of the previous session.

5- Static knee extension and flexion.

- Position

  The patient sat on the side of the table with both lower legs hanging. The hips and ankles were fixed in neutral rotational position. The exercise knee was fixed at 90 degrees of knee flexion. This angle was measured by a fluid goniometer placed at the lower third of the distance between the medial tibial plateau and the tip of the medial malleolus of the top

leg.

- Procedure

a- Static knee Extension. The patient was asked to cross the legs at the ankles. The exercising leg (bottom) was placed behind the other leg (top). The investigator asked the patient to extend the bottom leg forcefully, while the top leg was voluntarily firmly flexed. The patient was asked to use his/her maximum effort of the quadriceps muscle in the bottom leg without allowing movement to occur in the knees. There was thus concurrent activation of knee extensors in the exercised leg and of knee flexors in the so-called unexercised leg.

b- Static Knee Flexion. The patient reversed the crossed legs. The 'exercising leg' was kept on top. Then the bottom leg was held firmly while the top leg attempted to flex the knee against the extensors of the 'unexercised' knee.

For a and b, each exercise was performed five times. Each static extension or flexion took 5 seconds followed by 5 seconds rest.

8.3.2.3. Control Group

The patients in this group were asked to attend for three testing sessions only. These patients agreed to delay starting their physiotherapy treatments for 6 weeks during the time of the study. They had been asked not to participate in any additional exercise activity or medical treatment other than their prescribed medication. Patients in this group were given 10-15 minutes health care advice and before each test procedure. They were also allowed to contact the investigator any time during working hours throughout the period of the study.

After the third test procedure (six weeks), the patients were given the choice of continuing home exercises under the supervision of the investigator, or waiting for their routine physiotherapy treatments. Knee care and Open KCT home exercises were given to the control group after the sixth week of test procedure by the investigator.

8.3.3. Follow up Period of the Study

Squat Closed KCT and Open KCT in exercise groups were carried out in two training sessions per week for a six week period. After six weeks, the investigator asked all patients to stop supervised exercises and to resume their normal activities. The investigator subsequently contacted each patient by telephone to arrange a further test at fifty weeks from the baseline test. The intention was to follow up all subjects in all three groups at fifty weeks from the baseline test.

8.3.4. Data Analysis

The data were analysed using the Kruskal-Wallis (non-parametric) test to test the potential differences between MKE and MKF torques and myoelectrical activity at baseline and three, six, and fifty weeks. The level of pain, function activity, and 'feelings in general' were analysed at these periods by the same test procedure. The study also analysed these variables in each group individually at three and six weeks compared to baseline using the Wilcoxon test.

The data were aggregated in terms of muscle groups and joint angles. The medians of MKE and MKF torques, agonist myoelectrical activity, and antagonist coactivation index were correlated using the Pearson Correlation Coefficients. These variables were also correlated with degrees of joint degeneration (Spearman test), the level of pain, age, height, and weight (Pearson test). Scatter plots were used to illustrate correlations between the variables.

It was considered important to Check for chance differences between the patient groups resulting from differences in age, sex, height, and weight of subjects in each group. Men are likely to be able to generate stronger forces than women, and older adults are likely to generate weaker forces than younger ones. In addition, larger individuals are likely to be stronger than smaller ones, though of course some individuals will have more adipose tissue than others and so this relationship is likely to be very variable.

In order to check that differences in the composition of the groups of subjects would not have been such as to bias the results, careful comparisons were made between the numbers of males and females, the mean age of males and females, and the body weight of males and females in each of the three groups.

CHAPTER NINE
9. RESULTS

9.1. Subjects' Selection

All patients were referred from the following surgeries and specialists in the Southampton area:

-Rheumatology Department at Southampton General Hospital.

-Orthopaedic Unit at Southampton General Hospital

-Bath Lodge Practice.

-Shirley Surgery.

-Townhill Surgery.

-Portswood Practice.

-Drs. Bradberry, Fisher, Maclean, Shaw, Higgins, Meadows, and Sword.

-Blackthorn Surgery (Dr. Simon Goodison).

-Cansule Surgery (Dr. O M Obin).

-Spitfire Court Surgery (Dr. David Adey).

One hundred and twenty-four patients (73 women, 51 men) were taken from the physiotherapy out-patient waiting list (from June to October 1995), and fresh referrals patients (from October 1995 to June 1996) in both Physiotherapy Departments (Figure 9.1). Eighty-nine patients (58 women, 31 men) with bilateral or unilateral knee OA met the criteria of the study (as described in the pilot study, chapter seven, page 172). The patients' names, addresses, telephone numbers, and names of referring doctors were recorded. Ten patients were excluded from the study for medical reasons associated with OA of the knee. Four patients were not contacted because of unavailability or incorrect telephone numbers or addresses. A further six patients (4 women, 2 men) declined to enter the study for personal reasons. Each patient was advised by the investigator to arrange a convenient time, and to bring a pair of shorts and socks for the testing procedure.

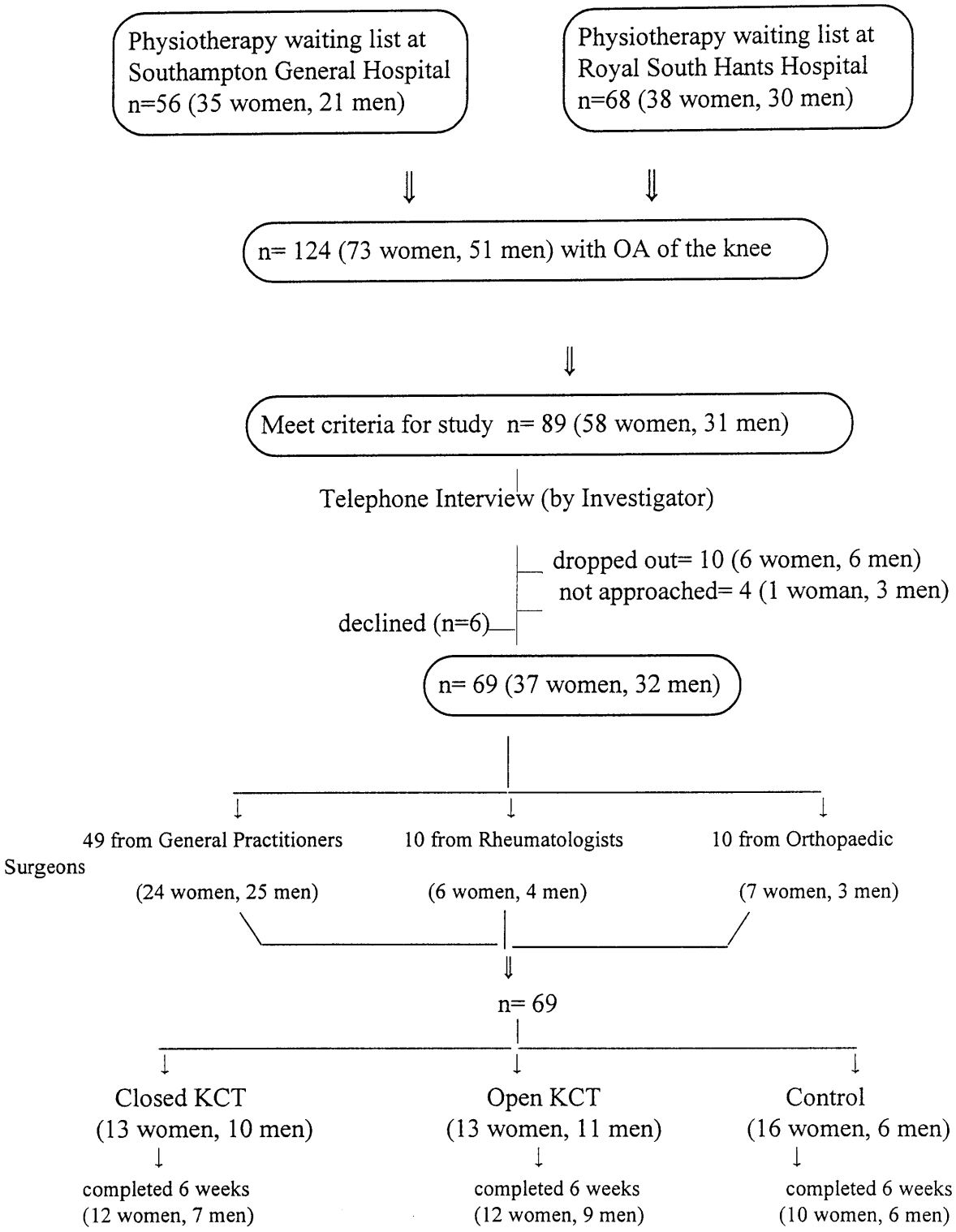


Figure 9.1. The diagram shows the provenance of patients selected for the study and the reasons for exclusion or for dropping out of the study.

- Recruitment:

Sixty-nine patients (37 women, 32 men), with a total of ninety-one OA affected knees, participated in the baseline period of the study. All patients had confirmed that they had seen their doctors several times for knee discomfort, and that they had not received any intra-articular injection within the past nine months. Conventional and radiological diagnosis was made as unilateral and bilateral OA of the knees by either general practitioners (24 female and 25 male subjects), rheumatologists (6 female and 4 male subjects) or orthopaedic surgeons (7 female and 3 male subjects).

A further inclusion criterion for the data analysis was that all patients attended all the exercise sessions and the first three test procedures (baseline, and three and six weeks). For those with OA of both knees, subjects were rated on the basis of the most painful knee (in VAS) or radiological features of OA in those who had similar symptoms in each knee.

Fifty-six patients (34 women, 22 men) from sixty-nine patients (37 women, 32 men) completed the six week programme. All patients had experienced knee pain for more than six months, and had radiological evidence of grade 2 to grade 4 OA of the knee (Kellgren and Lawrence, 1957; Burnett *et al*, 1994). All patients had symptomatic OA of the knee at the time of the baseline assessment.

All patients then had their functional ability and activity assessed by a general classification of functional capacity, appendix 8 (Copp, 1969). The level of functional activity was recorded in fifty six patients as twelve patients (21.4%) in grade 5 (normal), thirteen patients (23.2%) in grade 4 (almost active), twenty-eight patients (50.0%) in grade 3 (moderate), and three patients (5.4%) in grade 2 (slightly active).The characteristics of all participating patients are described in Table 9.1. The study population mean age was 65.2 +/- 11.4 years, mean height was 167.1 +/- 10.5

- Procedure for Selection of Subjects to each group

Sixty-nine patients had reconfirmed in face to face contact that there was no historical or other evidence of lower extremity musculoskeletal or neurological problems, cardio-pulmonary, respiratory, or other major medical problems. This was to ensure that all participants were fit for the assessment and training procedures.

The Squat Closed and Open KCT groups received six weeks of supervised training, while the control group had only testing procedures at baseline and three, six, and fifty weeks. Based on the number of patients attended at the sixth week test procedure, the three groups included:

Group 1) **Closed KCT**: 19 patients (12 women, 7 men) participated in this group. The most painful knee was selected in the five patients with OA of both knees.

Group 2) **Open KCT**: 21 patients (12 women, 9 men) performed several series of individual exercises supervised by the investigator. The most painful knee was selected from the six patients with bilateral OA of the knee.

Group 3) **control**: 16 patients (10 women, 6 men) were selected for the control group. The most painful knee was selected from the ten patients with bilateral OA of the knee.

The percentage changes during the study in MKE or MKF torque and myoelectrical activity were not significantly different in women and men using Mann-Whitney test ($p \geq 0.06$).

- Drop-out Rate:

There was a large fall in the number of patients, particularly in the control group, who were willing to participate between six weeks and fifty weeks after starting the study without supervised training. The drop out of patients in the study at three weeks was 8.7% (two patients) in Squat Closed KCT, 12.5% (three patients) in

Open KCT, and 22.7% (five patients) in controls. At six weeks, it was 13% (three patients) in Squat Closed KCT, 12.5% (three patients) in Open KCT, and 27.3% (six patients) in controls. At fifty weeks, it was 52.2% (twelve patients) in Squat Closed KCT, 75.0% (eighteen patients) in Open KCT, and 86.4% (nineteen patients) in controls (Table 9.2).

The data analysis at baseline, and three and six weeks were based on fifty-six patients who continued the exercise programmes and had the three test procedures (baseline, and three and six weeks) because it was inappropriate to make assumptions based on the analysis on the small sample size at fifty weeks.

Table 9.2.
The number of patients attending for assessment at each stage of the study in Closed KCT, Open KCT, and control groups.

Groups	Baseline (n= 69)		3 weeks (n= 59)		6 weeks (n= 56)		50 weeks (n= 20)	
	W	M	W	M	W	M	W	M
Closed	13	10	12	9	12	7	6	5
Open	13	11	12	9	12	9	4	2
Control	16	6	11	6	10	6	2	1
Total	42	27	35	24	34	22	12	8

(W= women, M= men)

At fifty weeks, three subjects from the control group reported that they had not had other exercises or physiotherapy following the sixth week test. These patients were instructed to perform home exercises (Open KCT) by the investigator after having the week six test. It was unethical to hold these patients without any treatment for fifty weeks. However, the number of patients in the control group at fifty weeks was too small to be statistically analysed.

9.2. Isometric Knee Torques

At the beginning of the study, the investigator expected to find significant differences in torques and myoelectrical activity between the different knee joint angles, particularly in the Open KCT group whose subjects were to perform isometric knee extension training at 90 degrees of knee flexion. However, data analysis showed similarities in torque and myoelectrical activity values at the three angles chosen. In order to simplify further the presentation and discussion of these findings, the following convention will be adopted in relation to torques and myoelectrical activity (chapter six, on pages 143 and 146). The schema below refers to torques (see page 228 for myoelectrical activity records).

Level 1: (There was no level 1 for torques because it was not possible to assess the torques developed by individual components of the quadriceps or hamstring muscles).

Level 2: The MKE and MKF torques developed by extensor or flexor muscles at each angle (30, 60, 90 degrees) for the group.

Level 3: The overall MKE and MKF torques from readings at all three knee angles developed by the extensor (or flexor) muscles for the group.

9.2.1. Maximum Isometric Knee Extension (MKE) Torques

9.2.1.1. Maximum Isometric Knee Extension (MKE) Torque Between Groups - Level 2

1- Baseline:

At baseline before starting training, the median MKE torques (level 2) were 64.8 Nm (Closed), 68.9 Nm (Open), and 60.9 Nm (control) at 30 degrees of knee flexion. At 60 degrees of knee flexion, the median torques were 76.0 Nm (Closed),

65.5 Nm (Open), and 56.2 Nm (control). At 90 degrees of knee flexion, the median MKE torques were 60.9 Nm (Closed), 68.0 Nm (Open), and 60.9 Nm (control). The differences in MKE torques were not statistically significant between Squat Closed KCT, Open KCT, and control groups at baseline ($p \geq 0.3$) (Table 9.3).

2- Three weeks:

At three weeks of exercise training, the median MKE torques (level 2) were 84.9 Nm (Closed), 82.3 Nm (Open), and 57.1 Nm (control) at 30 degrees of knee flexion. At 60 degrees of knee flexion, the median MKE torques were 85.0 Nm (Closed), 84.1 Nm (Open), and 54.9 Nm (control). At 90 degrees of knee flexion, the median MKE torques were 78.5 Nm (Closed), 76.9 Nm (Open), and 49.0 Nm (control). Statistically significant differences between the MKE torques were found between the three groups (level 2) at all three knee joint angles i.e. 30, 60, and 90 degrees of knee flexion ($p \leq 0.008$) (Table 9.3).

It can be summarized that the median MKE torque significantly increased in two exercise groups at three weeks.

3- Six weeks:

At six weeks of exercise training, the median MKE torques (level 2) were 114.9 Nm (Closed), 98.0 Nm (Open), and 58.5 Nm (control) at 30 degrees of knee flexion. At 60 degrees of knee flexion, the median MKE torques were 112.3 Nm (Closed), 98.2 Nm (Open), and 49.0 Nm (control). At 90 degrees of knee flexion angle, the median MKE torques were 94.0 Nm (Closed), 91.8 Nm (Open), and 47.9 Nm (control). Statistically significant differences in the torques were found between these three groups (level 2) at all three knee joint angles ($p < 0.0001$) (Table 9.3).

It can be concluded that the median MKE torque significantly increased in two

exercise groups at six weeks.

4- Fifty weeks:

At fifty weeks, the median MKE torques (level 2) were 103.9 Nm (Closed), 49.0 Nm (Open), and 54.9 Nm (control) at 30 degrees of knee flexion. The median MKE torques were 84.9 Nm (Closed), 71.7 Nm (Open), and 67.1 Nm (control) at 60 degrees of knee flexion. At 90 degrees of knee flexion, the median MKE torques were 89.1 Nm (Closed), 60.9 Nm (Open), and 53.9 Nm (control) (Table 9.3).

Table 9.3.
Comparison of the median maximum isometric knee extension (MKE) torque (level 2) at 30, 60, and 90 degrees at baseline and three, six, and fifty weeks between Closed KCT, Open KCT, and the control groups in patients with OA of the knee using Kruskal-Wallis test.

		MKE Torque (Nm)						
		Closed (n=19)		Open (n= 21)		control (n= 16)		p
Periods	Angles	Median	Range	Median	Range	Median	Range	
0	30°	64.8	21.2-175.0	68.9	16.0-207.8	60.9	21.0-152.6	0.9
	60°	76.0	30.4-165.8	65.5	21.2-231.8	56.2	18.3-168.0	0.3
	90°	60.9	28.0-164.3	68.0	18.3-231.8	60.9	19.1-140.3	0.9
3 weeks	30°	84.9	28.0-189.1	82.3	21.0-213.5	57.1	24.9-141.1	0.008*
	60°	85.0	36.6-183.0	84.1	31.2-243.9	54.9	24.6-119.0	0.0009*
	90°	78.5	42.6-164.3	76.9	21.5-250.0	49.0	23.6-119.5	0.0002*
6 weeks	30°	114.9	48.8-225.8	98.0	43.2-231.8	58.5	21.1-113.1	< 0.0001*
	60°	112.3	42.0-233.0	98.2	42.6-265.1	49.0	24.0-114.3	< 0.0001*
	90°	94.0	55.9-207.7	91.8	36.6-252.7	47.9	25.0-119.0	< 0.0001*
50 weeks ✣	30°	103.9	42.6-196.0	49.0	33.2-202.9	54.9	49.7-88.0	
	60°	84.9	39.7-255.8	71.7	35.5-158.1	67.1	37.1-89.1	
	90°	89.1	49.9-186.8	60.9	31.9-207.7	53.9	30.5-54.3	

*: statistically significant difference between the three groups.
✣: number of patients at 50 weeks (Closed= 11, Open= 6, and control= 3).

- Level 3

The findings were similar at all three knee angles, and therefore the investigator calculated the overall median MKE torques for all three angles (level 3) in order to minimize variability of the data (Table 8.4). The overall median MKE torques at the three knee flexion angles was 72.0 Nm (Closed), 70.5 Nm (Open), and 60.7 Nm (control) at baseline. At three weeks, the overall median MKE torques was 85.0 Nm (Closed), 81.4 Nm (Open), and 53.7 Nm (control). At six weeks, it was 112.0 Nm (Closed), 96.8 Nm (Open), and 51.2 Nm (control). At fifty weeks, they were 97.1 Nm (Closed), 56.7 Nm (Open), and 57.2 Nm (control).

The results of the overall of torques (level 3) compared between the three groups were shown:

- no statistically significant differences at baseline ($p= 0.6$).
- statistically significant differences at three and six weeks ($p\leq 0.01$).

Table 9.4.
Comparison of the overall maximum isometric knee extension (MKE) torque (level 3) at 30, 60, and 90 degrees at baseline and three, six, and fifty weeks between Closed KCT, Open KCT, and control groups in patients with OA of the knee using Kruskal-Wallis test.

Periods	Groups	MKE Torque (Nm)		
		Median	Range	P
Baseline	Closed (n= 19)	72.0	30.2-160.9	0.6
	Open (n= 21)	70.9	21.2-219.6	
	Control (n= 16)	60.7	24.4-147.4	
3 weeks	Closed b,c	85.0	37.1-163.8	0.01 *
	Open b,c	81.4	30.7-230.8	
	Control	53.7	23.2-117.4	
6 weeks	Closed b,c	112.0	57.5-209.7	0.001 *
	Open b,c	96.8	46.6-225.1	
	Control	51.2	20.7-115.5	
50 weeks	Closed (n= 11)	97.1	44.1-210.3	
	Open (n= 6)	56.7	33.5-176.1	
	Control (n= 3)	57.2	40.8.-76.8	

*: statistically significant difference between the three groups.
b: statistically significant difference compared to baseline using Wilcoxon test.
c : statistically significant difference compared to the control group using Mann-Whitney test.

Table 9.4 shows significant increases in the overall median MKE torques in two exercise groups at three and six weeks.

9.2.1.1.2. Maximum Isometric Knee Extension (MKE) Torque Within Groups

In Squat Closed KCT, the overall median MKE torque (level 3) increased at three and six weeks from baseline, and these changes were statistically significant ($p \leq 0.0005$) (Table 9.4). In Open KCT, the differences of the overall MKE torques (level 3) were similar to Squat Closed KCT at three and six weeks ($p \leq 0.0005$). The results showed no significant change in the overall MKE torques in the control group throughout the study ($p \geq 0.07$).

9.2.1.1.3. Percentage Change in MKE Torque

The percentage of the overall median was also computed based on the number of the patients who appeared for the three and six week tests (Table 9.2).

At three weeks, the percentage median MKE torques change from baseline was 18.1% (Closed KCT), 43.1% (Open KCT), and -18.1% (control). The difference in the percentage MKE torque change was statistically significant between Squat Closed KCT, Open KCT, and control at three weeks follow up ($p < 0.0001$). This statistically significant result was associated with statistically significant differences between each exercise group and controls ($p \leq 0.0002$). But there was no significant difference between the two exercise groups ($p = 0.9$).

At six weeks, the percentage median MKE torque change from baseline was 55.6% (Closed KCT), 47.5% (Open KCT), and -5.8% (control) at six weeks. There were statistically significant differences between the three groups ($p < 0.0001$), and between each exercise group and controls ($p < 0.0001$). But there was no significant difference between Closed KCT and Open KCT ($p = 0.5$).

9.2.2. Maximum Isometric Knee Flexion (MKF) Torque

9.2.2.1. Maximum Isometric Knee Flexion (MKF) Torque Between Groups - Level 2

1- Baseline:

The findings revealed that the median MKF torques (level 2) were 30.3 Nm (Closed), 28.0 Nm (Open), and 28.0 Nm (control) at 30 degrees of knee flexion. At 60 degrees of knee flexion, the median MKF torques were 22.7 Nm (Closed), 24.3 Nm (Open), and 30.5 Nm (control). At 90 degrees of knee flexion, the median MKF

torques were 22.0 Nm (Closed), 24.3 Nm (Open), and 18.3 Nm (control). The differences in the MKF torques (level 2) were not statistically significant at any of the three angles at baseline ($p \geq 0.6$) (Table 9.5).

2- Three weeks:

At three weeks of training, the median MKF torques (level 2) were 33.0 Nm (Closed), 35.7 Nm (Open), and 18.3 Nm (control) at 30 degrees of knee flexion. At 60 degrees of knee flexion, the median MKF torques were 34.7 Nm (Closed) , 37.2 Nm (Open), and 24.3 Nm (control). At 90 degrees of knee flexion, the median MKF torques were 28.7 Nm (Closed), 24.6 Nm (Open), and 18.6 Nm (control). Statistically significant differences were shown between the three groups in the MKF torques (level 2) at all three knee joint angles ($p \leq 0.03$) (Table 9.5).

At three weeks, the results showed increases in the median MKF torques (level 2) in the two exercise groups.

3- Six weeks:

At six weeks of training, the median MKF torques were (level 2) 40.8 Nm (Closed), 37.4 Nm (Open), and 24.3 Nm (control) at 30 degrees of knee flexion. At 60 degrees of knee flexion, the median MKF torques were 51.0 Nm (Closed), 33.6 Nm (Open), and 24.3 Nm (control). At 90 degrees of knee flexion, the median MKF torques were 40.3 Nm (Closed), 26.2 Nm (Open), and 12.4 Nm (control). Differences in the MKF torques were statistically significant between these three groups (level 2) at all three knee joint angles ($p \leq 0.001$) (Table 9.5).

It can be summarized that the median MKF torques significantly increases in the two exercise groups at six weeks.

4- Fifty weeks:

At fifty weeks from baseline, the median MKF torques (level 2) were 35.8 Nm (Closed), 24.3 Nm (Open), and 20.8 Nm (control) at 30 degrees of knee flexion. The median MKF torques were 39.5 Nm (Closed), 21.2 Nm (Open), and 24.3 Nm (control) at 60 degrees of knee flexion. At 90 degrees of knee flexion, the median MKF torques were 30.5 Nm (Closed), 21.0 Nm (Open), and 24.3 Nm (control) (Table 9.5).

Table 9.5.
Comparison of the median maximum isometric knee flexion (MKF) torque (level 2) at 30, 60, and 90 degrees at baseline and three, six, and fifty weeks between Closed KCT, Open KCT, and control groups in patients with OA of the knee using Kruskal-Wallis test.

		MKF Torque (Nm)						
		Closed (n= 19)		Open (n= 21)		control (n= 16)		p
Periods	Angles	Median	Range	Median	Range	Median	Range	
0	30°	30.3	6.2-63.3	28.0	10.9-128.1	28.0	6.1-83.7	0.9
	60°	22.7	2.4-83.7	24.3	12.4-182.9	30.5	6.9-79.7	0.6
	90°	22.0	0.0-66.6	24.3	6.9-134.1	18.3	5.3-55.9	0.9
3 weeks	30°	33.0	8.0-63.3	35.7	6.9-128.1	18.3	6.2-30.5	0.002 *
	60°	34.7	4.7-70.0	37.2	12.4-122.0	24.3	12.4-55.5	0.004 *
	90°	28.7	3.1-67.8	24.6	2.6-134.1	18.6	6.2-58.7	0.03 *
6 weeks	30°	40.8	12.2-98.0	37.4	6.9-114.0	24.3	6.4-55.9	0.001 *
	60°	51.0	6.2-119.0	33.6	6.1-100.8	24.3	6.2-55.9	0.0008*
	90°	40.3	12.4-98.3	26.2	6.1-136.0	12.4	6.1-63.3	0.0005*
50 weeks ✣	30°	35.8	14.5-67.6	24.3	9.3-97.7	20.8	12.4-18.1	
	60°	39.5	12.4-140.1	21.2	14.3-79.1	24.3	24.3-55.9	
	90°	30.5	12.4-76.9	21.0	6.9-72.9	24.3	12.4-34.7	

*: statistically significant difference between the three groups.
✣: number of patients at 50 weeks (Closed= 11, Open= 6, and control= 3).

- Level 3

The data for the median MKF torques (level 2) were consistent between the three angles. Thus, the investigator also took the overall median torque of MKF for these three angles. The overall median MKF torque (level 3) was 24.5 Nm (Closed), 27.0 Nm (Open), and 29.4 Nm (control) at baseline. At three weeks, the overall median MKF torque was 32.0 Nm (Closed), 32.6 Nm (Open), and 20.3 Nm (control). At six weeks, the overall median MKF torque was 47.8 Nm (Closed), 32.5 Nm (Open), and 20.4 Nm (control). At fifty weeks, it was 37.7 Nm (Closed), 21.1 Nm (Open), and 22.4 Nm (control).

The differences in the overall median MKF torques (level 3) in both exercise groups were statistically significant compared with the control group at three and six weeks (Table 9.6).

The findings showed between the three groups:

- no statistically significant differences at baseline ($p= 0.8$).
- statistically significant differences at three and six weeks ($p\leq 0.009$).

Table 9.6.
Comparison of the overall maximum isometric knee flexion (MKF) torque (level 3) at 30, 60, and 90 degrees at baseline and three, six, and fifty weeks between Closed KCT, Open KCT, and control groups in patients with OA of the knee using Kruskal-Wallis test.

Periods	Groups	MKF Torque (Nm)		
		Median	Range	P
Baseline	Closed (n= 19)	24.5	3.0-71.5	0.8
	Open (n= 21)	25.5	11.4-148.4	
	Control (n= 16)	28.9	2.7-86.8	
3 weeks	Closed b,c	32.0	5.3-56.0	0.002 *
	Open b,c	32.7	11.8-128.1	
	Control	20.3	2.3-53.6	
6 weeks	Closed b,c	47.8	10.3-95.8	0.0004 *
	Open b,c	30.5	8.1-115.2	
	Control	20.4	8.1-46.6	
50 weeks	Closed (n= 11)	37.7	13.8-99.0	
	Open (n= 6)	21.1	13.6-83.2	
	Control (n= 3)	22.4	20.3-37.1	

*: statistically significant difference between the three groups.
b: statistically significant difference compared to baseline using Wilcoxon test.
c : statistically significant difference compared to the control group using Mann-Whitney test.

Table 9.6 shows that the median MKF torques significantly increases in the two exercise groups compared to their baseline and controls.

9.2.2.2. Isometric Knee flexion (MKF) Torque Within Groups

The results showed that the overall MKF torques (level 3) at all three angles significantly increased at three and six weeks from baseline in Squat Closed KCT ($p \leq 0.002$). Open KCT also revealed significant increases in the overall MKF torques at three and six weeks compared with baseline ($p= 0.02$) (Table 9.6). No significant differences were seen in the overall MKF torques of the control group during the study ($p \geq 0.1$).

9.2.3.2. Percentage Change in MKF Torque

At three weeks, the percentage median MKF torque change from baseline was 30.6% (Closed KCT), 28.2% (Open KCT), and -29.8% (control). At six weeks, it was 95.1% (Closed KCT), 19.6% (Open KCT), and -29.4% (control). The changes in the percentage MKE torques were significantly different between Squat Closed KCT, Open KCT, and controls at three and six weeks ($p \leq 0.0001$). There were statistically significant differences between each exercise group and the control group ($p \leq 0.002$). There was also a statistically significant difference between Squat Closed KCT and Open KCT at six weeks ($p = 0.001$), but no significant difference was seen between the two exercise groups at three weeks ($p = 0.4$).

9.2.4. Relationship Between MKE and MKF Torques

A moderate positive association was seen between the overall mean MKE and MKF torques ($r = 0.75$) in all subjects in the study at baseline (Figure 9.2).

9.2.5. Summary Relating to Torque Data

The overall MKE and MKF torques significantly increased in both exercise groups at three weeks and increased further at six weeks. But the overall torque had declined at fifty weeks after withdrawal of the supervised training in both exercise groups. However, the number of subjects had dramatically fallen at fifty weeks, it was inappropriate to compute these data with the three and six weeks data.

9.3. Myoelectrical activity

The investigator had expected that the findings for the agonist and antagonist thigh muscle myoelectrical activity would vary during MKE and MKF at different knee joint angles. But the MKE and MKF myoelectrical activity changes were similar at all three measurement angles in this study. The convention used for torque (page

217) was also used to described the myoelectrical activity readings.

Level 1: The myoelectrical activity of each individual muscle in the agonist (or antagonist) group during MKE or MKF at each knee angle.

Level 2: The median myoelectrical activity of the agonist (or antagonist) muscle group during MKE or MKF at each knee angle.

Level 3: The overall myoelectrical activity of the agonist (or antagonist) muscle group during MKE or MKF for all three angles.

Appendix 12 shows the median, range, and p values of the differences between the individual myoelectrical activity of the agonist and antagonist muscles during MKE and MKF (level 1).

9.3.1. Maximum Isometric Knee Extension (MKE) Myoelectrical Activity

9.3.1.1. MKE Myoelectrical Activity of Agonist Qs Muscles

9.3.1.1.1. MKE Myoelectrical Activity of Agonist Qs Muscle Between Groups

- Level 2

1- Baseline:

At 30 degrees of knee angle, the median myoelectrical activity of the agonist Qs muscle (level 2) during MKE was 5.47 mV (Closed), 6.05 mV (Open), and 3.00 mV (control). At 60 degrees of knee angle, it was 4.44 mV (Closed), 4.24 mV (Open), and 2.30 mV (control). At 90 degrees of knee position, it was 4.59 mV (Closed), 5.20 mV (Open), and 3.36 mV (control). At baseline, the differences in the myoelectrical activity of the agonist Qs (level 2) during MKE at all three knee joint angles were not statistically significant as between Squat Closed KCT, Open KCT, and control groups ($p \geq 0.07$).

2- Three weeks:

At 30 degrees of knee flexion, the median myoelectrical activity of the agonist Qs muscle during MKE (level 2) was 6.06 mV (Closed), 8.08 mV (Open), and 3.53 mV (control). At 60 degrees of knee flexion, it was 5.03 mV (Closed), 6.01 mV (Open), and 2.47 mV (control). At 90 degrees of knee flexion, it was 5.40 mV (Closed), 6.20 mV (Open), and 2.83 mV (control). The differences in the myoelectrical activity of the agonist Qs muscle during MKE at 30, 60, and 90 degrees (level 2) were statistically significant between the Closed KCT, Open KCT, and control groups at three weeks ($p \leq 0.0002$) (Table 9.7).

In summary, significant increases occurred in the two exercise groups, while no significant change occurred in the control group between baseline and three weeks.

2- Six weeks:

At 30 degrees of knee flexion, the median myoelectrical activity of the agonist Qs muscle during MKE (level 2) was 7.26 mV (Closed), 6.97 mV (Open), and 3.76 mV (control). At 60 degrees of knee flexion, it was 7.03 mV (Closed), 7.51 mV (Open), and 2.47 mV (control). At 90 degrees, it was 6.65 mV (Closed), 9.01 mV (Open), and 2.65 mV (control). The differences in myoelectrical activity of the agonist (Qs) muscle during MKE at 30, 60, and 90 degrees (level 2) were statistically significant between the three groups at six weeks ($p \leq 0.0001$) (Table 9.7).

At six weeks, significantly greater myoelectrical activity was seen in the agonist Qs muscle in the two exercise groups as compared with the control group.

4- Fifty weeks:

At fifty weeks, the median myoelectrical activity of the agonist Qs muscle

(level 2) during MKE at 30 degrees of knee angle was 8.39 mV (Closed), 7.32 mV (Open), and 4.94 mV (control). At 60 degrees of knee angle, it was 6.74 mV (Closed), 6.54 mV (Open), and 6.18 mV (control). At 90 degrees of knee flexion, it was 6.81 mV (Closed), 7.77 mV (Open), and 7.07 mV (control) (Table 9.7).

Table 9.7.
Comparison of the median myoelectrical activity (mV) of the agonist quadriceps (Qs) muscle during maximum isometric knee extension (MKE) at 30, 60, and 90 degrees (level 2) at baseline and three, six, and fifty weeks between Closed KCT, Open KCT, and control groups in patients with OA of the knee using Kruskal-Wallis test.

		MKE Agonist Qs EMG (mV)						
		Closed (n= 19)		Open (n= 21)		control (n= 16)		p
Periods	Angles	Median	Range	Median	Range	Median	Range	
0	30°	4.45	1.76-9.01	8.18	2.12-18.37	5.83	4.77-7.89	0.1
	60°	3.51	1.50-8.48	6.24	3.18-10.95	7.22	4.94-9.71	0.2
	90°	3.53	1.90-7.59	6.18	4.94-13.25	6.54	5.30-10.24	0.4
3 weeks	30°	5.64	2.47-23.32	10.95	2.47-21.37	4.77	4.06-8.57	0.0002*
	60°	4.93	2.30-16.78	6.80	3.71- 13.60	5.65	3.44-6.67	0.0001*
	90°	4.10	2.41-13.43	7.77	5.48-16.78	5.74	4.77-7.42	0.0002*
6 weeks	30°	8.25	5.48-16.75	9.16	2.83-21.38	6.01	5.74-9.89	0.0001*
	60°	6.83	3.87-11.48	8.66	3.71-14.66	8.13	4.06-8.13	< 0.0001*
	90°	6.13	3.22-14.13	7.60	4.95-21.73	5.65	3.18-7.07	0.0001*
50 weeks ✣	30°	8.39	4.06-15.90	7.32	2.65-18.02	4.94	4.06-11.15	
	60°	6.74	3.79-14.27	6.54	3.35-14.84	6.18	3.44-8.44	
	90°	6.81	3.25-13.60	7.77	4.06-16.78	7.07	7.07-9.19	

*: statistically significant difference between the three groups.
✣: number of patients at 50 weeks (Closed= 11, Open= 6, and control= 3).

- Level 3

At baseline, the overall median myoelectrical activity of the agonist Qs muscle during MKE (level 3) was 4.48 mV (Closed), 5.47 mV (Open), and 2.68 mV (control). At three weeks, it was 5.43 mV (Closed), 6.81 mV (Open), and 3.09 mV

(control). At six weeks, it was 6.92 mV (Closed), 8.54 mV (Open), and 3.03 mV (control). At fifty weeks, the overall median myoelectrical activity of the agonist Qs was 7.44 mV (Closed), 6.10 mV (Open), and 6.07 mV (control).The differences in the overall median myoelectrical activity of the agonist Qs during MKE (level 3) were not significant at baseline and fifty weeks ($p \geq 0.2$), but they were statistically significant between the three groups at three and six weeks ($p = 0.0001$) (Table 9.8).

Table 9.8.
Comparison of the overall myoelectrical activity (mV) of the agonist quadriceps (Qs) muscle during maximum isometric knee extension (MKE) at 30, 60, and 90 degrees (level 3) at baseline and three, six, and fifty weeks between Closed KCT, Open KCT, and control groups in patients with OA of the knee using Kruskal-Wallis test.

Periods	Groups	MKE Agonist Qs EMG (mV)		
		Median	Range	P
Baseline	Closed (n= 19)	3.82	1.72-8.24	0.2
	Open (n= 21)	5.77	3.71-13.54	
	Control (n= 16)	6.55	5.36-8.24	
3 weeks	Closed b,c	4.93	2.40-17.84	0.0001 *
	Open b,c	7.18	4.36-15.49	
	Control	5.06	4.42-7.56	
6 weeks	Closed b,c	6.85	4.71-13.72	0.0001 *
	Open b,c	9.89	3.83-19.26	
	Control	6.51	4.42-8.36	
50 weeks	Closed (n= 11)	7.44	4.19-14.49	
	Open (n= 6)	6.10	3.42-16.55	
	Control (n= 3)	6.07	4.12-9.67	

*: statistically significant difference between the three groups.
b: statistically significant difference compared to baseline using Wilcoxon test.
c : statistically significant difference compared to the control group using Mann-Whitney test.

Table 9.8 shows that MKE agonist Qs myoelectrical activity increases in two exercise groups.

9.3.1.1.2. MKE Myoelectrical Activity of Agonist Qs Muscle Within Groups

The overall median myoelectrical activity of the agonist Qs during MKE at the three angles (level 3) increased from 4.48 mV (baseline) to 5.43 mV (three weeks), and 6.92 mV (six weeks) in Squat Closed KCT. The overall median myoelectrical activity of the agonist Qs muscle during MKE (level 3) significantly increased at three and six weeks from baseline ($p \leq 0.007$).

In Open KCT, the overall median myoelectrical activity of the agonist Qs muscle during MKE at the three angles (level 3) increased from 5.47 mV (baseline) to 6.81 mV (three weeks), and 8.54 mV (six weeks) (Table 9.8). The increase in the overall median myoelectrical activity of the agonist during MKE was statistically significant at three and six weeks from baseline. No statistically significant change was revealed in the overall median myoelectrical activity of the agonist Qs during MKE in the control group throughout the study.

9.3.1.1.2. Percentage Change in MKE Agonist Qs Myoelectrical Activity

At three weeks, the percentage overall median MKE myoelectrical activity change of the agonist Qs muscle from baseline was 21.2% (Closed KCT), 24.5% (Open KCT), and 15.3% (control). At six weeks, it was 54.5% (Closed KCT), 56.1% (Open KCT), and 13.1% (control). The percentage changes in the median MKE myoelectrical activity of the agonist Qs muscle were statistically significant between the three groups ($p= 0.0005$), and between each exercise group and control ($p \leq 0.006$) at three and six weeks. There was no significant difference between the changes that occurred in the two exercise groups ($p \geq 0.4$) over these periods (Table 9.15).

9.3.1.2. MKE Antagonist Coactivation Index Hs Muscles

9.3.1.2.1. MKE Antagonist Coactivation Index Hs Muscles Between Groups

- Level 2

1- Baseline:

The results of the present study showed that at 30 degrees of knee angle the median antagonist Hs coactivation index expressed in a ratio was 0.52 (Closed), 0.57 (Open), and 0.39 (control). At 60 degrees of knee angle, it was 0.37 (Closed), 0.27 (Open), and 0.32 (control). At 90 degrees of knee position, it was 0.44 (Closed), 0.33 (Open), and 0.45 (control). The differences in the antagonist Hs coactivation index during MKE at three knee joint angles (level 2) were not significant between the Squat Closed KCT, Open KCT, and control groups ($p \geq 0.07$).

2- Three weeks:

At 30 degrees of knee flexion, the median antagonist Hs coactivation index during MKE was 0.45 (Closed), 0.41 (Open), and 0.41 (control). At 60 degrees of knee flexion, it was 0.34 (Closed), 0.17 (Open), and 0.38 (control). At 90 degrees of knee flexion, it was 0.39 (Closed), 0.18 (Open), and 0.39 (control). The differences in the antagonist Hs coactivation index during MKE at 30, and 60 degrees (level 2) were not statistically significant between Closed KCT, Open KCT, and control groups ($p \geq 0.07$) at three weeks. But the differences were statistically significant at 90 degrees ($p= 0.01$) at three weeks (Table 9.9).

At three weeks, there was a statistically significant decreased antagonist Hs coactivation index in the two exercise groups compared to the control group at 90 degrees of knee flexion, but no significant difference occurred in the antagonist Hs coactivation index between the three groups at 30 and 60 degrees during MKE.

3- Six weeks:

At 30 degrees of knee flexion, the median antagonist Hs muscles coactivation index during MKE was 0.43 (Closed), 0.38 (Open), and 0.63 (control). At 60 degrees, it was 0.34 (Closed), 0.25 (Open), and 0.44 (control). At 90 degrees, it was 0.34 (Closed), 0.20 (Open), and 0.50 (control). The differences in the antagonist Hs coactivation index during MKE at 30 and 60 degrees of knee flexion angles (level 2) were not statistically significant between the three groups at six weeks (Table 9.9). But there were statistically significant at 90 degrees of knee flexion ($p= 0.02$).

The findings at six weeks were similar to the results at three weeks. The changes in the antagonist Hs coactivation index values were statistically significant between the three groups at 90 degrees of knee flexion. But there were not significantly different at 30 and 60 degrees of knee flexion.

4- Fifty weeks:

At fifty weeks, at 30 degrees of knee angle, the median antagonist Hs coactivation index (level 2) was 0.60 (Closed), 0.57 (Open), and 0.30 (control). At 60 degrees of knee angle, it was 0.52 (Closed), 0.25 (Open), and 0.50 (control). At 90 degrees of knee position, it was 0.52 (Closed), 0.37 (Open), and 0.33 (control) (Table 9.9).

Table 9.9.
Comparison of the median antagonist hamstring (Hs) muscles coactivation index during maximum isometric knee extension (MKE) at 30, 60, and 90 degrees (level 2) at baseline and three, six, and fifty weeks between Closed KCT, Open KCT, and control groups in patients with OA of the knee using Kruskal-Wallis test.

	MKE Antagonist Hs Coactivation Index EMG (Ratio)							
		Closed (n= 19)		Open (n= 21)		control (n= 16)		p
Periods	Angles	Median	Range	Median	Range	Median	Range	
0	30°	0.52	0.20-0.89	0.57	0.12-0.98	0.39	0.14-1.00	0.07
	60°	0.37	0.11-1.00	0.27	0.14-1.00	0.32	0.13-1.00	0.1
	90°	0.44	0.12-1.00	0.33	0.19-0.96	0.45	0.24-0.89	0.5
3 weeks	30°	0.45	0.13-1.00	0.41	0.07-1.00	0.41	0.20-0.97	0.5
	60°	0.34	0.08-1.00	0.17	0.0-0.80	0.38	0.10-0.90	0.07
	90°	0.39	0.11-1.00	0.18	0.04-1.00	0.39	0.29-0.92	0.01 *
6 weeks	30°	0.43	0.12-1.00	0.38	0.06-1.00	0.63	0.10-1.00	0.2
	60°	0.34	0.06-1.00	0.25	0.00-0.71	0.44	0.14-1.00	0.5
	90°	0.34	0.06-1.00	0.20	0.00-0.51	0.50	0.26-0.82	0.02 *
50 weeks ✣	30°	0.60	0.24-1.00	0.57	0.20-1.00	0.30	0.23-0.84	
	60°	0.52	0.16-1.00	0.25	0.15-0.48	0.50	0.37-0.52	
	90°	0.52	0.05-1.00	0.37	0.16-1.00	0.33	0.13-0.45	

*: statistically significant difference between the three groups.
✣: number of patients at 50 weeks (Closed= 11, Open= 6, and control= 3).

- Level 3

The findings for the overall median antagonist Hs coactivation index at the three knee angles (level 3) was 0.47 (Closed), 0.41 (Open), and 0.43 (control) at baseline. At three weeks, it was 0.41 (Closed), 0.28 (Open), and 0.46 (control). At six weeks, it was 0.39 (Closed), 0.29 (Open), and 0.52 (control). At fifty weeks, it was 0.64 (Closed), 0.38 (Open), and 0.40 (control).

There were statistically significant differences between the three groups at six weeks (p= 0.03), and between Open KCT and Squat Closed KCT and control groups

(Table 9.10). No significant differences were found in the overall antagonist Hs coactivation index during MKE at baseline and three weeks ($p \geq 0.06$).

Table 9.10.
Comparison of the overall antagonist hamstring (Hs) muscles coactivation index during maximum isometric knee extension (MKE)at 30, 60, and 90 degrees (level 3) at baseline and three, six, and fifty weeks between Closed KCT, Open KCT, and control groups in patients with OA of the knee using Kruskal-Wallis test.

Periods	Groups	MKE Antagonist Hs Coactivation Index EMG (Ratio)		
		Median	Range	P
Baseline	Closed (n= 19)	0.47	0.17-0.92	0.2
	Open (n= 21)	0.41	0.15-0.82	
	Control (n= 16)	0.43	0.10-0.92	
3 weeks	Closed	0.41	0.16-0.87	0.06
	Open	0.28	0.17-0.81	
	Control	0.46	0.10-0.79	
6 weeks	Closed p	0.39	0.10-0.84	0.03 *
	Open b, c	0.29	-0.63	
	Control	0.52	0.16-0.92	
50 weeks	Closed (n= 11)	0.64	0.16-0.86	
	Open (n= 6)	0.38	0.22-0.71	
	Control (n= 3)	0.40	0.33-0.49	

*: statistically significant difference between the three groups.
b: statistically significant difference compared to baseline using Wilcoxon test.
c : statistically significant difference compared to the control group using Mann-Whitney test.
p : statistically significant compared to Open KCT using Mann-Whitney test.

9.3.1.2.2. MKE Antagonist Hs Coactivation Index Within Groups

In Squat Closed KCT, the overall median antagonist Hs muscles coactivation index during MKE (level 3) was statistically significant within Open KCT, but it was not significantly changed within Squat Closed KCT and control group compared with baseline during the follow up periods of the study ($p \geq 0.09$). However, the differences in the antagonist Hs coactivation index were statistically significant between the three

groups at six weeks (p= 0.03) (Table 9.10).

9.3.1.2.3. Percentage Change in MKE Antagonist Hs Coactivation Index

At three weeks, the percentage change in the median antagonist Hs muscles coactivation index from baseline during MKE was -12.8% (Closed), -31.7% (Open), and 7.0% (control). The differences in percentage changes in the antagonist Hs muscles coactivation index during MKE were not significant between Squat Closed KCT, Open KCT, and control (p= 0.9) at three weeks.

At six weeks, the percentage change in the median antagonist Hs muscles coactivation index during MKE was -17.0% (Closed), -29.3% (Open), and 20.9% (control). Statistically significant differences were seen between the three groups (p= 0.04), between both exercise groups (p= 0.04), and between Squat Closed KCT and controls (p≤ 0.02) (Table 9.15).

9.3.2. Maximum Isometric Knee Flexion (MKF) Myoelectrical Activity

9.3.2.1. MKF Agonist Hs Muscles Myoelectrical Activity

9.3.2.1.1. MKF Agonist Hs Muscles Myoelectrical Activity of Between Groups

-Level 2

1- Baseline:

The findings of the current study revealed that at 30 degrees of knee angle the median myoelectrical activity of the agonist Hs muscles during MKF (level 2) was 2.39 mV (Closed), 2.00 mV (Open), and 2.92 mV (control). At 60 degrees of knee angle, it was 2.78 mV (Closed), 3.71 mV (Open), and 3.18 mV (control). At 90 degrees of knee position, it was 2.45 mV (Closed), 3.78 mV (Open), and 3.18 mV (control). The differences in myoelectrical activity of the agonist Hs muscles during

MKF (level 2) at three knee joint angles were not significant between Squat Closed KCT, Open KCT, and control groups ($p \geq 0.2$).

2- Three weeks:

The median myoelectrical activity of the agonist Hs during MKF (level 2) was 3.98 mV (Closed), 3.84 mV (Open), and 2.39 mV (control) at 30 degrees of knee flexion. At 60 degrees of knee flexion, it was 4.93 mV (Closed), 5.83 mV (Open), and 2.92 mV (control). At 90 degrees of knee flexion, it was 4.51 mV (Closed), 5.70 mV (Open), and 2.92 mV (control). The differences in the myoelectrical activity of the agonist Hs muscles during MKF at 30, 60, and 90 degrees (level 2) were statistically significant between Closed KCT, Open KCT, and control groups at three weeks ($p \leq 0.03$) (Table 9.11).

At three weeks, the findings showed that the agonist myoelectrical activity Hs had increased in the two exercise groups as compared to the control group at all the three knee joint angles.

2- Six weeks:

The median myoelectrical activity of the agonist Hs muscles in MKF (level 2) was 6.04 mV (Closed), 4.70 mV (Open), and 1.86 mV (control) at 30 degrees of knee flexion. At 60 degrees of knee flexion, it was 6.63 mV (Closed), 4.77 mV (Open), and 2.92 mV (control). At 90 degrees of knee flexion, it was 5.59 mV (Closed), 7.02 mV (Open), and 1.86 mV (control). The differences in the myoelectrical activity of the agonist Hs in MKF at the three knee joint angles (level 2) were statistically significant between the three groups at six weeks ($p \leq 0.02$) (Table 9.11).

The findings showed increases in the agonist Hs muscles activation in both the exercise groups at six weeks.

4- Fifty weeks:

At fifty weeks, the median myoelectrical activity of the agonist Hs muscles in MKF (level 2) was 6.47 mV (Closed), 4.24 mV (Open), and 5.30 mV (control) at 30 degrees of knee angle. At 60 degrees of knee angle, it was 6.63 mV (Closed), 7.68 mV (Open), and 6.89 mV (control). At 90 degrees of knee position, it was 5.70 mV (Closed), 6.10 mV (Open), and 8.74 mV (control) (Table 9.11).

Table 9.11.
Comparison of the median myoelectrical activity (mV) of the agonist hamstring (Hs) muscles during maximum isometric knee flexion (MKF) at 30, 60, and 90 degrees (level 2) at baseline and three, six, and fifty weeks between Closed KCT, Open KCT, and control groups in patients with OA of the knee using Kruskal-Wallis test.

	MKF Agonist Hs EMG (mV)							
		Closed (n= 19)		Open (n= 21)		control (n= 16)		p
Periods	Angles	Median	Range	Median	Range	Median	Range	
0	30°	2.39	0.27-11.80	2.00	0.53-14.58	2.92	0.27-10.87	0.8
	60°	2.78	0.40-12.99	3.71	0.80-28.09	3.18	0.66-11.93	0.5
	90°	2.45	0.53-19.08	3.78	0.80-27.30	3.18	0.27-16.43	0.2
3 weeks	30°	3.98	0.53-10.87	3.84	0.40-16.96	2.39	0.53-7.55	0.03 *
	60°	4.93	0.90-14.44	5.83	0.40- 23.59	2.92	0.27-13.78	0.01 *
	90°	4.51	0.26-15.64	5.70	0.26-32.07	2.92	0.44-24.51	0.02 *
6 weeks	30°	6.04	0.32-14.05	4.70	0.40-22.26	1.86	0.66-9.01	0.005*
	60°	6.63	0.53-17.23	4.77	0.40-25.18	2.92	0.27-13.38	0.02 *
	90°	5.59	1.06-19.35	7.02	0.40-25.18	1.86	0.40-18.82	0.0004*
50 weeks ✣	30°	6.47	1.59-12.19	4.24	1.86-12.19	5.30	3.45-11.40	
	60°	6.63	1.86-19.61	7.68	1.33-12.72	6.89	3.18-7.95	
	90°	5.70	3.71-21.73	6.10	2.12-19.35	8.74	3.18-9.81	

*: statistically significant difference between the three groups.
✣: number of patients at 50 weeks (Closed= 11, Open= 6, and control= 3).

- Level 3

At baseline, the overall median myoelectrical activity of the agonist Hs muscles in MKF (level 3) was 2.54 mV (Closed), 3.40 mV (Open), and 2.83 mV (control). At three weeks, it was 4.64 mV (Closed), 5.26 mV (Open), and 3.47 mV (control). At six weeks, it was 6.07 mV (Closed), 6.16 mV (Open), and 2.21 mV (control). At fifty weeks, the overall median myoelectrical activity of the agonist Hs in MKF was 6.63 mV (Closed), 7.33 mV (Open), and 5.48 mV (control). The differences in the overall myoelectrical activity of the agonist Hs in MKF (level 3) were statistically significant between the three groups at three and six weeks ($p \leq 0.01$), but no significant difference was seen between the groups at baseline ($p = 0.7$) (Table 9.12).

Table 9.12.
Comparison of the overall myoelectrical activity (mV) of agonist hamstring (Hs) muscles during maximum isometric knee flexion (MKF) at 30, 60, and 90 degrees (level 3) at baseline and three, six, and fifty weeks between Closed KCT, Open KCT, and control groups in patients with OA of the knee using Kruskal-Wallis test.

Periods	Groups	MKF Agonist Hs EMG (mV)		
		Median	Range	P
Baseline	Closed (n= 19)	2.54	0.49-14.62	0.7
	Open (n= 21)	3.40	1.10-23.32	
	Control (n= 16)	2.83	0.40-12.01	
3 weeks	Closed b,c	4.64	0.66-12.50	0.01 *
	Open b,c	5.26	0.27-22.44	
	Control	3.47	0.35-15.28	
6 wWeeks	Closed b,c	6.07	0.88-15.99	0.003 *
	Open b,c	6.16	0.27-21.64	
	Control	2.21	0.35-13.74	
50 weeks	Closed (n= 11)	6.63	3.53-15.02	
	Open (n= 6)	7.33	1.90-12.98	
	Control (n= 3)	5.48	5.48-9.01	

*: statistically significant difference between the three groups.
b: statistically significant difference compared to the baseline using Wilcoxon test.
c : statistically significant difference compared to the control group using Mann-Whitney test.

9.3.2.1.2. MKF Agonist Hs Muscles Myoelectrical Activity Within Groups

The overall median myoelectrical activity of the agonist Hs muscles in MKF at the three angles (level 3) increased from 2.54 mV (baseline) to 4.64 mV (three weeks), and 6.07 mV (six weeks) in Squat Closed KCT (Table 9.12). The increases in the overall median myoelectrical activity of the agonist Hs muscles during MKF were statistically significant in Squat Closed KCT at three ($p= 0.05$) and six weeks ($p= 0.0001$) from baseline.

In Open KCT, the overall median myoelectrical activity of the agonist Hs muscles during MKF (level 3) at the three angles increased from 3.40 mV (baseline) to 5.26 mV (three weeks), and 6.16 mV (six weeks) (Table 9.12). The increases in level 3 were statistically significant at three and six weeks from baseline ($p\leq 0.03$).

9.3.2.3. Percentage Change in MKF Agonist Hs Myoelectrical Activity

At three weeks, the percentage median MKF myoelectrical activity change of the agonist Hs muscles from baseline was 82.7% (Closed), 54.7% (Open), and 22.6% (control) (Figure 9.9). There was a statistically significant difference between the three groups at three weeks ($p= 0.04$) (Table 9.15).

At six weeks, the percentage median MKF myoelectrical activity change of the agonist Hs muscles was 139.0% (Closed KCT), 81.2% (Open KCT), and -21.9% (control) from baseline. The percentage changes in MKF myoelectrical activity of the agonist Hs muscles were statistically significant as between Squat Closed KCT, Open KCT, and control six weeks ($p< 0.0001$) and between each exercise group and control ($p\leq 0.01$). But there was no significant difference between the two exercise groups ($p= 0.2$).

9.3.2.2. Maximum Isometric Knee Flexion (MKF) Antagonist Muscles Myoelectrical Activity

9.3.2.2.1. MKF Antagonist Qs Muscle Myoelectrical Activity Between Groups

- Level 2

1- Baseline:

The findings showed that at 30 degrees of knee angle the median antagonist Qs muscle coactivation index in MKF (level 2) was 0.08 (Closed), 0.02 (Open), and 0.04 (control). At 60 degrees of knee angle, it was 0.09 (Closed), 0.02 (Open), and 0.13 (control). At 90 degrees of knee position, it was 0.08 (Closed), 0.07 (Open), and 0.03 (control). The differences in the antagonist Qs muscle coactivation index in MKF (level 2) were not significant as between Squat Closed KCT, Open KCT, and the control groups at the three knee joint angles ($p \geq 0.07$).

2- Three weeks:

At 30 degrees of knee flexion, the median antagonist Qs muscle coactivation index in MKF (level 2) was 0.05 (Closed), 0.03 (Open), and 0.18 (control). At 60 degrees of knee flexion, it was 0.08 (Closed), 0.04 (Open), and 0.07 (control). At 90 degrees of knee flexion, it was 0.08 (Closed), 0.04 (Open), and 0.09 (control). The differences in the antagonist Qs coactivation index in MKF (level 2) were not statistically significant at 30, 60, and 90 degrees of knee flexion between the three groups at three weeks ($p \leq 0.08$). (Table 9.13).

Thus, no significant differences had appeared in the antagonist Qs coactivation index between the three groups at three weeks.

2- Six weeks:

At 30 degrees of knee flexion, the median antagonist Qs muscle coactivation index during MKF was 0.08 (Closed), 0.03 (Open), and 0.06 (control). At 60 degrees of knee flexion, it was 0.10 (Closed), 0.04 (Open), and 0.07 (control). At 90 degrees of knee flexion, it was 0.10 (Closed), 0.05 (Open), and 0.08 (control). The differences in the antagonist Qs muscle coactivation index in MKF at 30 and 60 degrees of knee flexion angles (level 2) were not statistically significant between the three groups at six weeks ($p \geq 0.09$), but the difference at 90 degrees of knee flexion was statistically significant between the three groups ($p = 0.006$) (Table 9.13).

The only statistically significant difference in the antagonist Qs muscle coactivation index was at 90 degrees of knee flexion.

4- Fifty weeks:

At fifty weeks, at 30 degrees of knee angle the median antagonist Qs muscle coactivation index during MKF (level 2) was 0.10 (Closed), 0.05 (Open), and 0.00 (control). At 60 degrees of knee angle, it was 0.06 (Closed), 0.02 (Open), and 0.00 (control). At 90 degrees of knee position, it was 0.06 (Closed), 0.02 (Open), and 0.10 (control) (Table 9.13).

Table 9.13.
Comparison of the median antagonist quadriceps (Qs) muscle coactivation index during maximum isometric knee flexion (MKF) at 30, 60, and 90 degrees (level 2) at baseline and three, six, and fifty weeks between Closed KCT, Open KCT, and control groups in patients with OA of the knee using Kruskal-Wallis test.

	MKF Antagonist Qs Coactivation Index EMG (Ratio)							
		Closed (n= 19)		Open (n= 21)		control (n= 16)		p
Periods	Angles	Median	Range	Median	Range	Median	Range	
0	30°	0.08	0.00-0.29	0.02	0.00-0.62	0.04	0.00-0.33	0.3
	60°	0.09	0.00-0.62	0.02	0.00-1.00	0.13	0.00-0.50	0.07
	90°	0.08	0.00-0.33	0.07	0.00-0.96	0.03	0.00-0.66	0.5
3 weeks	30°	0.05	0.00-0.37	0.03	0.00-0.62	0.18	0.00-0.42	0.5
	60°	0.08	0.00-0.53	0.04	0.00-0.67	0.07	0.00-0.50	0.08
	90°	0.08	0.00-0.33	0.04	0.00-1.00	0.09	0.00-0.66	0.1
6 weeks	30°	0.08	0.00-0.57	0.03	0.00-0.34	0.06	0.00-0.33	0.6
	60°	0.10	0.00-0.45	0.04	0.00-0.19	0.07	0.00-0.60	0.09
	90°	0.10	0.00-0.35	0.05	0.00-0.17	0.08	0.00-0.53	0.006*
50 weeks ✣	30°	0.10	0.00-0.52	0.05	0.00-0.39	0.00	0.00-0.35	
	60°	0.06	0.00-0.59	0.02	0.00-0.47	0.00	0.00-0.00	
	90°	0.06	0.00-0.43	0.02	0.00-0.23	0.10	0.03-0.11	

*: statistically significant difference between the three groups.
✣: number of patients at 50 months (Closed= 11, Open= 6, and control= 3).

- Level 3

At three weeks, he overall median antagonist Qs muscle coactivation index during MKF (level 3) was 0.08 (Closed), 0.06 (Open), and 0.07 (control) at baseline. At three weeks, it was 0.08 (Closed), 0.04 (Open), and 0.09 (control). At six weeks, it was 0.10 (Closed), 0.04 (Open), and 0.07 (control). At fifty weeks, it was 0.07 (Closed), 0.05 (Open), and 0.04 (control) (Table 9.14).

The differences in the overall median antagonist (Qs) muscle coactivation index in MKF (level 3) did not reveal statistically significant between the three groups

until the six weeks (p= 0.05). There was no statistically significant difference in the overall antagonist Qs muscle coactivation in MKF at baseline and three weeks (p≥ 0.1) (Table 9.14).

Table 9.14.
Comparison of the overall antagonist quadriceps (Qs) muscle coactivation index during maximum isometric knee flexion (MKF) at 30, 60, and 90 degrees (level 3) at baseline and three, six, and fifty weeks between Closed KCT, Open KCT, and control groups in patients with OA of the knee using Kruskal-Wallis test.

Periods	Groups	MKF Antagonist Qs EMG (mV)		
		Median	Range	P
Baseline	Closed (n= 19)	0.08	0.00-0.30	0.3
	Open (n= 21)	0.06	0.00-0.81	
	Control (n= 16)	0.07	0.00-0.31	
3 weeks	Closed	0.08	0.00-0.34	0.1
	Open	0.04	0.00-0.63	
	Control	0.09	0.00-0.32	
6 weeks	Closed	0.10	0.00-0.44	0.05 *
	Open b,c	0.04	0.00-0.23	
	Control	0.07	0.00-0.31	
50 weeks	Closed (n= 11)	0.07	0.01-0.47	
	Open (n= 6)	0.05	0.02-0.31	
	Control (n= 3)	0.04	0.02-0.04	

*: statistically significant difference between the three groups.
b: statistically significant difference compared to baseline using Wilcoxon test.
c : statistically significant difference compared to the control group using Mann-Whitney test.

9.3.2.2.2. MKF Antagonist Qs Muscle Myoelectrical Activity Within Groups

The differences in the overall antagonist Qs muscle coactivation index (level 3) during MKF within groups were not significant in any of the three groups at three weeks compared with baseline (p≥ 0.09).

However, the overall median antagonist Qs muscle coactivation index in MKF (level 3) at the three angles had significantly decreased at six weeks from baseline after Open KCT (p= 0.002), but there had been no significant change after Closed KCT and in the controls.

9.3.2.2.3. Percentage Change in MKF Antagonist Qs Coactivation Index

At three weeks, the percentage change in the median MKE antagonist Qs muscle coactivation index at three weeks from baseline was 0.0% (Closed KCT), -33.3% (Open KCT), and 28.6% (control). At six weeks, it was 25.0% (Closed), -33.3% (Open), and 0.0% (control) at six weeks (Figure 9.9). The differences in the percentage change of the antagonist Qs muscle coactivation index were not significant between Squat Closed KCT, Open KCT, and control at three and six weeks (p≥ 0.06) (Table 9.15).

Table 9.15.
The percentage changes in the overall median of torque (Nm) and myoelectrical activity (mV) (level 3) during maximum isometric knee extension (MKE) and flexion (MKF) at three and six weeks from baseline in Squat Closed KCT (n= 19), Open KCT (n= 21), and control (n= 16) in patients with OA of the knee.

		Percentage Median Change (%)							
		3 weeks				6 weeks			
Activity	Subjects	Closed (n= 19)	Open (n= 21)	Control (n= 16)	p	Closed (n= 19)	Open (n=21)	Control (n= 16)	p
MKE	Torque	18.1 c	43.1 c	-18.1	< 0.0001*	55.6 c	47.5 c	-5.8	< 0.0001*
	Agonist	21.2 c	24.5 c	15.3	0.0005 *	54.5 c	56.1 c	13.1	< 0.0001*
	Antagonist	-12.8	-31.7	7.0	0.9	-17.0 p,c	-29.3	20.9	0.04 *
MKF	Torque	30.6 c	28.2 c	-29.8	< 0.0001*	95.1 p,c	19.6 c	-29.4	< 0.0001*
	Agonist	82.7	54.7	22.6	0.04 *	139.0 c	81.2 c	-21.9	0.0002 *
	Antagonist	0.0	-33.0	28.6	0.06	25.0	-33.3	0.0	0.7

*: statistically significant difference between the three groups using Kruskal-Wallis test.
c : statistically significant difference compared to the control group using Mann-Whitney test.
p : statistically significant difference to Open KCT using Mann-Whitney test.

9.3.4. Summary of Results of Readings of Agonist and Antagonist Myoelectrical Activity

The agonist myoelectrical activity significantly increased during MKE (Qs) and MKF (Hs) from baseline in the two exercise groups at three and six weeks. But there was no statistically significant change in the agonist myoelectrical activity of the controls throughout the study. These findings were supported by statistically significant percentage changes in both exercise groups at three and six weeks compared with baseline.

Statistically significant differences in the overall antagonist Hs coactivation index were seen between the three groups during MKE at six weeks. At six weeks, The percentage overall antagonist Hs coactivation index was also statistically significant difference between Open KCT and Squat Closed KCT, and between Open KCT and controls during MKE. No significant change in the antagonist Qs coactivation index was observed between the three groups during MKF.

9.4. Relationship Between Torques and Myoelectrical Activity During Maximum Isometric Knee Extension (MKE) and Flexion (MKF) in Patients with OA of the knee

Correlation analyses were performed to ascertain whether there was an association between the overall torques and the overall myoelectrical activity of the agonist and antagonist muscles coactivation index during MKE and MKF (level 3) using scatter plot diagrams.

The data were analysed in all patients at baseline (42 women, 27 men) and all the results of the relationships illustrated by scatter plot graphs (Figures 9.3 to 9.8). There was a moderate positive association between the overall MKE torque (level 3) and the overall myoelectrical activity of the agonist Qs muscle (level 3) $r= 0.75$ ($p< 0.001$) (Figure 9.3). There was a weak negative association between the overall

torques and the overall antagonist Hs muscles coactivation index during MKE (r= -0.11, p= 0.3) (Figure 9.4).

There was a moderate positive association between the overall torque (level 3) and the overall myoelectrical activity of the agonist Hs muscles during MKF (level 3) (r= 0.69, p< 0.001) (Figure 9.5). The relationship was weakly negative between the overall torque (level 3) and the overall antagonist Qs muscle coactivation index during MKF (level 3) but failed to reach statistical significance (r= -0.20, p= 0.06) (Figure 9.6).

9.5. Relationship Between Agonist and Antagonist Myoelectrical Activity During Maximum Isometric Knee Extension (MKE) and Flexion (MKF) in Patients with OA of the Knee

During MKE, the results showed a weak negative association between the overall agonist (Qs) myoelectrical activity and the overall antagonist (Hs) coactivation index at baseline in all subjects (42 women, 27 men) with OA of the knee (level 3) (r= -0.10, p= 0.4) (Figure 9.7). A similar association was found between the overall agonist (Hs) myoelectrical activity and the overall antagonist (Qs) coactivation index during MKF (level 3) (r= -0.02, p= 0.9) (Figure 9.8).

9.6. Summary of Findings of the Relationship Between Torque and Myoelectrical Activity

For the reasons given on page 84, it was not expected that there would be a close relationship between absolute torque and absolute myoelectrical activity amplitude. However, because there have been disagreements in the literature on this point, the baseline data were analysed in order to establish whether there was a consistent relationship between the torque and myoelecetrical activity in this sample of subjects.

1) In maximum isometric knee extension (MKE)

- a moderate positive association between the overall MKE torque and overall agonist Qs myoelectrical activity during MKE.

- a weak positive association between the overall MKE torque and overall antagonist Hs coactivation index during MKE.

- a weak negative association between the overall agonist Qs myoelectrical activity and antagonist Hs coactivation index during MKE.

2) In maximum isometric knee flexion (MKF)

- a moderate positive relationship between the overall MKF torque and overall agonist Hs myoelectrical activity during MKF.

- a weak negative association between the overall MKF torque and overall antagonist Qs coactivation index during MKF.

- a weak negative association between the overall agonist Hs myoelectrical activity and antagonist Qs coactivation index activity during MKF.

In conclusion these results support the decision not to assume a close relationship between these variables in the present study.

9.7. Self-reported Pain and Functional Knee Assessment (SPFKA)

9.7.1. Self-reported Knee Pain Assessment

a- Intensity of Pain

The median of the intensity of pain was 5.6 cm (baseline), 4.9 cm (three weeks), 3.7 cm (six weeks), and 2.6 cm (fifty weeks) in Squat Closed KCT. The median of intensity of pain in Open KCT was 5.3 cm (baseline), 4.6 cm (three weeks), 4.6 cm (six weeks), and 4.0 cm (cm). In the control group, the level of pain was 5.0 cm (baseline), 4.4 cm (three weeks), 4.3 cm (six weeks), and 4.6 cm (fifty weeks). The differences in the intensity of pain were only statistically significant between the three groups at six weeks (Table 9.16). There had been a trend in both exercise groups

towards reduction of pain throughout the study, but the differences were not statistically significant between these groups.

Using the Wilcoxon test, the findings showed significant reductions in the intensity of pain at three and six weeks compared with baseline in both exercise groups ($p \leq 0.01$). The decrease rate in the intensity of pain was similar in both exercise groups. There was no significant reduction in the intensity of pain in the control group throughout the period of the study ($p \geq 0.2$).

Table 9.16.
Comparison of the median intensity of pain at baseline and three, six, and fifty weeks between Closed KCT, Open KCT, and control groups in patients with OA of the knee using Kruskal-Wallis test.

Periods	Intensity of Pain (cm)						
	Closed (n= 19)		Open (n= 21)		control (n= 16)		P
	Median	Range	median	Range	Median	Range	
Baseline	5.6	1.2-8.4	6.0	2.0-10.0	4.0	2.0-8.6	0.4
3 weeks	4.9	1.2-8.0	4.6	2.0-7.2	4.0	2.0-8.6	0.5
6 weeks	3.7 b,c	0.0-5.8	4.6	2.0-6.1	4.4	1.0-8.8	0.05 *
. 50 weeks	2.6	0.0-7.5	4.0	1.1-7.8	4.0	1.0-8.9	

*: statistically significant difference between the three groups.
b: statistically significant difference compared to baseline using Wilcoxon test.
c : statistically significant difference compared to the control group using Mann Whitney test.

b- Characteristics of Pain

The pain characteristics were presented as the number of patients' responses to the questions in the pain section in the SPFKA (Table 9.17) because it was difficult to apply any statistical analysis on such data. Further, it was difficult to interpret the data describing the characteristics of pain due to variations in the patients' responses. On the advice of a statistician, the raw data is presented in table 9.17 which suggests that there was a slight but progressive decline in the number of different characteristics of pain reported during the study in both exercise groups, but not in the controls. It

appears that aching pain in both exercise groups became sharp pain at three weeks, but then reversed to the pattern at baseline by six weeks. No such changes were observed in controls. This indicates that there was no change in the intensity of pain at three weeks, its nature had changed but change was short-timed.

Table 9.17

The characteristics of pain in the SPFKA in patients with OA in Squat Closed KCT, Open KCT, and control at baseline and three and six weeks.

		Characteristics of Pain								
		Closed (n= 19)			Open (n= 21)			control (n= 16)		
Characteristics of Pain		Baseline	3 w	6 w	Baseline	3 w	6 w	Baseline	3 w	6 w
Location	Front	14	14	10	15	14	11	10	13	14
	Back	4	6	1	5	2	2	3	4	4
	Inner side	11	11	11	15	14	13	10	10	12
	Outer side	4	5	2	3	3	1	3	3	4
	Within	3	6	2	6	4	3	6	6	6
	Uncertain	1	1	0	1	1	0	1	1	1
Frequency	Constant	3	2	0	9	5	3	7	7	6
	Intermittent	12	13	11	9	10	13	7	7	7
	Occasional	4	4	6	3	6	3	2	2	3
Type	Sharp	2	15	4	7	12	3	3	4	4
	Ache	17	4	15	14	9	18	13	12	12
	Throbbing	0	0	0	0	0	0	0	0	0
	Burning	0	0	0	0	0	0	0	0	0
Combination	Stiffness	14	12	8	15	13	10	13	13	13
	Heaviness	11	5	3	9	6	2	9	8	8
Activity Cause Pain	Sleep	1	0	0	0	0	1	2	2	2
	Sitting	3	3	3	1	0	1	2	2	2
	Standing	1	2	2	2	2	0	1	0	0
	Walk	10	10	9	14	15	12	6	7	7
	Stairs	4	3	3	4	4	3	5	5	5

9.7.2. Self-reported Functional Knee Assessment

The investigator used three non-parametrical tests in order to analyse the data: the Kruskal-Wallis test (between the three groups), the Mann-Whitney test (between two different groups), and the Wilcoxon test (within groups). These tests used for the ordinal scales of functional activities and feelings in general.

1- Baseline:

At baseline, there were no statistically significant differences between the three groups in any functional activities ($p \geq 0.06$).

2- Three weeks:

Comparison between the three groups. At three weeks, the score for climbing down stairs was the only function to show a statistically significant difference between the three groups using the Kruskal-Wallis test (Table 9.18). The median score was 2.0 (slightly difficult) in Squat Closed KCT, 2.0 in Open KCT, and 3.0 (moderately difficult) at three weeks.

Table 9.18.
Comparison of functional activities at three weeks in patients with OA of the knee assigned to the Closed KCT and Open KCT, and control groups using Kruskal-Wallis test.

	The Median Level of Disability			P
Functional Activities	Closed (n= 19)	Open (n= 21)	control (n= 16)	
1. Sleeping	0.0	1.0	1.0	0.2
2. Lying	0.0	1.0	1.0	0.1
3. Bending Knee	2.0	1.0	2.0	0.2
4. Straightening Knee	1.0	1.0	2.0	0.3
5. Sitting	0.0	0.0	1.0	0.1
6. Standing	1.0	2.0	2.0	0.9
7. In/out of a Chair	2.0	2.0	2.0	0.8
8. Kneeling	3.0	3.0	3.0	0.8
9. Walking	2.0	2.0	2.0	0.5
10. Driving	4.0	4.0	4.0	0.2
11. Squatting	3.0	4.0	4.0	0.6
12. Cycling	4.0	4.0	4.0	0.1
13. Running	4.0	4.0	4.0	0.1
14. Climbing Up Stairs	2.0	2.0	2.0	0.4
15. Climbing Down Stairs	2.0 b,c	2.0 c	3.0	0.02 *

* : statistically significant difference between the three groups.
b : statistically significant difference compared to baseline using Wilcoxon test.
c : statistically significant difference compared to the control group using Mann-Whitney test.
- Functional disability assessment: 0= not at all, 1= slightly, 2= moderately, 3= severely, and 4= completely.

Comparison between two groups. Using the Mann-Whitney test, the differences in the scores for climbing down stairs were statistically significant between each exercise group and control at three weeks ($p \leq 0.02$). But there was no significant difference between the two exercise groups ($p= 0.7$).

Comparison within groups. At three weeks, the median score changed in climbing down stairs from moderate difficult (3.0) at baseline to slight difficult (2.0) at three weeks. The change in climbing down stairs was statistically significant

between three weeks and baseline using the Wilcoxon-Paired test in Squat Closed KCT (p=0.002), while no significant difference was seen within Open KCT (p= 0.2). This indicates that a change occurred only in Squat Closed KCT.

3- Six weeks:

Comparison between the three groups. At six weeks, the results in nine of the fifteen functional activity scores revealed statistically significant differences between the three groups using the Kruskal-Wallis test (Table 9.19). Nine functional activities improved after six weeks of exercise.

Table 9.19.
Comparison of functional activities at six weeks in patients with OA of the knee assigned to the Closed KCT and Open KCT, and control groups using Kruskal-Wallis test.

	The Median Level of Disability			P
Functional Activities	Closed (n= 19)	Open (n= 21)	control (n= 16)	
1. Sleeping	0.0 b,t,c	0.0 b,c	2.0	0.0004 *
2. Lying	0.0 b,c	0.0	1.0	0.0009 *
3. Bending Knee	1.0 b,t,c	1.0 b,c	2.0	0.0005 *
4. Straightening Knee	1.0 b,c	0.0 b,t,c	3.0	0.0009 *
5. Sitting	0.0 b,c	0.0 b	1.0	0.003 *
6. Standing	1.0	1.0	2.0	0.07
7. In/out of a Chair	1.0 b,t,c	2.0 b,t	3.0	0.03 *
8. Kneeling	3.0	3.0	3.0	0.1
9. Walking	2.0	2.0	2.0	0.06
10. Driving	4.0	4.0	4.0	0.5
11. Squatting	3.0 b,t,c	3.0 b	4.0	0.03 *
12. Cycling	4.0	4.0	4.0	0.2
13. Running	4.0	4.0	4.0	0.2
14. Climbing Up Stairs	2.0 b,t,c	2.0 b,t,c	3.0	0.0001 *
15. Climbing Down Stairs	1.0 b,t,c	2.0 b,t,c	2.0	0.0001 *

* : statistically significant difference between the three groups.
b : statistically significant difference compared to baseline using Wilcoxon test.
t : statistically significant difference to three weeks using Wilcoxon test.
c : statistically significant difference compared to the control using Mann-Whitney test.
- Functional disability assessment: 0= not at all, 1= slightly, 2= moderately, 3= severely, and 4= completely.

Comparison between two groups. Comparing Squat Closed KCT with control, the median disability scores for some functional activities changed in both exercise groups. The differences in these functional activities were statistically significant between each exercise group and control ($p \leq 0.01$). But no significant difference was seen between the two exercise groups ($p \geq 0.2$).The medians of these functional activities are described below.

Comparison within groups. Using the Wilcoxon-Paired test at six weeks, scores for functional activities such as sleeping, bending of the knee, standing, in and out of a chair, walking, squatting, and climbing up and down stairs were significantly increased compared with the scores at baseline and three weeks ($p \leq 0.01$) in Squat Closed KCT. In Open KCT, scores for functional activities such as sleeping, straightening of the knee, standing, and climbing up and down stairs were significantly increased compared with the scores at baseline and three weeks ($p \leq 0.01$).

4- Fifty weeks:

At fifty weeks, the investigator analysed the data in Squat Closed KCT and in Open KCT only, due to insufficient data in the control group. The differences were only statistically significant in walking function using the Mann-Whitney test ($p= 0.04$) (Table 9.20).

Table 9.20.
Comparison of functional activities at fifty weeks in patients with OA of the knee between Closed KCT and Open KCT groups using Mann-Whitney test.

	The Median of Disability		P ✧
Functional Activities	Closed (n= 11)	Open (n= 6)	
1. Sleeping	0.0	0.0	0.7
2. Lying	0.0	0.0	0.5
3. Bending Knee	1.0	1.0	0.3
4. Straightening Knee	0.0	1.0	0.4
5. Sitting	0.0	0.0	0.3
6. Standing	1.0	1.0	0.4
7. In/out of a Chair	1.0	2.0	0.3
8. Kneeling	2.0	3.0	0.4
9. Walking	1.0 b,t,s	2.0 t	0.04 *
10. Driving	4.0	4.0	0.2
11. Squatting	3.0	3.0	0.8
12. Cycling	4.0	4.0	0.2
13. Running	4.0	4.0	0.9
14. Climbing Up Stairs	2.0	2.0	0.9
15. Climbing Down Stairs	1.0	2.0	0.8

✧: analysis was done between Closed and Open KCT only.
* : statistically significant difference between the two exercise groups.
b : statistically significant difference compared to baseline using Wilcoxon test.
t : statistically significant difference compared to three weeks using Wilcoxon test.
s : statistically significant difference compared to six weeks using Wilcoxon test.
- functional disability assessment: 0= not at all, 1= slightly, 2= moderately, 3= severely, and 4= completely.

9.7.3. Feelings in General

1- Baseline:

Comparison between the three groups. The median score of the 'feelings in general' was same in all groups (i.e. good) (Table 9.21). No statistically significant difference was seen between the three groups in 'feelings in general'.

2- Three weeks:

Comparison between the three groups. The median score of the 'feelings in general' (i.e. good) had not changed from baseline in all the three groups (Table 9.21). But differences in 'feelings in general' differed significantly between the three groups at three weeks using the Kruskal-Wallis test. However, it is not possible from the data to conclude that any group showed a statistically significant change in median score.

Comparison between two groups. Using the Mann-Whitney test between each exercise group and control, there were significantly improvements in both exercise groups compared with the control group ($p \leq 0.04$). No statistically significant differences were found between the two exercise groups (Table 9.21).

3- Six weeks:

Comparison between the three groups. At six weeks, the median of 'feelings in general' was very good (2.0) in Squat Closed KCT, good (3.0) in Open KCT, and good in control (Table 9.21). The Kruskal-Wallis test revealed statistically significant differences between the three groups.

Table 9.21.
Comparison of the 'feelings in general' at baseline and three, six, and fifty weeks in patients with OA of the knee between Closed KCT and Open KCT, and control groups using Kruskal-Wallis test.

Periods	Feelings in General			
	Median			P
	Closed (n= 19)	Open (n= 21)	control (n=16)	
Baseline	3.0	3.0	3.0	0.7
3 weeks	3.0 c	3.0 c	3.0	0.002 *
6 weeks	2.0 b,c	3.0 c	3.0	0.001 *
. . 50 weeks	3.0 p	3.0	4.0	

*: statistically significant difference between the three groups.
b : statistically significant difference to baseline using Wilcoxon test.
p : statistically significant difference to Open KCT using Mann-Whitney test.
c : statistically significant difference to the control group using Mann-Whitney test.
- feeling in general: 1.0= excellent, 2.0= very good, 3.0= good, 4.0= fair, and 5.0= poor.
- the number of patients at fifty weeks was 11 in Closed, 6 in open, and 3 in control.

Comparison between two groups. Using the Mann-Whitney test between each exercise group and control, there were significant improvements in both exercise groups in comparison to the control group ($p \leq 0.01$). No significant difference was seen between Squat Closed KCT and Open KCT at three and six weeks.

Comparison within groups. Using the Wilcoxon paired test within each group, most of the differences were not statistically significant in all three groups throughout the study. The exception was that a statistically significant improvement in 'feelings in general' was observed at six weeks compared with baseline in Squat Closed KCT.

4- Fifty weeks:

It was inappropriate to analyse the data at fifty weeks because of small sample size. There was a trend for the median 'feelings in general' to decline in Squat Closed KCT (good) and control (fair), but the median 'feelings in general' did not support any such change in Open KCT during the study.

9.8. Relationship Between Isometric Knee Extension and Flexion Torques and Characteristics of Patients with OA of the knee

9.8.1. Relationship Between Isometric Knee Extension and Flexion Torques and Radiographic Grading of Osteoarthritis and the Intensity of Pain

The relationship was investigated between the radiographic grading used to identify the grades of OA changes in the subjects of the current study at baseline (n= 42 women, 27 men), and the overall MKE and MKF torques using the Spearman Correlation Coefficient (Appendix 13). The results showed a weak negative relationship between the overall MKE torque (level 3) and the radiographic grading of OA of the knee at baseline before starting the training ($r= -0.20$, $p= 0.05$). The overall MKF torque (level 3) was also weakly negative associated with the radiographic grading of OA of the knee at baseline ($r= -0.22$, $p= 0.04$).

The findings in this study showed that the overall MKE torque and MKF torque (level 3) had weak negative associations with the intensity of pain at baseline ($r= -0.16$, $p= 0.1$) and ($r= -0.17$, $p= 0.1$) respectively using Spearman Correlation Coefficient (Appendix 14).

9.8.2. Relationship Between Isometric Knee Extension and Flexion Torques and Age, Height, and Weight

There were weak negative relationships between the overall MKE and MKF torques and age $r= -0.28$ ($p= 0.006$), and $r= -0.39$ ($p< 0.001$) respectively (Appendix 15).

MKE and MKF torques had weak positive associations with height $r= 0.41$ ($p< 0.001$), and $r= 0.45$ ($p< 0.001$) respectively (Appendix 16). MKE and MKF torques had also weak positive associations with weight $r= 0.32$ ($p= 0.002$) and $r= 0.35$ ($p< 0.001$) respectively (Appendix 17).

9.9. Relationship Between Myoelectrical Activity and and Characteristics of Patients with OA of the knee

9.9.1. Relationship Between Myoelectrical Activity and Radiographic grading of OA

9.9.1.1. Agonist Myoelectrical Activity

The results showed weak negative relationships between the radiographic grading of OA of the knee and the overall myoelectrical activity of the agonist MKE and MKF (level 3) (r= -0.15, p= 0.2) and (r= -0.25, p= 0.02) respectively (Appendix 13).

9.9.1.2. Antagonist Coactivation Index

The radiographic grading also had weak negative relationships with the overall antagonist coactivation index during MKE and MKF (level 3) (r= -0.11, p= 0.08) and (r= -0.12, p= 0.07) respectively (Appendix 13).

9.9.2. Relationship Between Myoelectrical Activity and Pain Intensity

9.9.2.1. Agonist Myoelectrical Activity

The results also showed weak negative relationships between the intensity of pain and myoelectrical activity of the agonist MKE and MKF (level 3) (r= -0.17, p= 0.2) and (r= -0.20, p= 0.07) respectively (Appendix 14).

9.9.2.2. Antagonist Coactivation Index

Similarly, the intensity of pain had a weak negative association with the overall MKE antagonist Hs coactivation index (level 3) (r= -0.10, p= 0.4), and it had a

very weak negative association with the overall MKF antagonist Qs coactivation index (r= -0.02, p= 0.9) (Appendix 14).

9.9.3. Relationship Between Isometric Knee Extension and Flexion Myoelectrical Activity and Age, Height, and Weight

9.9.3.1. Agonist Myoelectrical Activity

There were weak negative relationships between MKE and MKF agonist myoelectrical activity and age r= -0.27 (p= 0.01) and r= -0.36 (p< 0.001) respectively (Appendix 15).

MKE and MKF myoelectrical activity had weak positive associations with height r= 0.12 (p= 0.3) and r= 0.18 (p= 0.08) respectively (Appendix 16). MKF myoelectrical activity had also a weak positive relationship with body weight r= 0.07 (p= 0.5), but MKE myoelectrical activity had a weak negative association with weight r= -0.04 (p= 0.7) (Appendix 17).

9.9.2.2. Antagonist Coactivation Index

The MKE and MKF antagonist coactivation indices had weak positive associations with age r= 0.35 (p= 0.001), and r= 0.10 (p= 0.4) respectively. While the MKE and MKF antagonist coactivation indices had weak negative associations with height r= -0.26 (p= 0.01) and r= -0.11 (p= 0.3), and weight r= -0.19 (p= 0.07) and r= -0.11 (p= 0.3) respectively.

In conclusion, the two forms of training were accompanied by marked increases in maximum isometric knee extension and flexion torques and by corresponding increases in the agonist myoelectrical activity. Statistically significant increases in torques and agonist myoelectrical activity were shown at three and six

weeks. There was a trend for Squat Closed KCT to produce greater torques than Open KCT, but this trend was not statistically significant.

There was a statistically significant decrease in the antagonist coactivation index in Open KCT compared with Closed KCT and controls.

In addition, the SPFKA showed significant improvements in lower extremity functional ability in both type of exercise at three and six weeks of training. The number of improved functional activities was greater in Squat Closed KCT than Open KCT at six weeks. It had been observed that changes in MKE and MKF torques and myoelectrical activity, and in the 'feelings in general' occurred before changes in the intensity of pain and functional activity.

Interpretation of some important aspects of pain (location, type, activity cause pain) was difficult because of lack of an appropriate statistical test and quantification of such data.

The results showed that MKE and MKF torques and myoelectrical activity had weak associations with radiographic grading of severity of OA, intensity of knee pain, age, height, and weight.

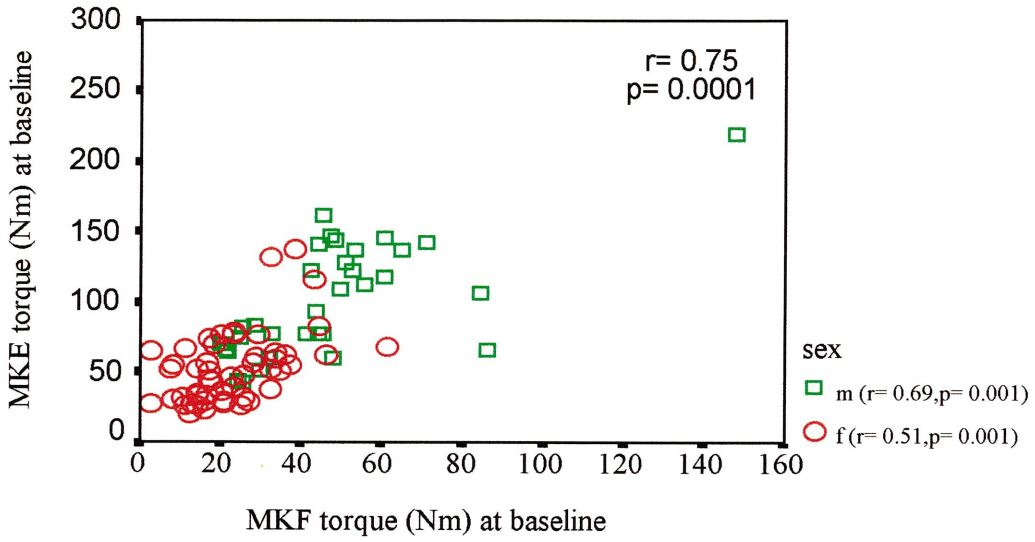


Figure 9.2: The relationship between the overall torque of isometric knee extension (MKE) and isometric knee flexion (MKF) (level 3) at 30, 60, and 90 degrees at baseline in all patients with OA of the knee.

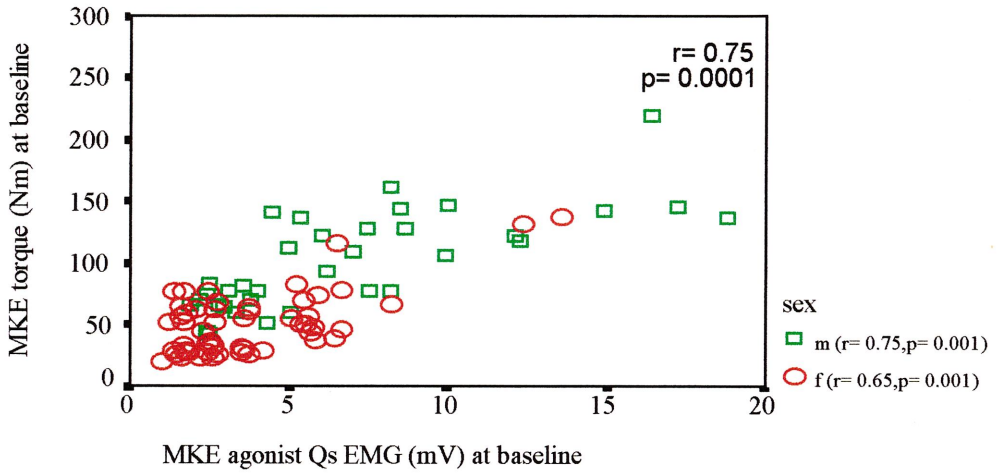


Figure 9.3. The relationship between the overall torque (Nm) and the overall myoelectrical activity (mV) of the agonist quadriceps (Qs) muscle (level 3) during isometric knee extension (MKE) at 30, 60, and 90 degrees at baseline in patients with OA of the knee.

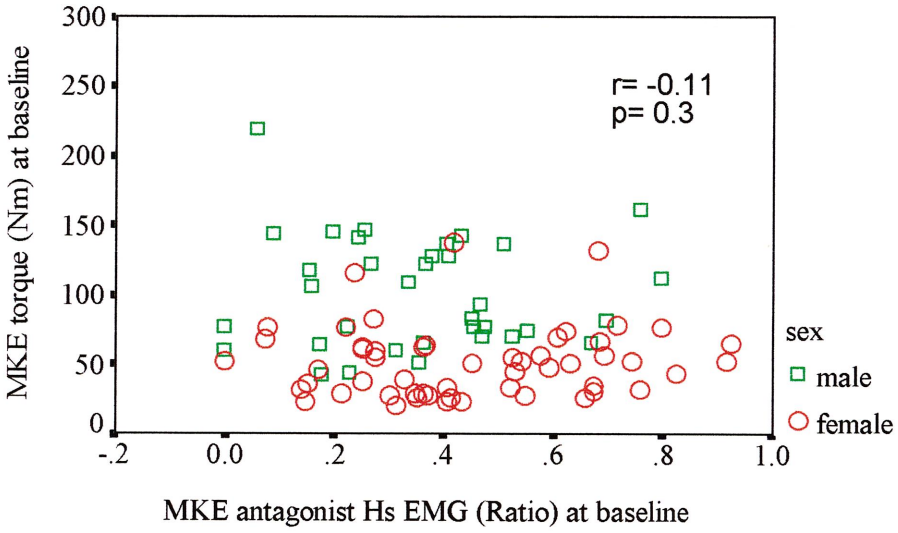


Figure 9.4. The relationship between the overall torques (Nm) and the overall antagonist hamstring muscles (Hs) coactivation index (Ratio) (level 3) during isometric knee extension (MKE) at 30, 60, and 90 degrees at baseline in patients with OA knee.

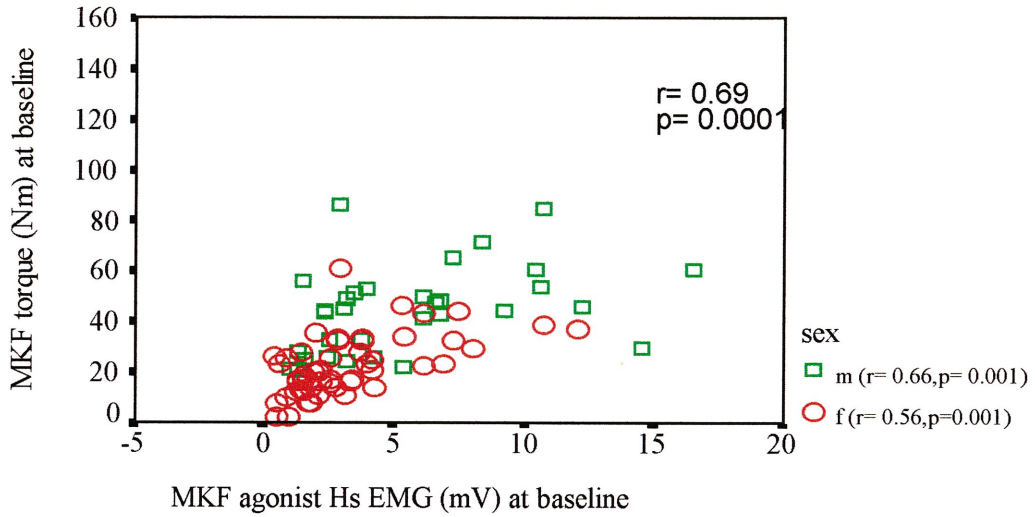


Figure 9.5. The relationship between the overall torques (Nm) and the overall myoelectrical activity (mV) of the agonist hamstring (Hs) muscles (level 3) during isometric knee flexion (MKF) at 30, 60, and 90 degrees at baseline in patients with OA of the knee.

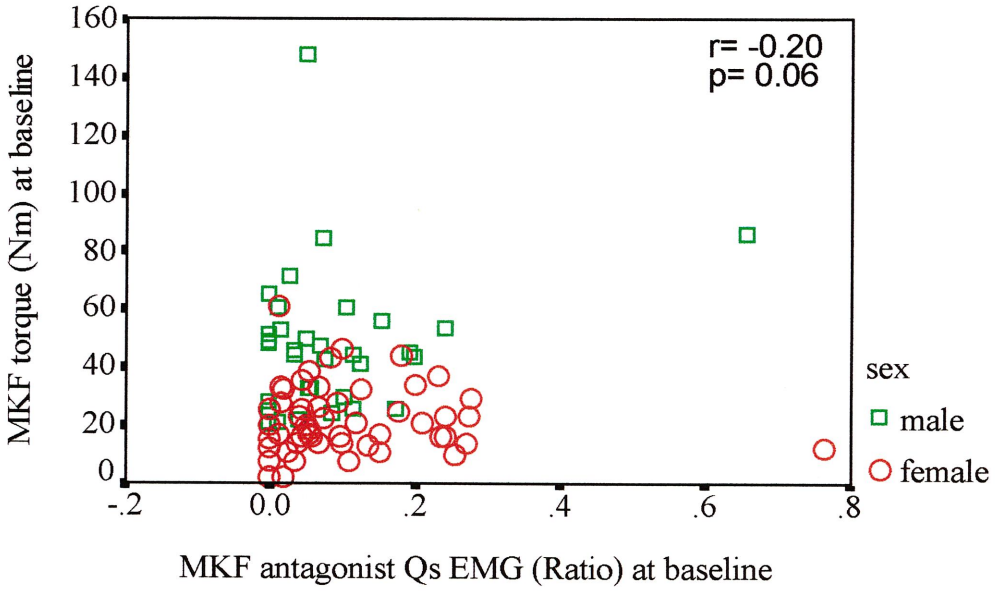


Figure 9.6. The relationship between the overall torques (Nm) and the overall antagonist quadriceps muscle (Qs) coactivation index (Ratio) (level 3) during isometric knee flexion (MKF) at 30, 60, and 90 degrees at baseline in patients with OA of the knee.

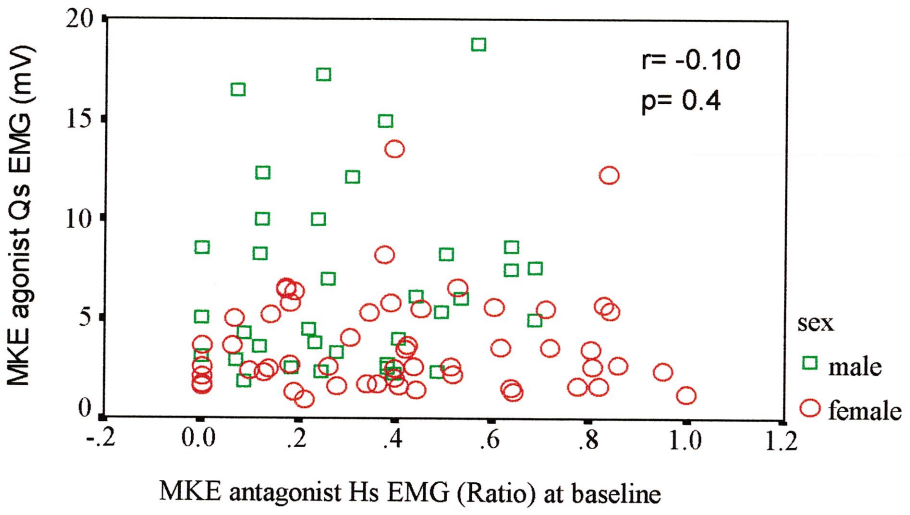


Figure 9.7: The relationship between the overall myoelectrical activity (mV) of agonist quadriceps (Qs) and antagonist hamstring (Hs) muscles coactivation index (Ratio) during isometric knee extension (MKE) (level 3) at 30, 60, and 90 degrees in all patients with OA of the knee.

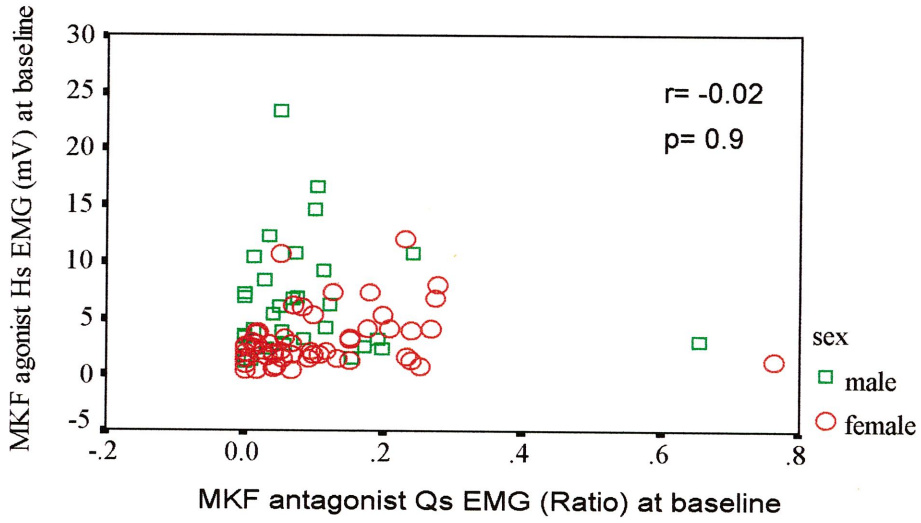


Figure 9.8: The relationship between the overall myoelectrical activity (mV) of agonist hamstrings (Hs) and antagonist quadriceps (Qs) muscles coactivation index (Ratio) during isometric knee flexion (MKF) (level 3) at 30, 60, and 90 degrees at baseline in all patients with OA of the knee. This graph illustrates that there was no statistically significant relationship between MKF agonist Hs myoelectrical activity and antagonist Qs muscle coactivation index, which indicates that antagonist signals cannot be attributed to cross-talks from the agonist.

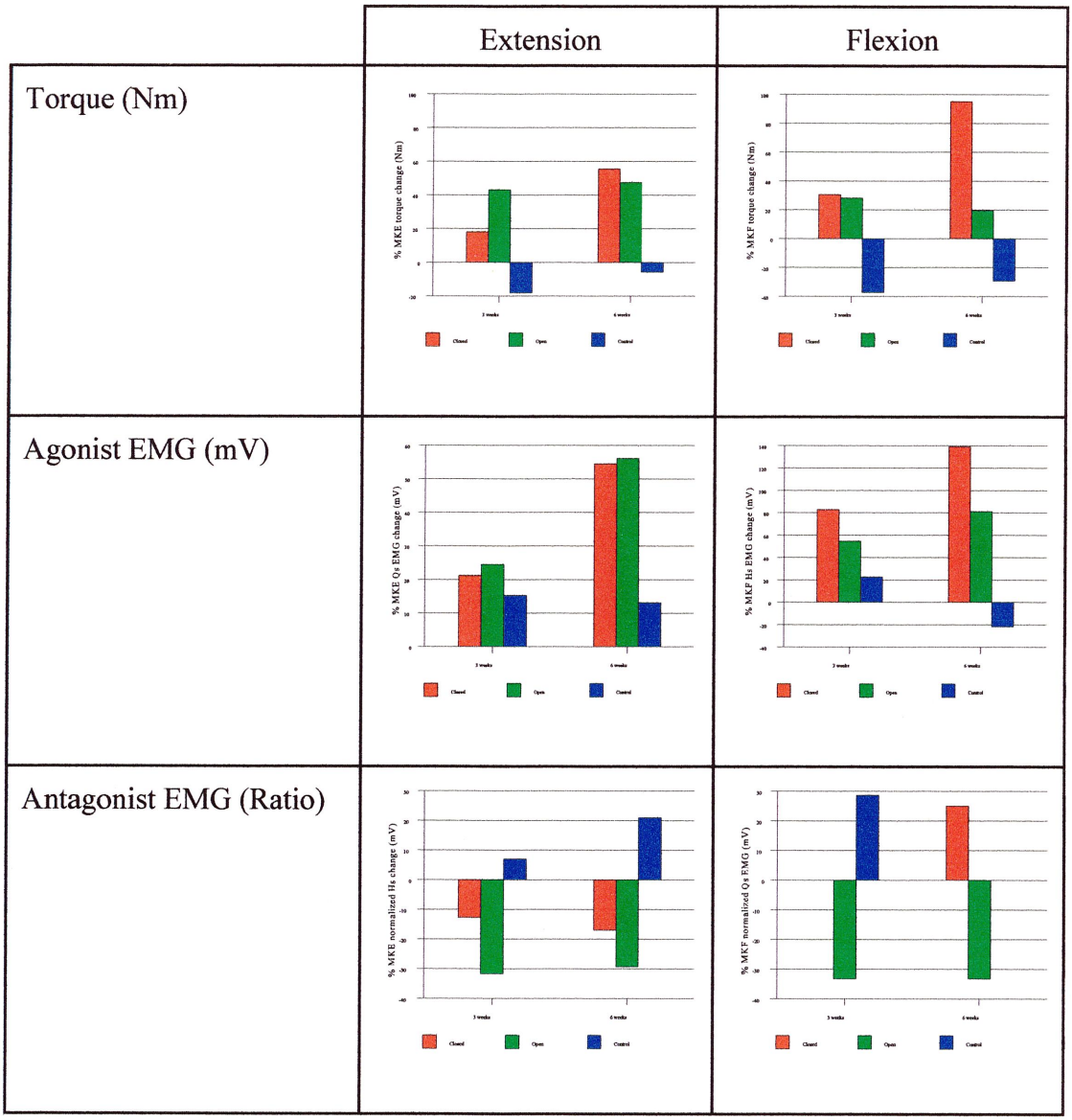


Figure 9.9. Percentage changes in torques, agonist myoelectrical activity, and antagonist coactivation index during maximum isometric knee extension (MKE) and flexion (MKF) at three and six weeks from baseline after receiving Squat Closed KCT, Open KCT, and control in patients with OA of the knee.

CHAPTER TEN
10. DISCUSSION

10.1. Introduction

This prospective study was designed as an exploratory investigation of changes in MKE and MKF torques, agonist myoelectrical activity, and antagonist coactivation index as between Squat Closed KCT, Open KCT, and control groups. The study found significant changes in maximum isometric extension and flexion torques, agonist myoelectrical activity, antagonist coactivation index, and functional activities. These changes were concurrent with reduction in pain. Further, several findings emerged from the use of Squat Closed KCT in patients with OA of the knee. Some functional activities such as sleeping and lying were improved after Squat Closed KCT. These findings were unexpected. Squat Closed KCT was satisfactorily used without exacerbating OA symptoms.

However, a high proportion of drop out in subjects throughout the study invalidated statistical analysis of the findings obtained at 50 weeks from baseline for the all patients studied. The data were therefore analysed only in relation to individual patients who had attended all three assessment sessions. On statistical advice, this strategy was preferred to repeated measures.

10.2. Patients' Considerations

All patients had received courses of analgesics or anti-inflammatory drugs before general practitioners or medical specialists referred them for physiotherapy assessment and treatment. Some of the patients had had intra-articular joint infiltrations before six months from participation. In addition, some patients had been on the physiotherapy waiting list for more than four months or had had different previous injuries, occupations, and lifestyle. These factors might have affected the

personality and function of the patients, although a careful history was taken from each patient prior to formulating any exercise training or assessment.

10.2.1. Sample Size

The number of patients participating in the study had fallen markedly at fifty weeks. Some patients might have lost interest or become busy with other life activities at fifty weeks. Others developed diseases or injuries which were not related to OA of the knee such as cancer (n=2), backache (n=3), hip pain (n=2), and broken bones (n=1). Some patients had changed their addresses or died. Thus, the patients who attended at fifty weeks follow up were selected patients with knee symptoms. But the majority of the patients completed the six week training period (Table 9.2). Thus, a fifty week follow-up might be too long for such patients.

10.2.2. Variation Among Patients

Although special care was taken to determine the consistency of the location surface electrodes at each assessment, different values between the measurements of torque, the agonist myoelectrical activity, and antagonist coactivation index were seen during MKE and MKF among subjects. Such changes might be attributed to variations between and within subjects. Variations between subjects were possibly due to differences in flexibility of the soft tissue structures, and restriction of movement between subjects. Changes between subjects might also be due to differences in muscle size, intervening tissue volume between the activated muscle and the electrodes, and placement of recording electrodes relative to the target muscle. The study also combined women and men data which cause a potential difference between subjects due to biological differences. Differences in muscle activity between women and men were reported in studies (Brownstein *et al*, 1985; Rice *et al*, 1989). Brownstein *et al* (1985) found that the mean peak knee extension torque and myoelectrical activity in four healthy men was greater than in seven healthy women.

Rice *et al* (1989) investigated strength of the muscles acting on shoulders, elbows, hands, hips, knees, and ankles in eighty-one women and thirty-seven men. They found that men strength was significantly greater than women strength. Additionally, Davis *et al* (1991) found in a cohort study in 3,972 patients with knee OA that women had greater functional difficulties than men with similar degree of OA changes. Since the peak torque varied between women and men and it coincided with maximum myoelectrical activity (Rothstein *et al*, 1983; Brownstein *et al*, 1985), the investigator would indicate that myoelectrical activity may differ between women and men. The differences between women and men might be attributed to greater subcutaneous fat in women than in men which might attenuate the EMG signals. However, the results in the current study showed no significant difference in the percentage changes of MKE and MKF torques and myoelectrical activity between women and men in the three groups throughout the study.

Differences in age and weight between groups might cause spurious changes in torques and myoelectrical activity. The mean age in both exercise groups was greater than the control group, and the mean weight of Squat Closed KCT was greater than Open KCT and control. However, the differences in the values of torques and myoelectrical activity were not significant at baseline.

Differences within subjects might be due to slight variation in placement of surface EMG electrodes relative to the specific muscle fibres, compliance of patients, and activity of patients prior to the assessments.

10.2.3. Patients' Compliance

It was assumed that all patients in the present study used their own volitional efforts to perform maximal isometric contractions. Some patients might not have generated maximal efforts during the baseline tests because they were afraid of increased pain. These patients were not familiar with the investigator, the equipment,

or the place. Thus, improvements in torques and myoelectrical activity might be simply due to patients' becoming more confident and thus making an increased effort rather than a physiological effect of training at three and six weeks. However, this is unlikely for the following reasons. Firstly, improvement did not occur in the control group. Secondly, high intra and inter-reliability tests in healthy subjects and patients were seen in chapter four. If patients used submaximal effort only during the first tests in the reliability study, this would have been apparent in the second test.

10.2.4. Medication

Medications such as non-steroid anti-inflammatory drugs (ibuprofen 200 mg, and diclofenic 50 mg) and paracetamol 300 mg were prescribed to these patients by general practitioners under different doses based on the severity of each condition. The investigator advised all patients to regularly continue taking their medication throughout the study. In longstanding disease, not all patients might have strictly followed this instruction. However, all patients agreed not to take any medication during the eight hours immediately prior to the test procedures. But it is possible that type of analgesics, dose, and regularity of taking drugs might have affected the results of this study.

Since higher doses of drugs are likely to have been used to control more severe symptoms of pain, it was likely that relationship between the severity of symptoms and the severity of radiographic features did not reflect the pathological changes in the knee alone. In cases of severe OA changes, the level of pain recorded by the questionnaire could have been lowered because patients were taking effective doses of analgesic drugs. This was unavoidable as it would not have been ethically acceptable to ask patients to withdraw taking analgesic drugs for a prolonged study of this nature.

10.2.5. Biases Associated with Lack of Masking of Investigator in Undertaking Treatment and Assessment

The findings in the current study might be contaminated by investigator bias because the same person was undertaking the assessments and training procedures. The investigator was aware of this confounding factor, but there were no other members of staff to carry out either the assessment or the training. Therefore, the investigator tried to minimize investigator bias by making every effort to treat all patients consistently and equitably, including careful balancing of the schedules and time spent in assessment and training. Further, the follow-up measurements were performed without referring to the previous values.

Despite these efforts, it is of course recognised that bias could unconsciously have occurred and that this is an important though unavoidable weakness of the study.

10.2.6. Control Group

The control group was used to control for the effects of both types of exercise, and effects of events that might occur outside training during the course of the supervised training (six weeks). The investigator gave only verbal advice, instructions, and support during the test procedures. This method might give less personal attention and satisfaction to the patients in the control group compared with both exercise groups, therefore, it might constitute a cause of bias. Better control of the information given and review of its presentation should be employed in future studies in order to improve consistency and equity between the control and exercise groups. Telephone follow-ups is another possibility to be explored further in future prospective studies.

10.2.7. Statistical Power Calculations

Statistical power means the ability of a statistical test to show a real significant

difference or the ability that a test supports the established hypothesis (Ottenbacher, 1995). Basically statistical power is estimated in relation to the probability of type 2 error (reject the proposed hypothesis when it is true). The opposite of a type 2 error is a type 1 error (accepting the proposed hypothesis when it is false).

The current study used non-parametrical analysis procedures. Further, the results of high statistically significant differences between the groups in the overall MKE and MKF torques and agonist myoelectrical activity in all tests at three and six weeks ruled out the possibility of type 1 error. Therefore, it would not be necessary to undertake the analysis of significant means (post hoc test) in order to check for a type I error.

The overall MKE and MKF antagonist coactivation index showed low significant differences between the three groups at six weeks. This might be contaminated with a type 1 error. A Bonferroni correction for multiple comparison procedures was undertaken in relation to p values of both antagonist muscles coactivation indices which confirmed the presence of statistically significant differences ($p= 0.04$).

After the pilot phase, it was still unclear as to whether the data would be normally distributed, and in particular whether the myoelectrical activity data would be reproducible and reliable enough over time for myoelectrical activity trends to be calculated. In the event, the myoelectrical activity data showed inconsistencies in between successive recordings in individual subjects and alternative strategies were adopted. For this purpose retrospectively using the results of the main study, an estimate of sample size was made. A type 1 error risk of 5% and a type 2 error risk of 20% (hence a power of 80%) were used to define statistical significance. It was calculated that a sample size of 40 patients for each group would have been needed in order to define statistical significant differences at a probability of 5%.

10.2.8. Patients Selection and Randomization Technique

From a questionnaire sent to surgeries, Orthopaedic and rheumatology departments at Southampton General Hospital, it was found that general practitioners and medical specialists referred 70-80% of their patients with OA knees for physiotherapy from June 1995 to may 1996. At baseline, the current study selected 55.6% of all patients with OA of the knee who were referred for physiotherapy in the Physiotherapy Departments at Southampton General and the Royal South Hants Hospitals.

All patients who agreed to participate in this study were randomly assigned to Squat Closed KCT, Open KCT, or control using three playing cards (face down). This technique was not statistically random though, but it was practicable. It might theoretically have been affected by investigator bias during the manual shuffling and placing of the cards. Thus, it would have been better to use more standard ways of randomization such a table of random numbers.

10.3. Training Considerations

Both forms of training resulted in increases in MKE and MKF torques. The increase in torque was associated with a corresponding increase in the agonist myoelectrical activity (Figure 10.1). The results agree with those of previous studies (Knight *et al*, 1979; Hakkinen and Komi, 1983). Increase in the MKE agonist myoelectrical activity was accompanied with decrease antagonist coactivation index in the two exercise groups, while no significant change occurred in the MKF antagonist coactivation index. These findings have not previously been described.

10.3.1. Change in Torque and Myoelectrical Activity

10.3.1.1. Change in MKE and MKF Torques

In chapter six, the findings showed that the overall median MKE and MKF torques in patients with OA of the knee was only 59.5% and 50.5% respectively of torques achieved by healthy subjects (page 141). On the other hand, the results showed that such patients could make good recovery and gain muscle strength in both exercise groups after six weeks of training. The percentage improvement in torques was 55.6% (Closed) and 47.5% (Open) during MKE, while it was 95.1% (Closed) and 19.6% (Open) during MKF at six weeks from baseline.

The percentage improvement in the current study was greater compared to those of Hakkinen *et al* (1994), Marks (1994b), and Lyngberg *et al* (1994) that training increased MKE and KMF torques in patients with OA of the knee. Hakkinen *et al* (1994) found a 32% increase in bilateral and 49% increase in unilateral knee extension strength during six months of dynamic knee exercises for acute inflammatory arthritis patients. Lengberg *et al* (1994) reported that isokinetic training increased knee extensor muscle strength by 21% at three weeks in patients with rheumatoid arthritis. The current study supports Lengberg *et al* (1994) who stated that muscle strength in patients was still lower than in healthy subjects of the same age and sex after three weeks of training.

The percentage gain trend in MKE torques was greater after Open KCT (43.1 %) than Squat Closed KCT (18.1%) at three weeks, but it became greater in Squat Closed KCT (55.6%) than in Open KCT (47.5%) at six weeks. This might suggest that muscle strength can be restored faster with Open KCT, but to a degree greater with Squat Closed KCT. Thus, it is possible that a combination of both forms of exercise would be preferable in patients with OA of the knee.

10.3.1.2. Relationship Between MKE and MKF Torques

The current findings showed a moderate positive association between MKE and MKF torques (Figure 9.2). These findings suggest that an increase in MKE torque was accompanied by an increase in MKF torque. Thus, strengthening exercises in one group of muscles could to some extent produce improvement in torques generated by opposing muscles. This mechanism might be caused by the central links between the motor neuron pools of the opposing muscles. The findings showed that the increase in percentage gain in extension and flexion at six weeks was more than at three weeks of training in both exercise groups (Table 9.15).

10.3.1.3. Changes in Myoelectrical Activity

The current findings showed moderate associations between torques and agonist myoelectrical activity at baseline during MKE and MKF (Figures 9.3, and 9.5). These findings might suggest that other factors involved in addition to myoelectrical activity in determining maximum isometric knee extension and flexion torques. The degree of immobilization of the joint and lack of muscle flexibility might partially affect the production of MKE and MKF torques.

The moderate positive associations between torque and agonist myoelectrical activity are consistent with the findings of Person and Kudina (1968) that agonist myoelectrical activity increased with increased force of muscular contraction. Person and Libkind (1970) reported that myoelectrical activity was directly related to the number of firing motor units in the muscle. The current findings are also in agreement with the results of Knight *et al* (1979) who reported that a progressive increase in loads on the knee extensors was accompanied by greater myoelectrical activity, and with those of Brownstein *et al* (1985) who reported that peak torque was associated with maximal myoelectrical activity in eleven healthy subjects.

In contrast, Thorstensson *et al* (1976b) found that myoelectrical activity decreased after exercise training in healthy subjects. Stoboy *et al* (1959) reported that myoelectrical activity did not change after a seven weeks period of training. They also reported that myoelectrical activity was significantly reduced after eleven weeks of training. De Vries (1968) reported that isometric knee extension myoelectrical activity decreased after four months of weight lifting training in healthy young subjects. However, all these later studies were undertaken in healthy young people. They did not provide a clear relationship between the changes in myoelectrical activity and changes of torque. The different results in these studies are most likely attributable to differences in the type and duration of training, measurement instrumentation, the muscle groups that were exercised, and the study populations.

Myoelectrical activity represents activation of contractile elements in muscles and greater muscular tension is accompanied by greater myoelectrical activity (Winter, 1979) . Therefore, an increase in myoelectrical activity in the current study implies stronger muscular activation. The increase in myoelectrical activation in both exercise groups could indicate the utilization of a greater number of motor units or increased firing frequencies (or combination of both) associated with decreased pain and improved neuromuscular function.

Weir *et al* (1994) found that MKE torque improved by 23.3% compared with 8.4% in myoelectrical activity of the quadriceps muscle. However, Komi and Buskirk (1972) reported that there was a parabolic relationship between myoelectrical activity and isometric contraction in thirty-one healthy young subjects. The current study found variability in the percentage median gains between the three groups at three, six, and fifty weeks from the values at baseline (Table 9.15). The investigator found that increase in the percentage MKE and MKF torques was associated with increase in the agonist moyoelectrical activity in both exercise groups at three and six weeks. For example at six weeks, MKE torque improved 55.6% compared with 54.5% in the agonist Qs myoelectrical activity in Squat Closed KCT. In Open KCT, MKE torque

improved 47.5% compared with 56.1% in the agonist Qs myoelectrical activity. The ratio between percentage increase in the agonist myoelectrical activity and percentage increase in toque was 0.98 (Closed) and 1.2 (Open) during MKE. But the percentage increase in the median MKE torque and agonist myoelectrical activity was associated with a percentage decrease in the median antagonist coactivated muscle index in Squat Closed KCT (-17.0%) and Open KCT (-29.3%) during MKE at six weeks. The ratio between the percentage increase in the median torque and the percentage decrease in the median antagonist coactivated Hs muscles index was -0.31 (Closed) and -0.62 (Open).

The results in the present study showed variation in ratios between changes in torques and myoelectrical activity throughout the study, supporting the findings of Weir *et al* (1994) who proposed two explanations for this variation. Firstly, the measurements of myoelectrical activity might not be fully represented in the generated torques. Secondly, isometric contraction is accompanied by activation of both the agonist and antagonist muscles. Thus, an alteration in the opposition to torques by antagonist muscles could cause a change in torque without alteration in the agonist myoelectrical activity. This explain the increase in MKE torque in the two exercise groups partly caused by increase agonist and decrease antagonist myoelectrical activity.

10.3.2. Squat Closed KCT

Squat Closed KCT was used in this study after the pilot study demonstrated satisfactorily that it might improve muscle performance without any exacerbation of symptoms in patients with OA of the knee. An unexpected finding in the prospective study was that Squat Closed KCT appeared to improve some functional activities such as sleeping and lying which had not been improved by Open KCT, despite the fact that these activities are not related to squatting. Improvement in these activities might be due to increased pain tolerance and flexibility of muscles, tendons, and ligaments

around the joint in these patients.

a- Squat Training Procedure:

The squat training regimen was selected from among other types of Closed KCT because it is more closely related to the functional activities used in daily life such as sitting and standing, and can be simply implemented using body weight as progressive resistance. In addition, it involves familiar patterns to patients. Squat Closed KCT causes natural pressure on the knee, alternatively eccentric and concentric muscle contractions, and integrated knee function with other parts of the body such as foot, ankle, hip, and back. The eccentric and concentric contractions produce stretching of the joint capsule, ligaments, tendons, and muscles (Baratta *et al*, 1988). Chandler *et al* (1988) reported that squat training improved stability in the knee in patient with ligamentous injuries. Zatterstrom *et al* (1992) used one leg squat exercise as functional training in patients with chronic anterior cruciate ligament insufficiency. Hodges and Richardson (1993) found that activation of the vastus medialis muscle increased more in squat weight bearing than non-weight bearing.

No patients complained about the modified Daily Adjusted Progressive Resistive Exercise (DAPRE) in Squat Closed KCT. It helped to gradually increase body weight without increase in pain. The body load on the legs was estimated by using the equation (body weight in standing x sin MTT angle), as described in chapter seven (page 177).

b- Instrumentation:

The design of the modified tilting table (MTT) passed through several stages of modification. It was changed from manual to electrical adjustment of the MTT tilt. An electrical actuator was built in to easily change the MTT tilting angle. A fluid goniometer was fixed at the side of the MTT to objectively read the MTT angle.

In general, the MTT was built of cheap materials and simply designed in order to be applicable in physiotherapy practice. But the MTT was too heavy to be moved from place to place. Therefore, all the training sessions were held in the Gait Laboratory of the University of Southampton at Southampton General Hospital.

There were a few problems with the MTT during the study. Some patients complained of back discomfort during the training because the sliding board (60 cm x 60 cm) was too small to support their back during performance of squats. Therefore, a longer sliding board would be advisable to allow patients to support their head and trunk. Some patients temporarily felt giddy when the MTT angle changed suddenly. Thus, one must change the MTT angle carefully, and allow enough rest before patients step down from the MTT in order to avoid falling.

Squat Closed KCT may not be appropriate for some surgical and medical conditions such as after recent abdominal surgery, cardiopulmonary insufficiency, and patients developing bradycardia when tilted.

c- Benefits of Squat Closed KCT:

The findings showed that Squat Closed KCT improved MKE and MKF torques and myoelectrical activity, and many functional activities such as using stairs, in and out of a chair, and squatting. These improvements were accompanied by a reduction in pain, and an increase in squat excursion and MTT angle tolerance. The improvements in squat ability might be due to:

1- increase in the flexibility of soft tissues around the knee such as muscles, tendons, ligaments.
2- improvement in activities that required bilateral actions such as getting in and out of a chair.
3- better synergistic activation of agonist and antagonist muscles.

Furthermore, some pressure on the arthritic knee may be necessary to protect the remaining healthy tissues in the joint from disuse weakness. Therefore, it can be assumed that Squat Closed KCT activated and mobilized these tissues by repetitive functional loading. If this is true, then the study supports Woo *et al* (1981) who found that weight bearing exercises improved tendon strength without increasing in its thickness in swine digital flexors. They suggested that weight tendon strength in weight bearing exercise was related to biochemical composition and mechanical properties rather than tendon hypertrophy.

Klein (1961) found that excessive squatting caused stretched ligaments and tendons around the knee in weight-lifters. He claimed that a deep squat tended to weaken the ligaments and cause knee injuries in weight lifters. But the training in the current study was not undertaken in a similar fashion to that of weight lifters who frequently use heavy weights. Squat Closed KCT was performed slowly and carefully without exacerbating the OA symptoms using the painful squat angle and a close supervision by the investigator ensured that there was no excessive load on the joint ligaments. Otherwise, Squat Closed KCT might loosen the tight tissues in the tendons and ligaments by repetitive bouncing.

d- The Strategy of Repetition of Exercises Requiring Progressive Increases in Work:

Four sets of different repetitions of squatting appeared to be enough to produce improvement in a single session because the initial 'painful squat angle' continued to improved in each subsequent session. This strategy of sets and repetitions was previously reported by Knight (1979) in the DAPRE programme. In 1985, Knight found a 230 % improvement in muscle strength in eight post knee surgery and thirteen post injury cases with the DAPRE programme.

Berger (1962) reported that six repetitions were the optimal number of

repetitions in an individual set. If a patients performs more than six repetitions the load needs to be increased. In the current study, the trends of muscle torques and myoelectrical activity dramatically improved with Squat Closed KCT. In addition, some patients reported that they had an immediate reduction in pain and improvement in walking after the training sessions.

A few patients reported that they experienced pain at the front of the lower end of the thigh on the second day of the training session during the first two weeks, although their 'painful squat angle' was improving. Interestingly, these patients had pain relief immediately following the training sessions. However, this pain disappeared at three weeks. The pain above the patella was expected by the investigator as a delayed muscle soreness after unaccustomed exercises (as described previously in chapter seven, page 193). The delayed muscle pain might occur due to eccentric muscle work during Squat Closed KCT. This form of training might damage myofibrils and connective tissues, and cause inflammation within the muscle. But reduction in pain and improving of squat angle at three weeks might suggest that exercise restored flexibility and length of the quadriceps muscle.

10.3.3. Open KCT

It was difficult to find evidence that traditional Open KCT can result in clinical benefits in patients with OA of the knee in the literature. Some of the known studies have been preliminary, and required expensive instrumentation such as isokinetic machines, and other studies incorporated long-held concepts have now been challenged. Knight (1990) reported that the DAPRE technique (Open KCT) has been effectively used to strengthen muscles in healthy young subjects, and in some post-surgical conditions such as reparative ligamentous surgery and menisectomy in the knee. But the investigator observed clinically that some patients with this type of exercise developed knee pain and discomfort, particularly during the early stages. In addition, the DAPRE technique might produce a great pressure on the knee with

weight lifting which might cause more articular damage. The recommended various types of Open KCT for OA of the knee have been based on clinical experience rather than scientific study.

In consultation with physiotherapists working in the Physiotherapy Department at Southampton General Hospital, the investigator selected five exercises as Open KCT that all clinicians believed to be safe. These exercises were performed using traditional isometric and isotonic contractions. In the straight leg raise exercise, the progression of exercise depended on the ability of each patient to perform a number of repetitions in each set, while in isometric knee extension or flexion was performed a five seconds of maximum contraction against the crossed opposite leg. Thus, there was lack of consistency in determining the progression in Open KCT.

Various difficulties faced the investigator in monitoring the progression grading in these exercises between sessions. For example, the maximum number of repetitions in straight leg raise might be limited to the hip flexor strength rather than to the knee extensors (Wessel, 1994). In straight leg raise, the main function of the quadriceps muscle was to stabilize the knee rather than perform the resistive training. The number of repetitions reflected the strength of the hip flexors rather than that of the knee extensors. There was also a lack of scientific evidence in relation to increase in the number of repetitions.

Static knee extension and flexion training was performed in a cross leg sitting position. With such technique the resistive force generated in patients with bilateral OA of the knee might be less effective compared to the resistance generated by unaffected leg in patients with unilateral OA of the knee.

Despite these difficulties, most of the patients in Open KCT were satisfied with the exercise procedures. The attendance of patients was similar to the attendance in Squat Closed KCT at six weeks(Table 9.2). The patients complied with their

training.

10.3.4. Comparison Between Effects of Squat Closed KCT and Open KCT

Comparison between and within groups at baseline, and three and six weeks of training showed that patients with OA of the knee who participated in Squat Closed KCT and Open KCT under close supervision improved, but the control group patients who participated in testing procedures only did not. The two forms of exercises resulted in similar gains in MKE and MKF torque and agonist myoelectrical activity following three and six weeks. Although these findings revealed that the amount of improvement in Squat Closed KCT was greater than in Open KCT, no statistically significant differences between the two forms of training were seen in relation to MKE or MKF torques and myoelectrical activity. However, some benefits had been seen in Squat Closed KCT patients compared with Open KCT patients (Table 10.1).

Table 10.1.
Comparison of performance between Squat Closed KCT and Open KCT.

Aspects of Comparison	Squat Closed KCT	Open KCT
1- Muscle Activation	-synergistic agonist/antagonist. -eccentric and concentric. -bilateral muscle work Qs or Hs resisted by body weight. -increased torque and EMG.	-isolated one group. -only concentric. -unilateral muscle work (Qs one leg against Hs the other leg). -increased torque and EMG (size of increase is possibly less than Closed KCT).
2- Joint Movement	-under functional joint pressure. -involved many joints. -dynamic. -bilateral: legs extend and flex together.	-under nonfunctional joint pressure. -involved single joint. -static. -one leg extends and other flexes each against the other.
3- Type of Exercises	-performed only one type of exercise.	-performed five types of exercises.
4- Progression	-depended on body-weight and repetitions.	-depended only on repetitions.
5- Assessment Load	-can easily be assessed.	-difficult to be assessed.
6- Test Procedure	-not familiar to patients.	-familiar to patients.
7-Functional Activities	-activity familiar to patients. -more improvements in functional activities.	-not familiar to patients. -less improvement in functional activities.
8- Pain	-improved. -easy to estimate painful load.	-improved. -difficult to estimate painful load.
9- Feelings in General	-improved.	-improved.

a- Agonist and Antagonist Synergistic Activation:

It has been accepted that agonist and antagonist muscles are activated synergistically in order to perform economical movements and functions. The antagonist muscles are actively inhibited through the mechanism of reciprocal inhibition, except perhaps at the end of a movement or when the movement is stopped by the limitation of the joint or external force. Integration of the central control and the feedback loops from proprioceptors is probably responsible for a periodicity and modulation of the motoneural activity (Astrand and Rodahl, 1986).

Young (1993) reported that flexion in the arthritic knee was caused by activation of flexor and reciprocal inhibition of extensor muscles. In chapter six, the results showed similar mechanism in maximum isometric contractions in patients with OA of the knee. This might lead us to believe that arthrogenic muscle inhibition continuously works in two directions as inhibitory to the agonist and simultaneously facilitatory to the antagonist muscles. The increase in the antagonist coactivation index probably supported the insufficient joint from the excessive stretch protecting against further damage to ligaments and capsule of the diseased joint. Young *et al* (1987) reported that even small changes at the joint can influence muscle activation. Their suggestion that disturbance in the agonist-antagonist mechanism contributes to flexion knee deformity would imply in an ambient bias towards inhibition of the quadriceps and disinhibition of the hamstring muscles.

Conversely, the antagonist coactivation index became smaller in both exercise groups. This shows that the relative balance of myoelectrical activity shifted in favour of the agonist muscles, but this does not necessary mean that antagonist activity declined in absolute terms. It is possible that the decrease in antagonist coactivation index was accompanied by a greater increase in the absolute value of the agonist than the antagonist myoelectrical activity. However, theoretical possibility of some contaminated with cross-talk means that it would be unwise to speculate further at this stage.

Some studies have claimed that antagonist muscle coactivation is actually an artifact caused by cross talk between surface electrodes which have picked up signals generated from other muscles through tissue conduction (Person and Kudina, 1968; Koh and Grabiner, 1992). However, the present study found a weak relationship between the percentage gain of myoelectrical activity in quadriceps and antagonist hamstring muscle index during MKE ($r= 0.07$, $p= 0.5$) (Figure 10.2). Like Solomonow *et al* (1987) and Baratta *et al* (1989), we have not been able to demonstrate significant cross talk as explained in chapter six, greater antagonist

muscle coactivation index was accompanied by weaker agonist activation in patients as compared to healthy subjects.

Kim *et al* (1995) found that quadriceps and hamstring muscles could be reflexively activated independently of their roles as flexors or extensors to provide stability to the knee joint by mechanically stimulating the ligaments.

b- Bilateral versus Unilateral training:

The two exercise groups used different techniques of training. Squat Closed KCT was performed bilaterally and symmetrically, while Open KCT was performed asymmetrically in cross leg resistance isometric exercise. The current study was similar to a study undertaken by Gerberich *et al* (1989) who compared bilateral and unilateral alternative resistive exercises in healthy women using constant resistive computerized exercise instrumentations and a Cybex testing machine. Gerberich *et al* (1989) found there were no significant improvements in quadriceps strength in bilateral and alternative unilateral paddling in twenty-nine healthy women. But they found significant improvements in muscle strength in both exercise groups compared with seventeen nonexercise control subjects.

Few studies have investigated the differences between bilateral and unilateral exercises. Secher (1975) and Fleck and Kraemer (1997) reported that the force developed by bilateral actions was less than the sum of the force developed by each leg independently. Flecker and Kraemer (1997) suggested that a decrease in force developed with bilateral actions was caused by an inhibition protective mechanism initiated by the golgi tendon organs. Secher (1978) reported that bilateral training improved the activities that required bilateral actions.

Astrand and Rodahl (1986) indicated that maximal oxygen uptake in unilateral leg exercises is greater than bilateral leg exercises. They suggested that unilateral leg

exercises required more effort and produced better results than bilateral exercises in cardiopulmonary function. This difference might be attributed to more central hemodynamical effects after bilateral exercises in contrast to unilateral leg exercises. This also might be the reason why patients did not feel exertion or fatigue during Squat Closed KCT. This issue requires further investigation.

It should be explained that voluntary contraction of extensors or flexors in unilateral one leg Open KCT was accompanied by reverse action of the other leg. It is possible that some cross inhibition occurred between contralateral limbs performing opposite tasks. It may be that greater MKE torque would be generated if both legs extending together rather than one leg extends while the other leg flexes during exercises. This possibility needs further study.

- Effect of Different Exercise:

The results in the present study support those of Stiene *et al* (1996) who found that Closed and Open KCT significantly improved isokinetic knee extension in twenty-three patients with patellofemoral dysfunction. Kreindler *et al* (1989) also found that Closed KCT, isokinetic exercise, and traditional progressive strengthening exercises improved isokinetic knee extension and flexion after six weeks of training in thirty-two patients referred to a private physiotherapy practice. However, La Free *et al* (1995) found that improvement in Closed KCT was significantly greater than in Open KCT in forty healthy subjects, but our results could not support their claim.

the findings in our study showed that a twice per week exercise for six weeks could increase torques and myoelectrical activity. This period has been recommended by many studies in order to improve muscle strength and reduce pain in OA of the knee (Marks, 1994b; Fleck and Kraemer, 1997; Fransen *et al*, 1997; Pfeirer *et al*, 1997). However, two patients failed to reach 90 degrees of squatting at the end of the six week period because they were slower than the others in the process of

improvement in Squat Closed KCT. This suggests that some patients may need a longer period for exercises.

The findings in the current study also are in agreement with the results of a single case study by Marks (1994b), who reported that isometric knee extension training significantly increased maximal isometric knee extension torque in a patient with OA of the knee at six weeks.

These results differ from the results of Reynold *et al* (1992) and Worrell *et al* (1993) who reported no significant change in isokinetic knee extension torque with progressive resistance in one leg lateral step-up exercise as Closed KCT for healthy subjects. Worrell *et al* (1993) found significant improvements in the closed kinetic functions such as leg press, step-ups, and hop tests. The methods in the present study differ from the methods of Worrell *et al* (1993) in applying resistance, range of knee motion, measurement techniques, and subject selection. They found that improvement in functional activities without improvement in isokinetic torque. They attributed the findings as a result of variation between the method of training and the method of assessment. But La Free *et al* (1995) showed a good relationship between isokinetic knee extension torque and leg press peak torque ($r = 0.79$ to $r = 0.84$). Stiene *et al* (1996) reported that isokinetic knee extension accurately measured the improvement of muscle strength in Closed KCT and Open KCT.

c- Cross-leg training effects:

The present study did not investigate the results of cross-training effect, because some patients in the study had OA changes in both knees. It was difficult to use unilateral Squat Closed KCT in these patients. However, studies have reported increased torque and myoelectrical activity of the untrained limb after unilateral training (Lyngberg *et al*, 1994; Weir *et al*, 1994). The cause of the cross-training effect is currently unclear, however, it may be due to adaptation in the central nervous

who found an increase in myoelectrical activity in biceps brachii in weight lifters at early stage of training.

The findings are also in agreement with the results of our pilot study which showed improvement in both extensor and flexors torques and myoelectrical activity. The findings lend support to the current Squat Closed KCT results which include both eccentric and concentric contractions. This finding supports the evidence of Janda (1993) who indicated that repetitive bouncing stretch might improve muscular flexibility and provide energy in the tightened muscles, tendons, and ligaments around the diseased joint. This finding also supports Stiene *et al* (1996) who reported more functional benefits gained with Closed KCT than Open KCT.

10.3.7. Detraining Effects

At fifty weeks, maximum isometric torques and myoelectrical activity declined, but the number of patients was too small by this stage for firm conclusions to be drawn. After supervised exercise was terminated, the subjects were instructed to continue exercises at home. Fifty weeks was chosen as sufficient time to observe whether patients could regularly continue unsupervised home exercises. At this period, only selected subjects remained who still had pain and needed care. But most of the subjects lost interest in participating. It was difficult to quantify the effects of the exercises on these patients because some patients had other forms of treatment such as a change in drugs, had undertaken other recreational activities, been injured, or contracted other diseases.

10.4. Assessment Considerations

Measurement of torques, myoelectrical activity, and the SPFKA were shown to be reasonably consistent in quantitatively monitoring the performance of the thigh muscles, intensity of pain, and function in the current study (as described in chapters

four and five). These findings support the view, but repeated measurements after a long period were probably affected by pain, joint restriction, and the degree of patients' compliance.

10.4.1. Baseline Measures

Ideally, at least three measurements are needed to establish a baseline state. But in this study, the need to do this was reduced by the strategy of employing a prospective control group. However, the lack of more baseline information then made it difficult to study differences between individuals in the groups.

10.4.2. Torque and Myoelectrical Activity at Different Knee Joint Angles

The findings of isometric knee extension and flexion torques and the individual myoelectrical activity were consistent at the three angles (30, 60, and 90 degrees). The investigator expected that the torques and myoelectrical activity would change at each different knee angle.

As a result of the similarity between individual myoelectrical muscle activation at each angle (level 1) and similarity between torques and myoelectrical activity values at all three angles (level 2), the investigator combined the data of torque and myoelectrical activity at all three angles during MKE or MKF respectively, and calculated the overall MKE or MKF torque' or ' the overall MKE or MKF myoelectrical activity' (level 3). This technique of reduction was helpful in producing an integrated measure of the thigh muscle strength.

10.4.3. Painful Squat Angle Test

Using the 'painful squat angle' gave several advantages to the Squat Closed

KCT training regimen. The investigator monitored the tolerance of squat, degree of progression level, and severity of condition in each individual patient.

The investigator believes that the painful squat angle test was a good predictor of the ability of patients to squat and helped in selecting a convenient MTT inclination. Patients in the Squat Closed KCT group performed this test using a variety of angles and squat excursions.

Wilk *et al* (1996) reported that vertical squat caused stresses on the posterior and anterior cruciate ligaments by the articular shear forces. If the joint capsule and ligaments shorten as results of arthritic changes and disuse, as Cyriax (1984) explained in his 'capsular pattern' signs, the painful squat angle test could logically be used in clinical practice. Because of time constraints, the investigator did not undertake formal testing of the reliability and validity of this test.

10.4.4. Self-reported Pain and Functional Knee Assessment (SPFKA)

This study suggests that improvements in torques and myoelectrical activity were associated with improvement in 'feelings in general' and followed by improvement in functional activity and reduction in pain.

Improvement in 'feelings in general' in both exercise groups compared to the control group after three weeks suggests that exercise might improve well-being in patients with OA of the knee before improving functional activity and reduction in pain. The improvement of the 'feelings in general' in Squat Closed KCT was greater and lasted longer than in Open KCT. These results support Semble *et al* (1990) who indicated that planned exercise programmes improve self-esteem and decrease depression.

The current findings are in agreement with those of Fisher *et al* (1991) who reported that a significant improvement in isometric knee torque was accompanied with decreased dependency (10 %), difficulty (30 %), and pain (40 %) in fifteen patients with OA of the knee after two months of training. In another study, Fisher *et al* (1993b) found that improvements in muscle strength caused improvements in functional activities. The increase in functional activities was associated with a decrease in pain.

Callaghan *et al* (1995) reported that reduction in pain was not significantly different after four weeks of training in patients with OA of the knee. The current study found no significant change in the intensity of pain was observed at three weeks, but pain reduced 33.9% (Closed) and 23.3% (Open) at six weeks. At fifty weeks, pain in Squat Closed KCT was less 53.6% compared to 33.3% in Open KCT from baseline. Because of the small number of subjects at fifty weeks, it is not clear whether Squat Closed KCT was more effective in pain reduction than Open KCT in patients with OA of the knee.

The current study showed that the location, frequency, and nature of pain changed without changing in the intensity of pain. However, difficulties were existed to statistically analyse and interpret these data although these details would be necessary in clinical practice.

10.4.5. Relationship Between Different Measurements of Osteoarthritis (OA) of the Knee

The current results showed that the assessment of radiographic features and pain did not predict muscular performance in patients with OA of the knee. Thus, the study suggests that muscle performance and functional activities should specifically be included in the assessment of patients with OA of the knee.

The present results support those of Ledingham *et al* (1995) who reported that

radiographic changes poorly predicted clinical symptoms and signs in patients with OA of the knee. They also agree with those of Larsson *et al* (1979) who found a weak relationship between radiographic features and walking ability. But the current results differ from those of Bellamy and Buchanan (1986) who reported good associations between pain and functional activities (chapter three, page 30). The differences in the results might be due to differences in subjects and methods used in the study.

The present findings showed that exercise increased muscle performance, functional activities, and 'feelings in general' and reduced pain, but that these outcomes were weakly associated with each other. This indicates that exercise may have broader effects than simply strengthening muscles. The current results support those of Chamberlain *et al* (1982), Adler (1985), Bunning and Materson (1991), Fisher *et al* (1993), and Ettinger and Afable (1994) who reported that exercise not only improved muscle strength and functional ability, but decreased pain in OA of the knee during the period of training. The present findings also support the results of Fisher *et al* (1993b) and Marks (1994b) that muscle strength and functional activities declined when patients stopped doing training.

The present findings differ from those of Callaghan *et al* (1995), Hurley and Newham (1992), and Young (1993) who stated that exercise did not help patients with OA of the knee. These studies used different forms of exercises and assessments, and smaller sample sizes than the current study.

10.4.6. MKE and MKF Torques and Myoelectrical Activity Associations with Age, Height, and Weight

The results of the present study indicated that MKE and MKF torques, agonist myoelectrical activity, and antagonist coactivation indices had weak association with age, height, and weight in patients with OA of the knee (Appendices 13, 14, and 15). This implies that age, height, and weight were not related to the production of torques

or myoelectrical activity in patients with OA of the knee.

10.5. Clinical Implications

OA of the knee progressively decreases torque and myoelectrical activity, however these variables can be improved with exercise (Samble *et al*, 1990; Bunning and Materson, 1991). The present study investigated the effects of a Squat Closed KCT programme that can be effectively used in patients with OA of the knee. Six weeks of exercise twice per week was enough to produce gains in muscle performance and function in these patients. The investigator believes that deterioration of OA of the knee in clinical setting may be due to several reasons :

- disuse.
- muscular disturbance.
- articular and periarticular damage and deformation.
- immobility and medication.
- insufficient natural load on the diseased knee joint.
- abnormal stress on the knee due to daily functional activities and training regimens.
- lack of gradually progressive Closed KCT training that provides natural pressure on the knee.
- insufficient exercises.

Open KCT may improve muscle performance temporarily during training, but it may cause further damage to the articular knee due to excessive mechanical pressures on the joint (Cress *et al*, 1996; Doucette and Child, 1996; Wawrzyniak *et al*, 1996; Wilk *et al*, 1996).

The anterior lower thigh knee pain in some patients in Squat Closed KCT might be due to physiological muscle soreness rather than muscle injury as these patients were not used to this type of exercise or exertion. Thus, one should make

patients aware in order to ensure patients' compliance.

Assessments of muscle performance, pain, and function may produce anecdotal evidence as each assessment measures a completely different aspect of the disease. In addition, each assessment has a wide variability on its own. The present study suggested a 'painful squat angle' test in order to assess pain, joint range of motion, muscle strength, and functional weight bearing ability with one test. This may help clinicians as well as researchers to decide and predict the progression in patients with OA of the knee. The 'painful squat angle' test investigates the ability of a patient to undertake a squat without pain at the inclined MTT.

10.6. Suggestions for Further Work

1- This study showed the effects of Squat Closed KCT on patients with chronic OA of the knee. However, further studies would be required to investigate the application of Squat Closed KCT to acute knee injuries or inflammation with acute pain, swelling, and restriction of the range of motion.

2- This study could not investigate the effects of Squat Closed KCT on different types of OA of the knee (patellofemoral, medial tibiofemoral, and lateral tibofemoral) because greater numbers of subjects would have been needed given the overlapping of the different types with ordinary radiographic features. It would be advisable to undertake further studies to observe the effects of this training regimen on different types of OA using more advanced techniques to identify the effects on each type of OA.

3- The current study did not consider women and men separately because this would have reduced the sizes of the group below the level at which statistically significant changes would be demonstrable. This is a weakness of the study because the effects of expanding the range of values recorded in each group can not be identical with precision. Further studies in which layer groups of women and men ca

be studied separately are necessary. Such studies would also enable assessment as to whether exercise of this nature has different effects in women and man.

4- Some reports have suggested that electrical stimulation is useful in preventing muscle atrophy following knee disorders (Young, 1993; Oldham *et al*, 1995). Therefore, a comparison of the effects between a Squat Closed KCT regimen and electrical stimulation would be of value.

5- The present study was an open one in which the investigator and the patients knew the process of the assessment and training. The investigator might have been biased to give attention to one group rather than to the other. Although the investigator tried to minimize such bias, it might unconsciously have occurred. Thus, replication of the study should be undertaken under masked conditions.

6- All patients in the study had been referred to the Rehabilitation Units for physiotherapy treatment and were Southampton residents. Therefore, the investigator does not know to what extent these results can be applied to patients with OA of the knee generally.

7- A further study would be helpful to explore further the relationship between changes in torque and myoelectrical activity and functional activities.

8- This study investigated the effects of training on isometric knee extension and flexion torques and myoelectrical activity. Further investigation is required to test the benefits of these exercises on different speeds of contraction using an isokinetic device.

10.7. Conclusion

The current findings showed that Squat Closed KCT was more effective in improving muscular performance than Open KCT in patients with knee OA. Closed KCT, with graded increase of body weight on the legs, provided greater MKE and MKF torques and myoelectrical activity, and improved feelings in general in a shorter time. But this study was unable to show any significant differences in the torques or myoelectrical activity achieved by the two exercise regimens.

Twice per week exercises for six weeks improved the patients' condition not only by increasing MKE and MKF torques and myoelectrical activity but by enhancing function and feelings in general, and reducing pain.

Body weight is a crucial factor in disabled patients because all functional activities are related to body weight. Thus this study selected Squat Closed KCT using a vertical load with body-weight on the inclined MTT. The technique can be safely and effectively used for assessment and treatment in clinical practice. Also, the modified daily adjustable progressive resistive exercise technique using MTT is practically simple and safe. However, continuation of training under regular supervision is probably essential for maintaining this improved level of muscular performance, and thus clinical benefit.

This study found that neither radiographic features nor pain assessments predicted muscle performance. The assessment of muscle performance should be related to the techniques which represent activation of muscles, including torques and myoelectrical activity.

The findings suggest that strengthening exercises in one group of muscles could to some extent produce increases in the torques generated by antagonist muscles. Thus an increase occurred both in knee flexion torque and in the agonist Hs muscle myoelectrical activity in response to Squat Closed KCT.

It appears likely that an arthrogenic reflex mechanism produces weakness of agonist and an increase in the antagonist coactivation index. Such inhibition of agonist quadriceps activation could increase maladaptative and biomechanical stresses within the joint. However, the decreased antagonist coactivation index found in the present study during MKE in both exercise groups could indicate an increase in joint and muscle flexibility leading to better motor coordination and reciprocal innervation. Overall, the evidence is consistent with view that exercise is beneficial in restoring

and maintaining joint and muscle flexibility. But it will be important to undertake longitudinal studies over a number of years in order to show that these short-term improvements are not being achieved at the expense of a subtle acceleration of the pathological changes of OA in the joint.

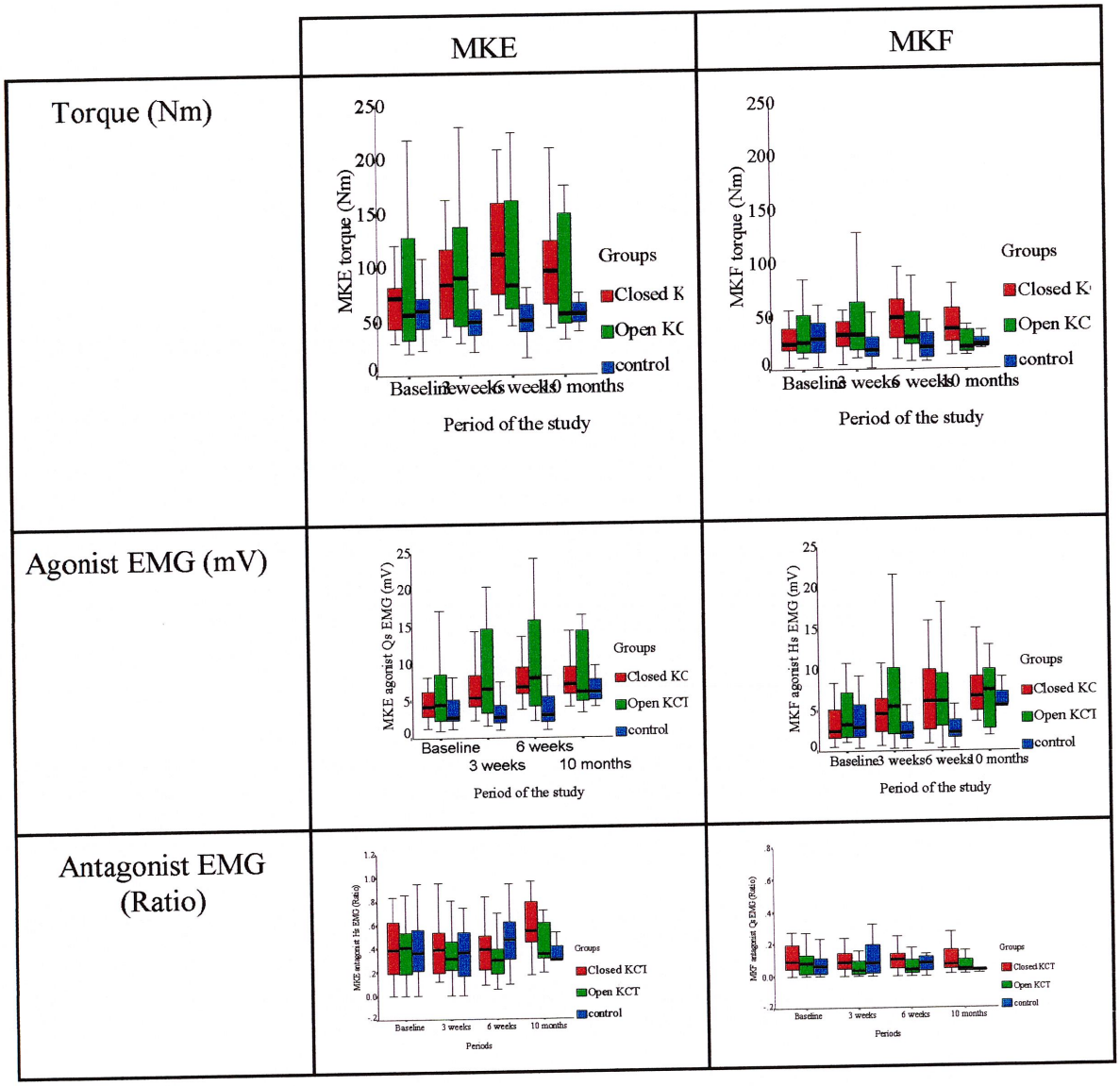


Figure 10.1. Comparison of the overall median, interquartile, and range of torques (Nm) and myoelectrical activity of the agonist (mV) and antagonist muscles coactivation index (Ratio) between Closed KCT (n= 19), Open KCT (n= 21), and control (n=16) during maximum isometric knee extension (MKE) and maximum isometric knee flexion (MKF) at baseline and three, six, and fifty weeks in patients with OA of the knee.

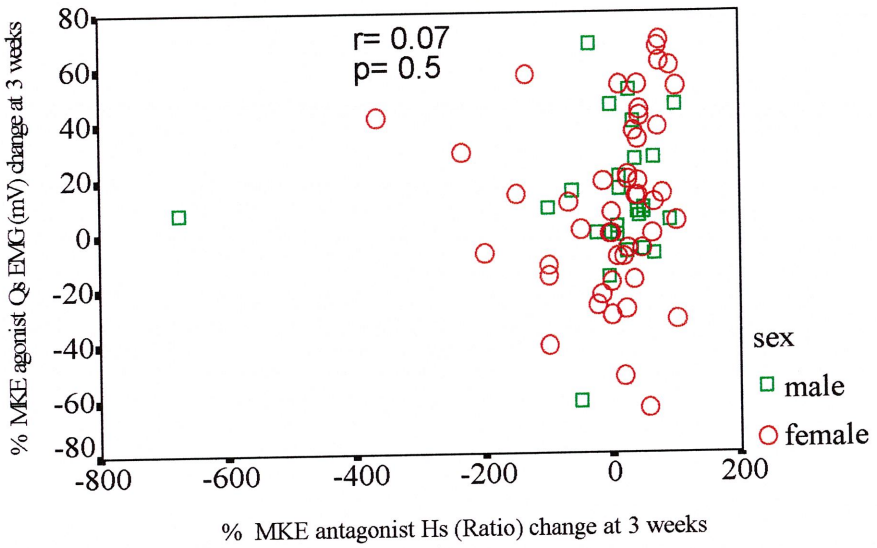


Figure 10.2. Relationship of the percentage change in myoelectrical activity between agonist quadriceps (Qs) (mV) and antagonist hamstring (Hs) muscles coactivation index (Ratio) during MKE at three weeks from baseline in all patients with OA of the knee. The poor association is evidence that cross-talk between recording electrodes was not a major factor in amplitude of the antagonist Hs coactivation index.

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Appendix 1

Cincinnati Rating System

Pain

20 —— No pain in my knee.
16 —— Occasional pain with strenuous sports or heavy work; knee not entirely normal; some limitation, but minor and tolerable.
12 —— Occasional pain with light recreational sports or moderate work activities.
8 —— Pain, usually brought on by sports, light recreational activities or moderate work. Occasionally occurs with walking, standing, or light work.
4 —— Pain is a significant problem with activities as simple as walking. Relieved by rest. Unable to do sports.
0 —— Pain present all time, even during walking, standing, or light work.

Intensity of pain: ——Mild. ——Moderate. ——Severe.

Location of pain: ——Medial (inner side).
——Lateral (outer side).
——Anterior (front).
——Posterior (back).
——Diffuse (all over).

Frequency of pain: ——Intermittent. ——Constant.

Type of pain: ——Sharp.
——Aching.
——Throbbing.
——Burning.

Overall activity level:

20— No limitation; normal knee; able to do everything including strenuous sports or heavy labour.
16— Perform sports, including vigorous activities, but at a lower performance level, involves guarding or some limits to heavy labour.
12— Light recreational activities possible with rare symptoms; more strenuous activities cause problems. Active but in different sports; limited to moderate work.
8— No sports or recreational activities possible. Walking activities possible with rare symptoms; limited to light work.
4— Walking, activities of daily living cause moderate symptoms; frequent limitation.
0— Walking, activities of daily living cause severe problems; persistent symptoms.

Walking:

10— Normal, unlimited.
8— Slight/mild problem.
6— Moderate problem: smooth surface possible up to 800 meters.
4— Severe problem: only two to three blocks possible.
2— Severe problem: requires cane, crutches.

Stairs:

10— Normal, unlimited.
8— Slight/mild problem.
6— Moderate problem: only 10-15 steps possible.
4— Severe problem: requires banister, support.
2— Severe problem: only one to five steps possible.

Running:

5— Normal, unlimited: fully competitive, strenuous.
4— Slight/mild problem: run hall-speed.
3— Moderate problem: only two to four km possible.
2— Severe problem: only one to two blocks possible.
1— Severe problem: only a few steps.

Appendix 2

Functional Index Questionnaire

Today, do you or would you have any problem in your ....knee at all?

	Unable to do	Can do with difficulty	Able to do
1. Walking as far as a mile	( )	( )	( )
2. Climbing up 2 flights of stairs (16 steps)	( )	( )	( )
3. Squatting	( )	( )	( )
4. Kneeling	( )	( )	( )
5. Sitting for prolonged period with your knees bent in one position	( )	( )	( )
6. Climbing up 4 flights of stairs (32 steps)	( )	( )	( )
7. Running a short distance, say 100 meters.	( )	( )	( )
8. Walking a short distance (About a city block)	( )	( )	( )

Appendix 3

Self-reported Pain and Functional Knee Assessment (SPFKA)

Name:..... Date:.....

Age:..... Sex: F / M

1- Pain is in:-
Left knee[.....] or Right knee[.....] (Please indicate only one knee)

2- Duration of Pain is:- ..... days/ ..... months/ ..... years.

3- Intensity of Pain:-
(Please mark (1) on the line below for your pain intensity level)

No pain **Extremely painful**



Please tick (✔) in appropriate boxes below

4- Pain Started:-

Onset of pain	Suddenly	Gradually

5- Location of Pain at:-

	Front	Back	Inner side	Outer side	Within	Uncertain
Site of pain						

6- Pain is:-

Constant	Intermittent	Occasional

7- Type of Pain:-

Sharp	Aching	Throbbing	Burning

8- Pain is combined with:-

Stiffness	Leg Heaviness

9- Pain usually ocurrs with.... ..... [indicate activities causing pain],
and continues for :- ..... seconds, ...minutes, ...hours, ... days, ...months.

Appendix 3 (cont.)

Please tick (✔) in an appropriate box:-

[use a separate form for each knee]

a)For walking, I often use:-

Walking Aid	Nothing	Stick	Crutches	Frame	Wheelchair
	.....	....	....	....	.....

b) My left knee(...) or right knee(...) stops me from:

	Functional Activities	Not at all	Slightly	Moderately	Severely	Completely
1	Sleeping					
2	Lying					
3	Bending Knee					
4	Straighten Knee					
5	Sitting					
6	Standing					
7	In & Out of a Chair					
8	Kneeling					
9	Walking					
10	Driving					
11	Squatting					
12	Cycling					
13	Running					
14	Climbing Up Stairs					
15	Climbing Down Stairs					

Feelings in General	Excellent	Very Good	Good	Fair	Poor

Appendix 4

Patient's Consent Form

I agree to participate in the research study being conducted by Ahmed Mohamed in the Rehabilitation Research Unit of Southampton General Hospital.

I understand that weakness of the thigh muscles is associated with knee osteoarthritis. The purposes of this study are: 1) to identify the weakness of the muscle, and 2) to determine the effect of exercise training on the knee pain and function. If the exercise training reduces the pain and improves the function, the specialists will be able to have a scientific evidence for their rehabilitation practice. A thorough explanation of the study purposes, equipment, and its procedures will be given to me by the investigator. The investigator will assess the active knee extension and flexion strength by using a specially modified chair and electromyographic surface electrodes on both legs.

I understand that active extension and flexion knee exercises may cause a slight soreness in the knee and thigh muscles as a result of the muscular contractions. The soreness, if present, should not last more than a couple of days.

I have been given the right to ask, and have had answered, any questions concerning the study at any time. Ahmed Mohamed at 794575 is available to answer my questions or concerns. This information will be subject to the confidentiality of Southampton General Hospital. The data will be used for publication in the medical literature or teaching purposes, no names will be used, and other identifiers, such as photographs, audio- or videotape, will be used only with my special written permission.

I understand that I may refuse to participate or may withdraw consent and discontinue participation in the study at any time without prejudice to me. I also understand that the investigator may terminate my participation in this study at any time after he has explained the reasons.

I have explained to_____ the purposes of the research and the procedures required to the best of my ability.

Ahmed Mohamed_____ Date--------- Investigator

I confirm that Ahmed Mohamed has explained to me in detail the purposes and procedures of the study. I have read and understand this consent to give my consent to participate as a subject in this research project.

Participant---------- Signature ---------- Date----------

Appendix 5

Doctor's Consent Form

Ref:.....Age:.....

Dear Consultant/GP

I am a research physiotherapist, attempting to quantitatively identify muscular weakness in patients with osteoarthritis of the knee, and determine the effects of exercise rehabilitation training on the muscle strength, pain, and functional activities. This experimental study will be implemented in Physiotherapy Rehabilitation Unit, Southampton General and Royal South Hants Hospitals.

I should be grateful if you would kindly give your permission for this contact to be made on your patient, and let me know if you feel that it would be inappropriate for us to do so. Please indicate your views below and post to us in the SAE enclosed.

With many thanks.

Your sincerely,

A. Mohamed
Rehabilitation Research Unit
Mail Point 874
Level C West Wing
Southampton General Hospital
Southampton SO16 6YD.
Tel: (01703)794575

.....

Dear Mohamed,

.... I would be happy to implement the study on my patients.

.... Please do not contact the patient, because

.....

Appendix 6

Physiotherapist's Consent Form

Dear .....

I am a research physiotherapist, conducting research within the Rehabilitation Research Unit of Southampton General Hospital. Currently, I am investigating muscular performance in patients with knee osteoarthritis. Through my project, I would like to assess muscular performance by a strain gauge and integrated electromyography. Pain and functional activity will be also assessed with a self-report questionnaire. Then, repeated measures will be taken after three and six weeks of the exercise training. Normally, the test will take 45 minutes.

I would be grateful if you could kindly participate in this study by giving me the access to your patients. Please indicate your views below and post to me in the SAE enclosed. I assure you that your patients will be very well looked after.

Many thanks.

Your sincerely,

A R Mohamed
Rehabilitation Research Unit
C Level West Wing
SGH
Southampton SO16 6YD

.....

Dear Mohamed,

.... I would be happy to let my patients contribute in your study.
.... Please do not contact my patients, because .....

Appendix 7

Letter to Patients

Dear

With the permission of your physiotherapist at .....Hospital, we are writing to ask if you would participate in a research project to study the effect of strengthening exercises in knee disorder people.

The study will involve strengthening exercises and muscular tests before and after exercises by a qualified physiotherapist. From this we would hope to be able to gain information so that future services can be structured to meet individual needs.

We assure you that you will be very well looked after and all information will be kept in the strictest confidence.

If you are interested to participate in this study please contact Ahmed Mohamed on 794575 or the Rehabilitation Reception on 796466.

Sincerely yours,

Ahmed Mohamed
Research Physiotherapist
University Rehabilitation Research Unit

Appendix 8

Rehabilitation Research Unit
Subject Profile

Please fill the items from 1 to 9:-

1	Name	Surname First Middle .....

2	Sex	F.../ M...	3	Age:.....

4	Marital Status	Married	Single	Divorced	Widow
		.....	.....	.....	.....

5	Weight	.....	6	Height	.....cm

7	Occupation	.....	Retired: N0 ... yes...

8	Dominant leg	Right.....	Left.....

9	General Function Capacity

	Grade 5	Fully employed/employable in usual work and able to undertake normal physical recreation; housewives able to do a full day's housework, shopping, etc.
	Grade 4	Doing light/part-time work and only limited physical recreation. Housewives: all except the heaviest housework.
	Grade 3	Not employed and unemployable. No physical recreation. Housewives: only light housework and limited shopping.
	Grade 2	Confined to house or wheel-chair, but able to look after themselves in the essentials of life.
	Grade 1	Bedridden and completely dependent on others.

Appendix 8 (cont.)

10	Range of Knee Motion		Extension		Flexion		
		Left					
		Right					
11	Knee Deformity		Varum	Valgus	Recarvatum		
		Left					
		Right					
12	Circumference Thigh Measure		4 cm	8cm	12cm	16cm	20cm
		Left					
		Right					
13	Leg Length		Thigh		Leg		
		Left					
		Right					
14	Medication						
15	Dose						

Contact Address:

Tel:

Appendix 9

Raw Data Sheet

Test No:.....

Date:.....
Time:.....
Day :.....

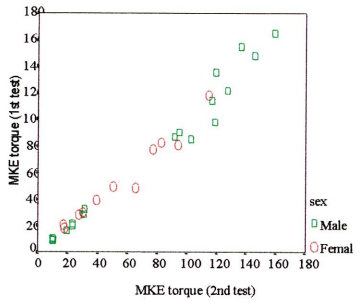
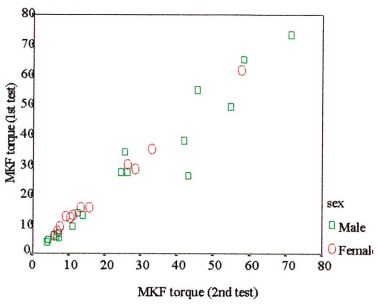
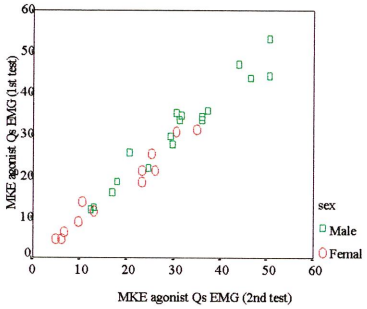
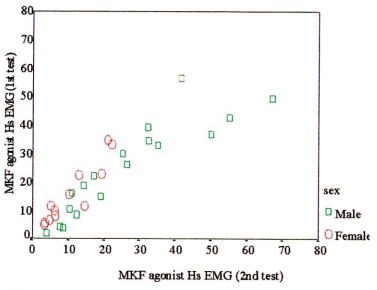
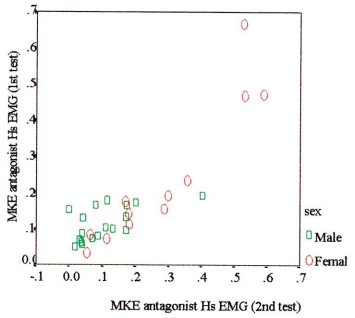
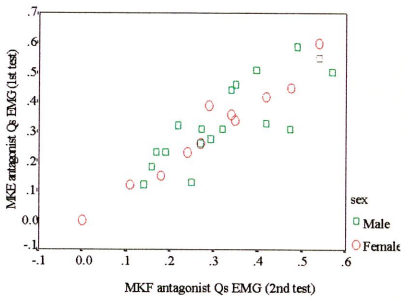
Name:..... Age:..... Sex: F/M

No	Muscle	MKE						SQC	SLR	TKE
		90		60		30				
		E	F	E	F	E	F			
L	VM									
	RF									
	VL									
	HL									
	HM									
	F									

No	Muscle	MKE						SQC	SLR	TKE
		90		60		30				
		E	F	E	F	E	F			
R	VM									
	RF									
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	HM									
	F									

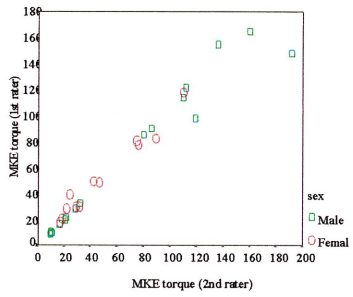
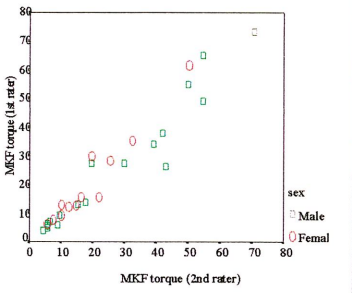
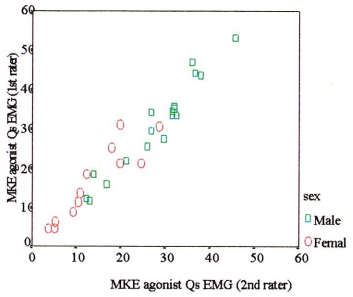
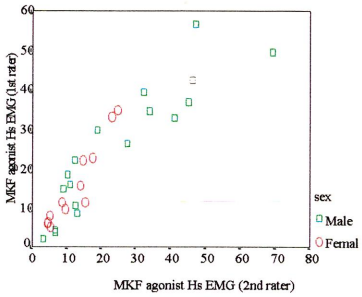
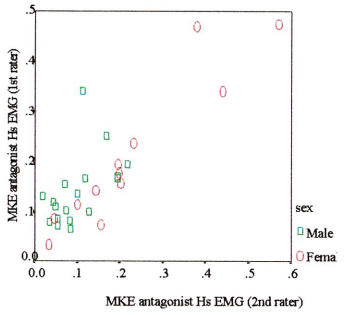
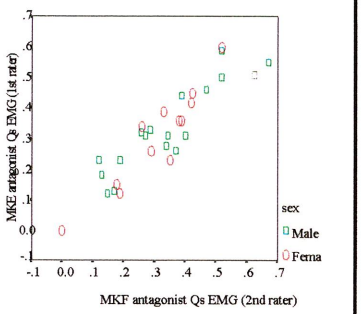
Appendix 10

Diagrams show intra-rater overall torque and myoelectrical activity during isometic knee extension (MKE) and flexion (MKF) in thirty knees of fifteen healthy subjects.

Intra-rater	Extension	Flexion
Torque (Nm)		
	r= 0.98, p< 0.001 Female (r= 0.98, p< 0.001), Male (r= 0.98, p< 0.001)	r= 0.97, p< 0.001 Female (r=0.96, p< 0.001), Male (r= 0.97, p< 0.001)
Agonist EMG (mV)		
	r= 0.97, p< 0.001 Female (r= 0.94, p< 0.001), Male (r= 0.96, p< 0.001)	r= 0.89, p< 0.001 Female (r= 0.92, p< 0.001), Male (r= 0.86, p< 0.001)
Antagonist EMG (Ratio)		
	r= 0.89, p< 0.001 Female (r= 0.89, p< 0.001), Male (r= 0.81, p< 0.001)	r= 0.80, p< 0.001 Female (r= 0.87, p< 0.001), Male (r= 0.78, p< 0.001)

Appendix 11

Diagrams show inter-rater overall torque and myoelectrical activity during isometic knee extension (MKE) and flexion (MKF) in thirty knees of fifteen healthy subjects.

Inter-rater	Extension	Flexion
Torque (Nm)	 r= 0.97, p< 0.0.001 Female (r= 0.98, p< 0.001), Male (r= 0.97, p< 0.001)	 r= 0.96, p< 0.001 Female (r= 0.97, p< 0.001), Male (r= 0.96, p< 0.001)
Agonist EMG (mV)	 r= 0.95, p< 0.001 Female (r= 0.91, p< 0.001), Male (r= 0.96, p< 0.001)	 r= 0.91, p< 0.001 Female (r= 94, p= 0.08), Male (r= 0.90, p< 0.001)
Antagonist EMG (Ratio)	 r= 0.85, p< 0.001 Female (r= 0.81, p< 0.001), Male (r= 0.70, p= 0.002)	 r= 0.79, p< 0.001 Female (r= 0.73, p= 0.6), Male (r= 0.77, p< 0.001)

Appendix 12

Comparison of the medians and ranges torques, and agonist myoelectrical activity (EMG) and antagonist coactivation index for individual muscles during maximum isometric knee extension and flexion between Squat Closed KCT, Open KCT, and control groups at baseline, and three and six weeks in patients with OA of the knee.

1- During maximum isometric knee extension:

a- Agonist Qs Muscle Myoelectrical Activity (mV):

		Agonist Vastus Medialis EMG (mV)						
Angles	Periods	Closed (n= 19)		Open (n= 21)		control (n=19)		P
		Median	Range	Median	Range	Median	Range	
30°	Baseline	5.30	1.85-14.31	5.70	0.53-35.51	3.71	1.06-9.08	0.07
	3 weeks	6.94	2.12-29.15	8.74	1.59-44.52	3.78	1.06-10.60	0.004
	6 weeks	7.42	4.77-25.97	8.22	2.65-53.00	4.24	0.80-9.01	0.002
60°	Baseline	4.24	0.26-7.95	3.97	0.53-27.56	3.18	1.06-12.19	0.3
	3 weeks	4.48	2.12-29.15	4.87	1.59-37.10	3.18	0.53-7.95	0.0008
	6 weeks	7.95	2.62-18.02	5.30	2.65-39.75	2.65	0.80-9.01	<0.0001
90°	Baseline	4.24	1.06-11.66	5.30	0.53-28.09	4.24	1.06-12.72	0.3
	3 weeks	5.30	1.59-15.37	6.89	1.59-41.34	3.18	1.06-10.60	0.002
	6 weeks	6.54	3.69-27.03	8.36	1.59-48.23	3.18	1.06-9.54	0.0001

*: statistically significant difference.

		Agonist Rectus Femoris EMG (mV)						
Angles	Periods	Closed (n= 19)		Open (n= 21)		control (n=19)		P
		Median	Range	Median	Range	Median	Range	
30°	Baseline	4.24	1.06-19.61	5.04	0.26-21.20	2.65	0.53-6.36	0.4
	3 weeks	4.77	1.59-19.61	7.42	1.06-27.03	2.65	0.53-6.89	0.3
	6 weeks	6.95	1.06-22.26	5.83	1.06-27.03	3.18	0.53-8.48	0.004
60°	Baseline	5.30	0.53-13.25	4.51	0.26-18.02	2.12	1.06-7.42	0.4
	3 weeks	5.83	1.59-18.55	4.74	1.06-18.55	2.65	1.06-6.24	0.0005
	6 weeks	7.42	1.59-24.91	6.10	1.59-23.32	3.18	0.53-7.95	0.002
90°	Baseline	4.24	1.06-15.37	4.77	0.53-18.02	2.12	0.53-6.89	0.3
	3 weeks	5.30	1.85-15.90	5.83	1.06-30.21	2.12	1.06-5.83	<0.0001
	6 weeks	7.42	2.24-23.09	8.81	1.06-22.79	2.65	1.32-5.83	<0.0001

*: statistically significant difference.

Appendix 12
(cont.)

Angles	Periods	Agonist Vastus Lateralis EMG (mV)						
		Closed (n= 19)		Open (n= 21)		control (n=19)		P
		Median	Range	Median	Range	Median	Range	
30°	Baseline	5.30	1.85-22.26	4.77	1.06-22.26	2.65	0.53-8.24	0.1
	3 weeks	5.83	2.65-26.50	7.02	1.59-26.50	3.18	0.53-10.60	<0.0001
	6 weeks	7.95	3.71-38.16	7.02	2.65-29.15	3.32	0.53-14.31	0.0003
60°	Baseline	4.24	1.06-14.31	3.45	0.53-13.78	2.65	0.53-13.25	0.1
	3 weeks	6.18	2.12-14.31	6.10	1.32-15.37	2.65	0.80-9.54	0.0009
	6 weeks	6.89	2.65-19.10	7.69	2.12-19.96	2.65	1.06-12.72	0.0004
90°	Baseline	4.77	2.06-21.20	5.28	1.06-22.26	3.18	0.26-11.13	0.5
	3 weeks	4.31	2.24-18.55	7.16	1.06-24.11	3.18	0.53-11.13	0.005
	6 weeks	6.36	2.12-23.66	8.36	2.65-34.45	2.65	0.53-12.19	0.0006

*: statistically significant difference.

b- Antagonist Hs Muscle Coactivation Indices (Ratio):

Angles	Periods	Antagonist Lateral Hamstring EMG (Ratio)						
		Closed (n= 19)		Open (n= 21)		control (n=19)		P
		Median	Range	Median	Range	Median	Range	
30°	Baseline	0.59	0.00-1.00	0.83	0.00-1.00	0.33	0.00-1.00	0.06
	3 weeks	0.58	0.00-1.00	0.50	0.00-1.00	0.67	0.22-1.00	0.3
	6 weeks	0.50	0.16-1.00	0.45	0.00-1.00	1.00	0.00-1.00	0.6
60°	Baseline	0.35	0.00-1.00	0.26	0.00-1.00	0.42	0.00-1.00	0.07
	3 weeks	0.50	0.08-1.00	0.17	0.00-0.42	0.33	0.00-1.00	0.01
	6 weeks	0.39	0.11-1.00	0.22	0.07-1.00	0.43	0.00-1.00	0.04
90°	Baseline	0.53	0.11-1.00	0.33	0.00-1.00	0.36	0.00-1.00	0.06
	3 weeks	0.51	0.00-1.00	0.22	0.00-1.00	0.33	0.00-1.00	0.05
	6 weeks	0.39	0.07-1.00	0.11	0.00-1.00	0.50	0.00-1.00	0.0006

*: statistically significant difference.

Appendix 12
(cont.)

Angles	Periods	Antagonist Medial Hamstring EMG (Ratio)						
		Closed (n= 19)		Open (n= 21)		control (n=19)		P
		Median	Range	Median	Range	Median	Range	
30°	Baseline	0.40	0.00-1.00	0.33	0.00-1.00	0.33	0.00-1.00	0.3
	3 weeks	0.29	0.00-1.00	0.30	0.00-1.00	0.36	0.00-1.00	0.8
	6 weeks	0.23	0.07-1.00	0.29	0.03-1.00	0.57	0.09-1.00	0.04
60°	Baseline	0.35	0.11-1.00	0.20	0.00-1.00	0.18	0.00-1.00	0.07
	3 weeks	0.29	0.00-1.00	0.30	0.00-0.42	0.36	0.00-1.00	0.8
	6 weeks	0.23	0.07-1.00	0.29	0.03-1.00	0.57	0.09-1.00	0.04
90°	Baseline	0.30	0.00-1.00	0.17	0.00-0.50	0.33	0.00-1.00	0.1
	3 weeks	0.23	0.06-0.75	0.20	0.00-0.50	0.24	0.00-1.00	0.3
	6 weeks	0.19	0.00-1.00	0.16	0.00-0.50	0.27	0.08-1.00	0.3

*: statistically significant difference.

2- During maximum isometric knee flexion:

a- Agonist Hs Muscle Myoelectrical Activity (mV):

Angles	Periods	Agonist Lateral Hamstring EMG (mV)						
		Closed (n= 19)		Open (n= 21)		control (n=19)		P
		Median	Range	Median	Range	Median	Range	
30°	Baseline	2.39	0.00-7.58	1.06	0.00-13.25	2.12	0.00-10.60	0.5
	3 weeks	2.39	0.00-9.01	2.65	0.00-14.31	2.12	0.00-8.21	0.1
	6 weeks	4.94	0.00-16.43	3.98	0.00-14.84	1.59	0.00-11.13	0.005
60°	Baseline	2.65	0.00-8.48	2.12	0.00-18.02	1.59	0.00-12.72	0.9
	3 weeks	3.54	0.00-13.78	2.92	0.00-22.26	1.59	0.00-16.43	0.08
	6 weeks	6.01	0.53-19.08	3.98	0.00-24.38	1.59	0.00-13.25	0.004
90°	Baseline	1.99	0.00-14.31	2.39	0.00-25.97	1.59	0.00-14.31	0.8
	3 weeks	2.92	0.00-7.42	4.51	0.00-30.21	1.85	0.00-26.50	0.04
	6 weeks	3.92	0.53-24.38	5.57	0.00-15.37	1.59	0.00-16.96	0.003

*: statistically significant difference.

Appendix 12
(cont.)

Agonist Medialis Hamstring EMG (mV)								
Angles	Periods	Closed (n= 19)		Open (n= 21)		control (n=19)		P
		Median	Range	Median	Range	Median	Range	
30°	Baseline	2.12	0.53-19.61	2.65	0.26-22.26	3.71	0.26-13.43	0.6
	3 weeks	4.51	1.06-14.84	3.84	0.53-20.93	3.18	0.00-10.60	0.03
	6 weeks	5.92	0.26-15.90	5.57	0.53-30.21	2.65	0.00-12.19	0.03
60°	Baseline	2.65	0.26-19.61	4.51	0.53-38.16	3.71	0.53-15.37	0.2
	3 weeks	5.57	1.06-25.97	6.89	0.80-28.09	3.18	0.26-11.13	0.02
	6 weeks	7.95	0.53-17.43	6.10	0.26-25.97	2.65	0.26-13.51	0.09
90°	Baseline	2.65	0.53-24.38	5.04	0.26-30.74	3.44	0.00-18.55	0.3
	3 weeks	5.83	0.26-27.56	7.16	0.00-41.87	4.24	0.53-22.52	0.04
	6 weeks	6.10	1.06-23.85	7.69	0.00-36.57	2.12	0.53-20.67	0.009

*: statistically significant difference.

b- Antagonist Qs Muscle Coactivation Indices (Ratio):

Antagonist Vastus Medialis EMG (Ratio)								
Angles	Periods	Closed (n= 19)		Open (n= 21)		control (n=19)		P
		Median	Range	Median	Range	Median	Range	
30°	Baseline	0.09	0.00-0.42	0.02	0.00-1.00	0.06	0.00-0.86	0.1
	3 weeks	0.07	0.00-0.38	0.04	0.00-0.67	0.14	0.00-0.67	0.8
	6 weeks	0.12	0.00-0.56	0.05	0.00-0.60	0.11	0.00-0.67	0.3
60°	Baseline	0.14	0.00-1.00	0.00	0.00-1.00	0.00	0.00-0.53	0.06
	3 weeks	0.09	0.00-0.71	0.03	0.00-0.33	0.00	0.00-1.00	0.02
	6 weeks	0.13	0.00-1.00	0.05	0.00-0.33	0.00	0.00-1.00	0.1
90°	Baseline	0.11	0.00-0.71	0.07	0.00-1.00	0.00	0.00-0.57	0.07
	3 weeks	0.13	0.00-0.43	0.02	0.00-0.17	0.00	0.00-0.75	0.008
	6 weeks	0.12	0.00-0.70	0.06	0.00-0.25	0.04	0.00-1.00	0.02

*: statistically significant difference.

Appendix 12
(cont.)

Angles	Periods	Antagonist Rectus Femoris EMG (Ratio)						
		Closed (n= 19)		Open (n= 21)		control (n=19)		P
		Median	Range	Median	Range	Median	Range	
30°	Baseline	0.05	0.00-0.40	0.00	0.00-0.50	0.00	0.00-0.33	0.2
	3 weeks	0.03	0.00-0.50	0.01	0.00-0.50	0.03	0.00-1.00	0.8
	6 weeks	0.04	0.00-0.55	0.02	0.00-0.44	0.00	0.00-0.17	0.04
60°	Baseline	0.00	0.00-1.00	0.00	0.00-0.40	0.00	0.00-0.50	0.1
	3 weeks	0.03	0.00-0.60	0.00	0.00-1.00	0.00	0.00-0.25	0.02
	6 weeks	0.06	0.00-0.50	0.00	0.00-0.20	0.00	0.00-0.30	0.06
90°	Baseline	0.00	0.00-1.00	0.00	0.00-1.00	0.00	0.00-0.25	0.2
	3 weeks	0.04	0.00-0.73	0.00	0.00-1.00	0.00	0.00-0.67	0.6
	6 weeks	0.07	0.00-0.50	0.00	0.00-0.20	0.00	0.00-1.00	0.05

*: statistically significant difference.

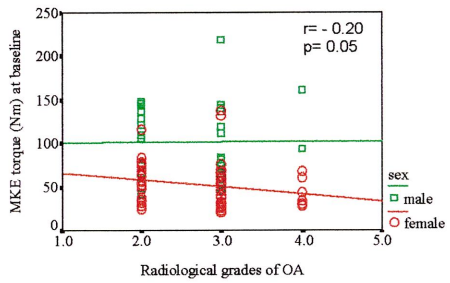
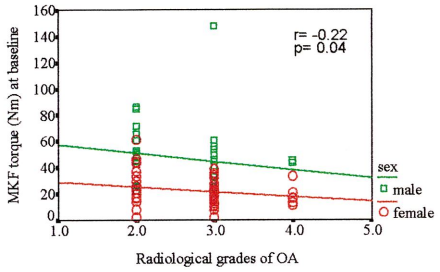
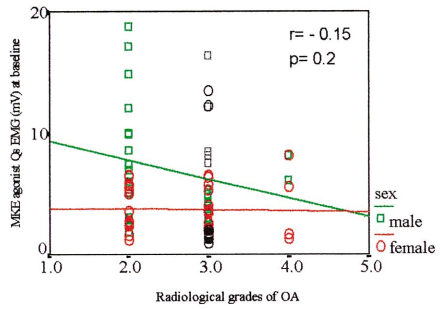
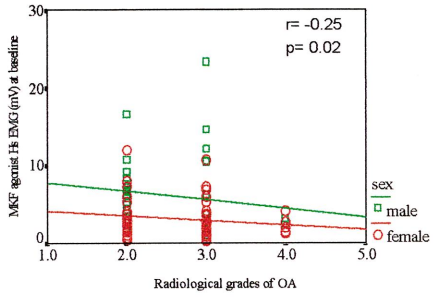
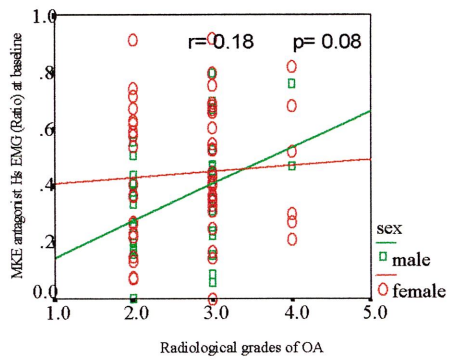
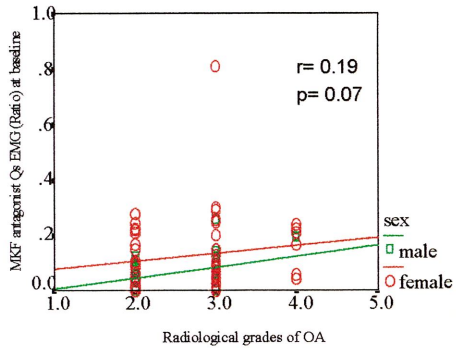
Angles	Periods	Antagonist Vastus Lateralis EMG (Ratio)						
		Closed (n= 19)		Open (n= 21)		control (n=19)		P
		Median	Range	Median	Range	Median	Range	
30°	Baseline	0.09	0.00-0.28	0.00	0.00-0.56	0.00	0.00-0.20	0.3
	3 weeks	0.06	0.00-0.41	0.02	0.00-0.67	0.07	0.00-0.93	0.8
	6 weeks	0.06	0.00-0.60	0.03	0.00-0.50	0.00	0.00-0.33	0.9
60°	Baseline	0.08	0.00-1.00	0.00	0.00-1.00	0.00	0.00-0.53	0.2
	3 weeks	0.07	0.00-0.75	0.00	0.00-0.75	0.00	0.00-0.40	0.1
	6 weeks	0.06	0.00-0.60	0.03	0.00-0.50	0.00	0.00-0.33	0.9
90°	Baseline	0.09	0.00-0.56	0.01	0.00-1.00	0.00	0.00-0.20	0.08
	3 weeks	0.08	0.00-0.80	0.00	0.00-1.00	0.00	0.00-0.57	0.03
	6 weeks	0.05	0.00-0.47	0.02	0.00-0.33	0.07	0.00-0.61	0.1

*: statistically significant difference.

Appendix 13

Scatter plot graphs showing the relationship between the degree of radiographic knee OA and the overall torques, agonist myoelectrical activity, and antagonist coactivation index during maximum isometric knee extension (MKE) and flexion (MKF) at 30, 60, and 90 degrees in all patients at baseline session. These graphs illustrate that:

1- a corresponding regression lines are shown in men (green line) and women (red line).
2- the radiographic grading is weakly related with torque and EMG.
3- the reduced torques in more severe grades of OA are accompanied with reduced amplitudes of EMG agonist muscles.
4- men are shown to develop stronger torques and larger EMG amplitude in agonist muscles than women, but the antagonist coactivation index is similar in men and women.

	Extension	Flexion
Torques (Nm)	 Female (r= -0.29, p= 0.03), Male (r= -0.03, p= 0.8)	 Female (r= -0.16, p= 0.2), Male (r= -0.31, p= 0.07)
Agonist EMG (mV)		 Female (r= -0.16, p= 0.3), Male (r= -0.34, p= 0.04)
Antagonist EMG (Ratio)		

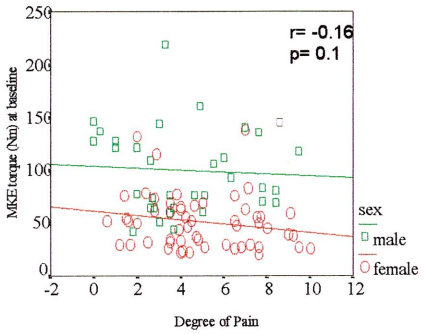
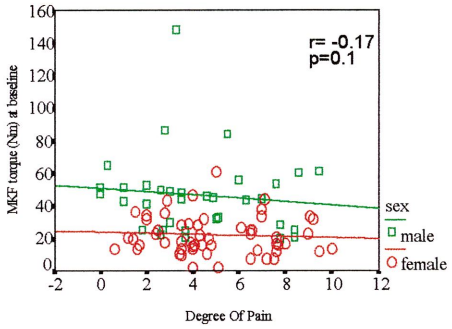
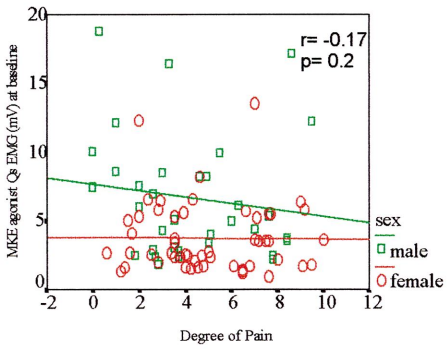
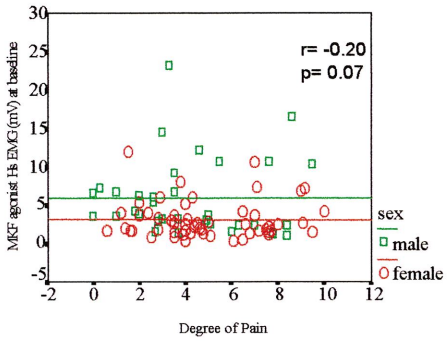
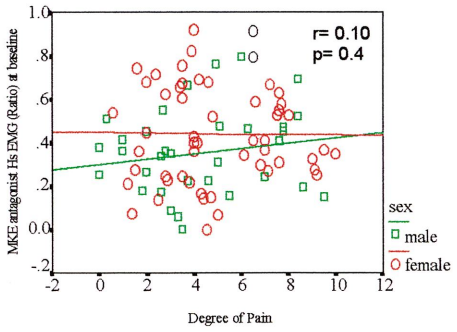
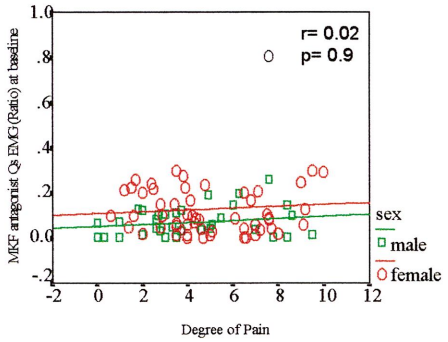
Appendix 14

Scatter plot graphs showing the relationship between the intensity of pain and the overall torques, agonist myoelectrical activity, and antagonist coactivation index during maximum isometric knee extension (MKE) and flexion (MKF) at 30, 60, and 90 degrees in all patients at baseline session. These graphs illustrate that:

3- a corresponding regression lines are shown in men (green line) and women (red line).

2- while men develop greater torques and agonist myoelectrical activity than women at all levels of perceived pain, there is no statistically significant relationship between pain and torques and myoelectrical activity.

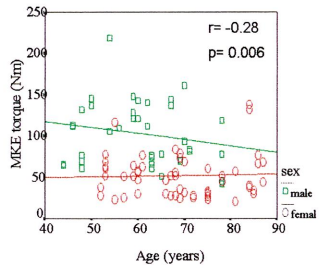
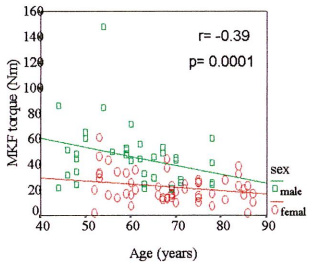
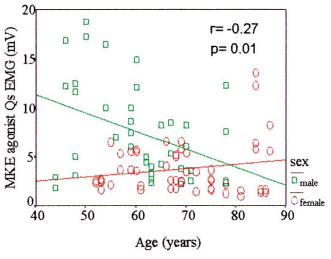
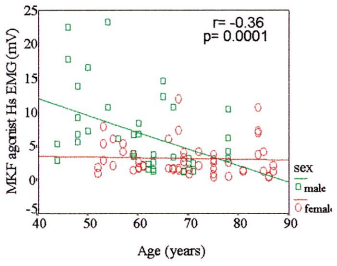
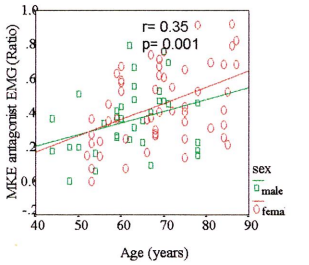
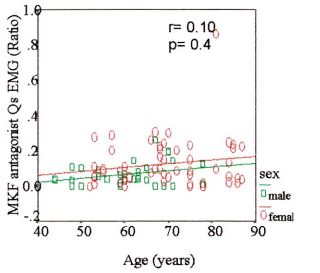
3- the antagonist coactivation indices do not reflect the level of pain experienced.

	Extension	Flexion
Torques (Nm)		
Agonist EMG (mV)		
Antagonist EMG (Ratio)		

Appendix 15

Scatter plot graphs showing the relationship between age and the overall torques, agonist myoelectrical activity, and antagonist coactivation index during maximum isometric knee extension (MKE) and flexion (MKF) at 30, 60, and 90 degrees in patients with OA of the knee at baseline session.

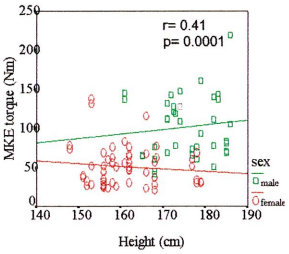
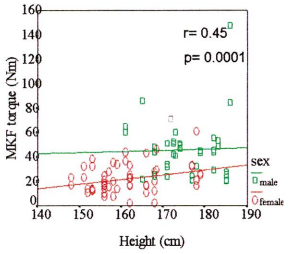
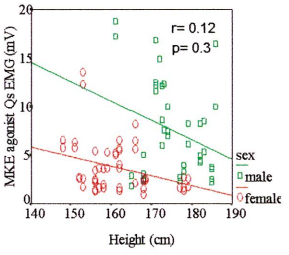
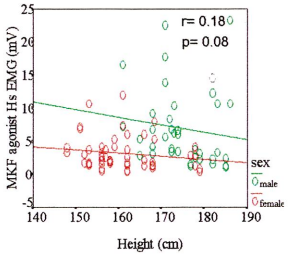
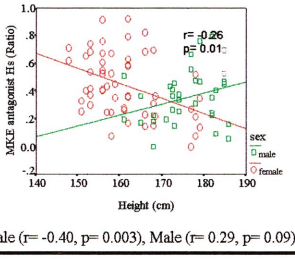
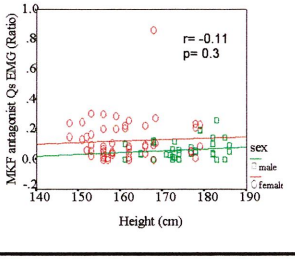
1- a corresponding regression lines are shown in men (green line) and women (red line).
2- age is weakly related with torques, agonist myoelectrical activity, and antagonist coactivation index.
3- the reduced torques and agonist myoelectrical activity are observed with increasing age.
4- the antagonist coactivation indices increase with increasing age.
5- men are shown to develop stronger torques than women.

	Extension	Flexion
Torque (Nm)	 Female (r= 0.03, p= 0.8), Male (r= -0.19, p= 0.2)	 Female (r= -0.23, p= 0.08), Male (r= -0.29, p= 0.07)
Agonist EMG (mV)	 Female (r= 0.18, p= 0.08), Male (r= -0.38, p= 0.02)	 Female (r= -0.5, p= 0.7), Male (r= -0.43, p= 0.006)
Antagonist EMG (Ratio)	 Female (r= 0.32, p= 0.02), Male (r= 0.28, p= 0.1)	

Appendex 16

Scatter plot graphs showing the relationship between height and the overall torques, agonist myoelectrical activity, and antagonist coactivation index during maximum isometric knee extension (MKE) and flexion (MKF) at 30, 60, and 90 degrees in patients with OA of the knee at baseline session.

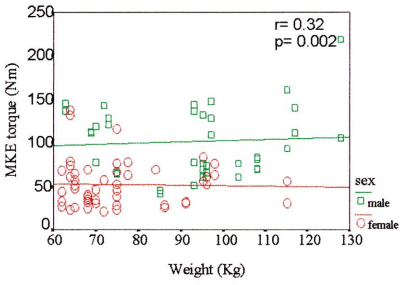
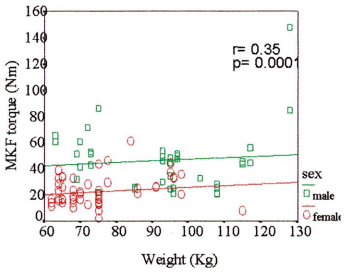
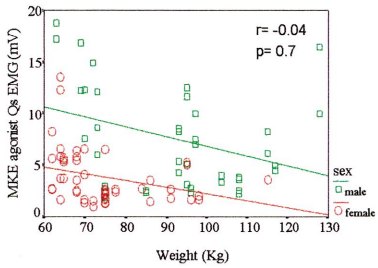
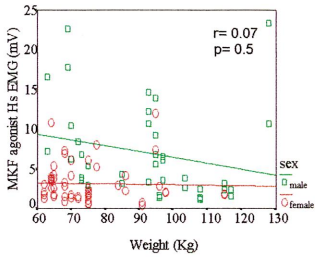
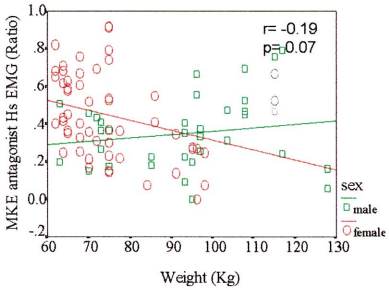
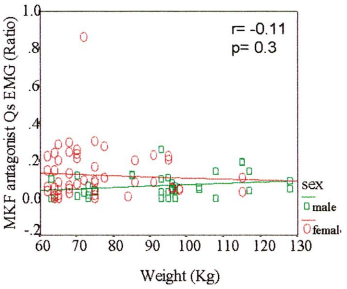
1- a corresponding regression lines are shown in men (green line) and women (red line).
2- the height is weakly related with torques, agonist myoelectrical activity, and antaginist coactivation index.
3- men are shown to develop stronger torques and larger EMG amplitude in the agonist muscles than women.

	Extension	Flexion
Torque (Nm)	 Female (r= -0.10, p= 0.4), Male (r= 0.11, p= 0.5)	 Female (r= 0.29, p= 0.03), Male (r= 0.03, p= 0.9)
Agonist EMG (mV)		
Antagonist EMG (Ratio)	 Female (r= -0.40, p= 0.003), Male (r= 0.29, p= 0.09)	

Appendix 17

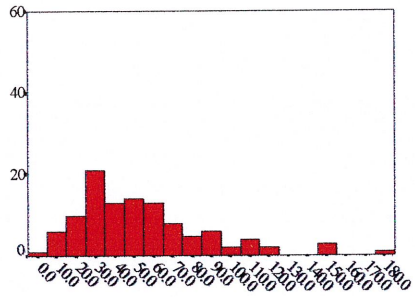
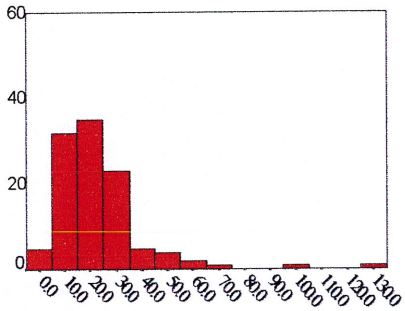
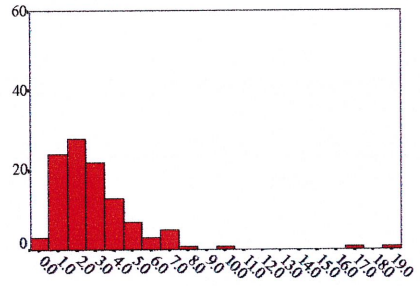
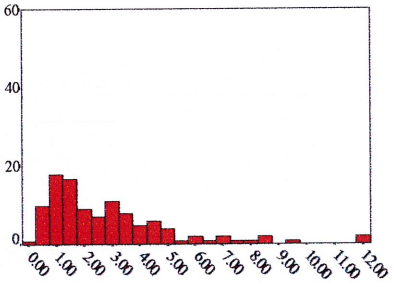
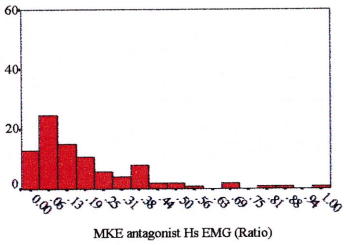
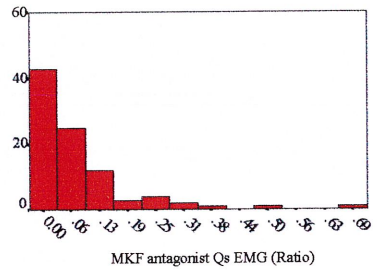
Scatter plot graphs showing the relationship between body weight and the overall torques, agonist myoelectrical activity, and antagonist coactivation index during maximum isometric knee extension (MKE) and flexion (MKF) at 30, 60, and 90 degrees in patients with OA of the knee at baseline session.

1- a corresponding regression lines are shown in men (green line) and women (red line).
2- weight is weakly related with torques, agonist myoelectrical activity, and antagonist coactivation index.
3- men are shown to develop stronger torques and larger EMG amplitude in agonist muscles than women.

	Extension	Flexion
Torque (Nm)	 Female (r= -0.03, p= 0.8), Male (r= 0.06, p= 0.7)	 Female (r= 0.15, p= 0.3), Male (r= 0.10, p= 0.6)
Agonist EMG (mV)		
Antagonist EMG (Ratio)		

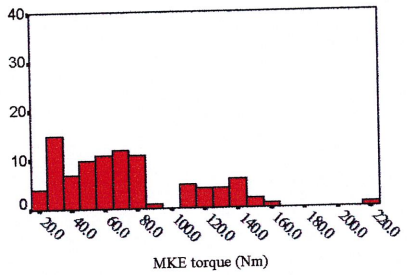
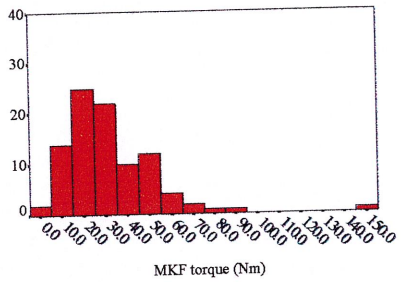
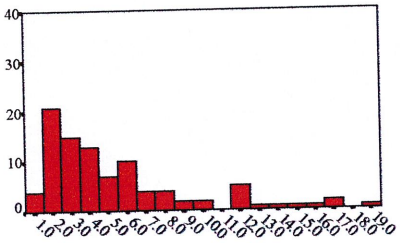
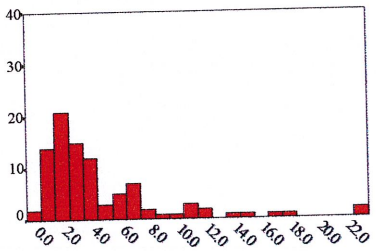
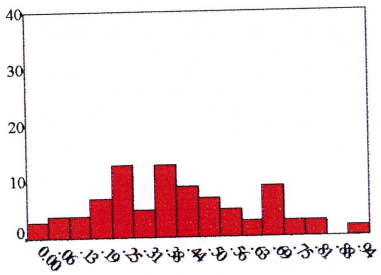
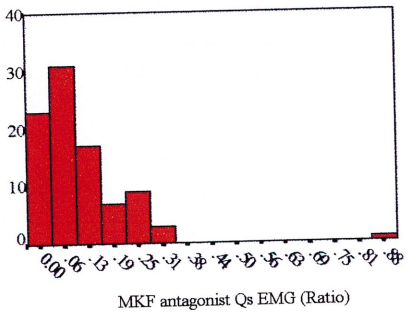
Appendix 18

Histogram showing the distribution of the values of torque (Nm), agonist myoelectrical activity (mV), and antagonist coactivation index (Ratio) during maximum isometric knee extension and flexion in healthy subjects and patients with OA of the knee (chapter six).

	Extension	Flexion
Torque (Nm)		
Agonist EMG (mV)		
Antagonist EMG (Ratio)		

Appendix 19

Histogram showing the distribution of the overall torques (Nm), agonist myoelectrical activity (mV), and antagonist coactivation index (Ratio) during maximum isometric knee extension (MKE) and flexion (MKF) in all patients with OA of the knee at baseline (prospective study).

	Extension	Flexion
Torque (Nm)	 1	 2
Agonist EMG (mV)	 3	 4
Antagonist EMG (Ratio)	 5	 6

1: MKE torque.
2: MKF torque.
3: MKE agonist Qs.
4: MKF agonist Hs.
5: MKE antagonist Hs.
6: MKF antagonist Qs.