

**DYNAMOMETRY OF THE KNEE EXTENSORS;  
ISOMETRIC AND ISOKINETIC TESTING  
IN HEALTHY SUBJECTS AND PATIENTS.**

**(Krachtmeten van de kniestickekkers;  
isometrische en isokinetische tests  
bij gezonden en patienten).**

PROEFSCHRIFT

TER VERKRIJGING VAN DE GRAAD VAN DOCTOR

AAN DE ERASMUS UNIVERSITEIT ROTTERDAM

OP GEZAG VAN DE RECTOR MAGNIFICUS

PROF.DR. C.J. RIJNVOS

EN VOLGENS BESLUIT VAN HET COLLEGE VAN DEKANEN.

DE OPENBARE VERDEDIGING ZAL PLAATSVINDEN OP

WOENSDAG 3 JANUARI 1990 OM 15.45 UUR.

door

**Hendrik Jan Stam**

geboren te Rotterdam

## PROMOTIECOMMISSIE

PROMOTOR: Prof. B.D. Bangma  
PROMOTOR: Prof.Dr. R.A. Binkhorst  
OVERIGE LEDEN: Prof.Dr.Ir. C.J. Sijders  
Prof. R. van Strik

De uitgave van dit proefschrift is mede tot stand gekomen door een subsidie van de Nederlandse Vereniging voor Reumabestrijding.

## CONTENTS

ABBREVIATIONS.	6	
CHAPTER 1	GENERAL INTRODUCTION AND PURPOSE OF THE STUDY.	
1.1	Introduction.	7
1.2	Manual strength testing.	8
1.3	Isometric strength testing.	9
1.4.1	Isotonic strength testing.	10
1.4.2	Isokinetic strength testing.	11
1.5	The object of strength testing.	15
1.6	Factors influencing strength testing.	17
1.7	Relationship between results of strength testing and functional variables.	18
1.8	Aim and general design of the study.	19
1.9	References.	22
CHAPTER 2	THE QUADRICEPS DYNAMOMETER: DESIGN AND TORQUE ANGLE CURVES.	
2.1	General design and use of the Q.D.	29
2.2	Isometric and isokinetic dynamometry with the Q.D.	31
2.3	Torque angle curves of the Q.D. and the Cybex II.	
2.3.1	Introduction.	32
2.3.2	Materials and methods.	36
2.3.3	Results.	37
2.3.4	Discussion.	38
2.4	The influence of angular velocity and starting position.	
2.4.1	Introduction.	40
2.4.2	Materials and methods.	41
2.4.3	Results.	42
2.4.4	Discussion.	44
2.5	References.	51

CHAPTER 3	ISOMETRIC AND ISOKINETIC DYNAMOMETRY: VARIABILITY AND SPECIFICITY.	
3.1	Introduction.	53
3.2	Materials and methods.	54
3.3	Results.	56
3.4	Discussion.	58
3.5	References.	62
CHAPTER 4	DYNAMOMETRY OF THE KNEE EXTENSORS OF MENISCECTOMY PATIENTS.	
4.1	Introduction.	64
4.2	Materials and methods.	64
4.3	Results.	68
4.4	Discussion.	79
4.5	References.	88
CHAPTER 5	A FOLLOW-UP STUDY OF MENISCECTOMY OF THE KNEE.	
5.1	Introduction.	91
5.2	Materials and methods.	92
5.3	Results.	93
5.4	Discussion.	97
5.5	References.	100
CHAPTER 6	MUSCLE STRENGTH IMPAIRMENT AND DISABILITY IN GUILLAIN-BARRÉ PATIENTS.	
6.1	Introduction.	102
6.2	Materials and methods.	103
6.3	Results.	104
6.4	Discussion.	107
6.5	References	109

GENERAL DISCUSSION.	110
SUMMARY.	113
SAMENVATTING.	117
APPENDIX I. Technical note.	121
APPENDIX II. Training programme.	125
CURRICULUM VITAE.	127

## **Abbreviations.**

- C.V. - Coefficient of Variation
- Degr. - Degree(s)
- G.B. - Guillain-Barré
- N - Newton
- Nm - Newtonmeter
- M.t.j.p. - Maximal torque joint position
- Q.D. - Quadriceps Dynamometer
- Q.R. - Quadriceps Ratio
- R.M. - Repetition maximum
- R.o.m. - Range of motion
- Sec. - Second(s)
- S.D. - Standard Deviation

## CHAPTER 1.

### GENERAL INTRODUCTION AND PURPOSE OF THE STUDY.

#### 1.1. Introduction.

In the classical medical model of illness the concept of disease is symbolically depicted as a sequence:

ETIOLOGY → PATHOLOGY → MANIFESTATION.

In rehabilitation medicine however, this approach is incomplete because it stops short of the consequences of disease. Especially in chronic and progressive or irreversible disorders the sequence is more extended and may be presented as:

DISEASE → IMPAIRMENT → DISABILITY → HANDICAP.

Impairments are abnormalities or losses of body structures or system functions and they represent disturbances at the organ level.

Disabilities reflect the consequences of impairment in terms of functional performance and activities and thus represent disturbances at the level of the person.

Handicap is a more complex concept and relates to the disadvantages experienced by the individual as a result of impairments and disabilities (W.H.O. 1980).

In rehabilitation medicine the main purpose is to prevent handicaps by intervention on both the impairment and the disability level.

Loss of muscle strength is one of the many impairments resulting from neuromuscular diseases, trauma or prolonged inactivity and may therefore cause serious disabilities and handicaps.

When in a rehabilitation program the increase of muscle strength is prescribed one needs to establish the extent of muscle weakness and to follow the effect of therapy by means of frequent strength tests. Several methods of strength testing have been developed and are used in clinical practice as well as for research purposes. These methods may be classified on the basis of the physiological definition of the type of muscle contraction (e.g. isometric, isotonic, isokinetic) or the method used to measure the strength of the muscle contraction (e.g. manual, training equipment and dynamometers).

The restrictions of manual strength testing have led to the development of other methods and therefore manual strength testing will be discussed first. Subsequently, isometric, isotonic and isokinetic strength testing will be described. Other relevant aspects, like the object of strength testing, influences on the reliability of the measurements and the practical value are also discussed.

At the end of chapter 1 the purpose of this thesis is formulated and the contents of the following chapters are described.

## 1.2 Manual strength testing.

Manual strength tests are frequently used in clinical practice and are an essential part of general physical examinations (Licht 1965).

The main advantage of a manual test is the fact that it provides a quick global assessment of strength (Westers 1982). A dynamometer is not needed and the subject can be tested wherever and whenever wished by the examiner (Rompe 1972).

In manual muscle testing the principles of gravity and applied external load (by the examiner) are used to determine the ability of a subject to develop muscle tension voluntarily (Lamb 1985). The patient is requested to move a limb segment against gravity through the complete range of motion against an external load. This type of contraction of the muscle tested is in fact isotonic.

It should be emphasized that *in vivo* the muscle strength testing is an indirect measurement. This applies not only to manual tests, but also to the isotonic, isometric and isokinetic types of strength testing described in the following paragraphs. The real force a muscle develops can only be assessed *in vitro* with isolated muscles.

The force of the knee extensors for example is transferred through the patella and patellar ligament to the tibia. The perpendicular distance between the knee axis and the line indicating the direction of the knee extension force is the moment arm. Thus muscle strength of the knee extensors can only be measured as a torque i.e. the product of force and moment arm (Smidt and Rogers 1982). This means that the external manifestation of muscle force largely depends on the biomechanical characteristics of the joint involved.

A well-known and frequently used manual test is the scale of the Medical Research Council (M.R.C. 1975). This scale has proven its value in clinical practice and is described in table 1.1.

*Table 1.1* M.R.C. scale for manual strength testing.

- 0 = no contraction.
- 1 = flicker or trace of contraction.
- 2 = active movement with gravity eliminated.
- 3 = active movement against gravity.
- 4 = active movement against gravity and resistance.
- 5 = normal strength.

A major disadvantage of the M.R.C. scale is the large distance between each grade and the impossibility to detect small changes in strength (Rompe 1972). Kendall et al. (1972) noted that a more detailed grading is important, especially in determining a prognosis. They used a percentual scale with much smaller steps than those of the M.R.C. scale.

Another disadvantage of most manual grading scales is the fact that gravity is used. The strength required to move a limb through a full range against gravity, expressed as a percentage of normal strength, is different for all muscle groups (v.d. Ploeg et al. 1984).

The subjectivity of the examiner, who applies the external load to the limb, is a source of variability. The perception of a force is the mental integration of the product of force and time. A stronger contraction exerted for a short time may appear weaker than a weaker contraction sustained for a longer period of time (Westers 1982).

Finally, in manual muscle testing much attention has to be paid to proper positioning, stabilisation and the way in which the external forces are applied. This makes it rather difficult to compare the results of different examiners. Furthermore, it negatively influences the reliability of the tests.

Manual muscle testing is a valuable tool for the clinical assessment of patients with muscle weakness, but it is not useful for research purposes or when smaller strength changes have to be detected. As a result other strength testing methods have been developed using strength training equipment or specially designed dynamometers.

### **1.3 Isometric strength testing.**

Isometric strength measurement became popular mainly in relation to the disadvantages of the isotonic testing methods (Hettinger 1961; Rompe 1972). The movement of the body segment, the length of the muscle and the biomechanical circumstances of the involved joint remain constant during the isometric contraction. Most isometric devices are provided with means and instructions to guarantee an exact positioning and immobilisation of the subject in order to prevent compensating movements of other muscles.

Compared with isotonic strength tests isometric dynamometry is a quick and accurate method (Westers 1982) and the variability is acceptable in healthy subjects as well as in patients (Wiles and Karni 1983).

Normal values have been established based upon the study of large groups of healthy subjects and a variety of athletes (Vos 1976).

A possible disadvantage of isometric tests is that strength is only measured at one position in the range of motion. If the examiner wants to study strength through the complete range of motion several isometric contractions have to be performed at different joint positions (Williams and Stutzman 1959).

A review of all instruments designed to measure isometric strength is not within the scope of this study and would fill a volume all by itself. For further reading we refer to Mayhew and Rothstein (1985) who recently discussed the design, reliability and validity of instruments based upon the principles of the cable tensiometer and the strain gauge devices.

During the past decade complicated instruments, like for example the hydraulic isometric force testing unit of Mendler (1972) and the apparatus described by Hook and Tornvall (1969) were made more or less redundant and out of date by the introduction of instruments which combine measurement of isometric and dynamic strength in one apparatus.

Simple hand-held dynamometers are cheap and still frequently used in clinical practice. They are especially useful in the evaluation of muscle force in patients with progressive neurological diseases. Their reliability is acceptable when the examination is performed under standardized conditions (v.d. Ploeg et al. 1984; Hyde 1985).

The usefulness of the hand-held dynamometers is limited by the strength of the examiner in resisting the contractions of the patient's muscles. For this reason the hand-held instruments are not suitable for measuring minor degrees of weakness in adults (Edwards and Hyde 1977).

The general use and the popularity of isometric instruments diminished since isokinetic dynamometers became commercially available. These isokinetic dynamometers measure strength under dynamic conditions which is considered more physiological than an isometric contraction.

Up to the present it is not clear whether this apparent disadvantage of isometric dynamometry results in a lower predictive validity. In other words, it is not yet known whether isometric strength tests are less useful in predicting functional performance.

#### **1.4.1 Isotonic strength testing.**

Isotonic strength testing is in fact a general term for a whole range of tests performed under dynamic circumstances.

In an isotonic contraction the resistance that is offered to the moving body segment remains constant during the entire motion (Hislop and Perrine 1967). In most isotonic testing this resistance consists of free weights (dumb bells or bar bells) or weights integrated in a machine which is used for isotonic exercises as well.

Isotonic strength is usually expressed as a 'repetition maximum' (R.M.). For example: 5 R.M. = 50 kg means that a certain muscle or muscle group can move not more than 50 kg through the whole range of motion (r.o.m.) in 5 consecutive contractions.

There are some major disadvantages in isotonic strength testing:

- to find the maximal weight (to determine an R.M.) a trial and error procedure has to be followed. This may take a variable amount of time and thus introduces a source of variability e.g. by causing fatigue.
- the force a muscle can exert varies with the speed of the contraction. In isotonic testing however, the velocity of the contraction is not registered and cannot be influenced. This negatively affects the reliability of isotonic tests (Westers 1982).
- the performance of a muscle also depends on the length of the muscle and the biomechanical conditions of the involved joint. For example: the knee extensors can exert less force at the beginning and the end of their r.o.m. In the middle part the length of the muscles and the biomechanical circumstances of the knee joint will result in a larger force production (Hislop and Perrine 1967; Williams and Stutzman 1959). In isotonic testing, however, strength is determined by the maximal weight a muscle can move through the full r.o.m. Thus strength of the knee extensors in the middle part of the r.o.m. is underestimated.
- strength testing with weights results in many compensating movements produced by other muscle groups. Proper positioning of the subject and immobilisation of other body segments is not easy and therefore often neglected. Isotonic dynamometers have been developed for strength testing only. These dynamometers meet with most disadvantages of testing with free weights or training equipment.

A possible advantage of isotonic testing is the fact that the machines and weights that are used for strength training can be used for testing as well. From this point of view isotonic testing is relatively cheap and easily applicable.

#### **1.4.2 Isokinetic strength testing.**

An isokinetic contraction is strictly speaking a dynamic contraction. The special feature of an isokinetic contraction is that the speed of the moving body segment is held constant without regard to the force exerted by the subject. This can only be achieved by special devices.

In 1967 Hislop and Perrine introduced the concept of isokinetic exercise. Thistle et al. (1967) reported that the isokinetic apparatus, in addition to its use as an exercise device, could be used in measurement of muscle performance as well. In this paragraph only the application of the isokinetic apparatus as an instrument for measurement of muscle strength, a dynamometer, will be described.

## Cybex II.

The instrument most frequently used nowadays is the Cybex II, which consists of an electronic servomotor controlling a movable lever arm. The lever arm movement can be set for angular velocities from 0 to 300 degr./sec. (note 1). The lever arm is attached to a subject's limb. The subject is then asked to move as fast as possible and to attempt to accelerate beyond the preset speed. This is, however, not possible because the machine is designed to maintain limb movements at a constant preselected angular velocity.

In isokinetic dynamometry torque (Nm), joint position (degrees) and sometimes angular velocity (degr./sec.) are measured.

The relationship between torque and joint position can be presented by a torque angle curve, as shown in figure 1.1. Such a torque angle curve can be obtained at each preselected angular velocity.

The most frequently used parameter of the torque angle curve is maximal torque. The angle in the range of motion (r.o.m.) where maximal torque occurs is called maximal torque joint position (m.t.j.p.). In fact work (expressed as force x distance or torque x angular displacement) or power (expressed as work/time) are probably better parameters than maximal torque alone, because work and power reflect muscle performance throughout the r.o.m., whereas maximal torque only represents the performance at one joint position. A reason not to use work as a parameter is that several authors report high correlation coefficients between maximal torque and work or power (Moffroid and Kusiak 1975; Rothstein et al. 1983).

## Quadriceps Dynamometer.

The dynamometer used in this study is the Q.D. (Quadriceps Dynamometer). This instrument was designed to measure isometric, isokinetic and isotonic contractions and therefore some technical features differ from the Cybex II dynamometer (Pronk and Niesing 1983).

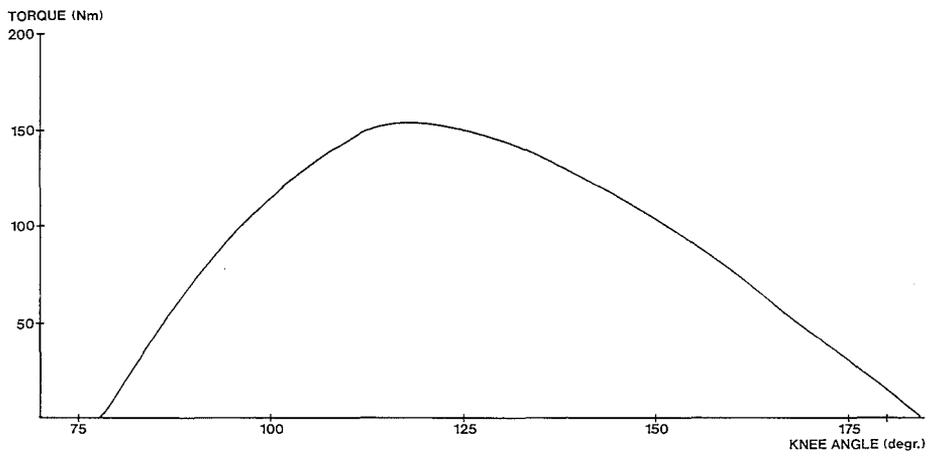
The principles of calculations of torque, the position of the subject on the dynamometer and the alignment of the axis of rotation (of the machine and the involved joint) are essentially the same in both dynamometers.

An example of a torque angle curve obtained with the Q.D. is presented in figure 1.2.

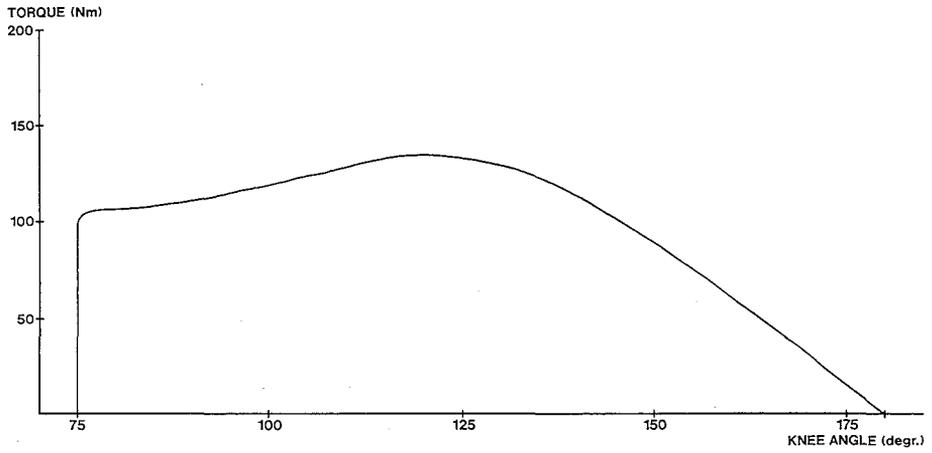
It is clear that the shape of the curves of the Cybex II and the Q.D. show some striking differences. It is expected that the differences in design will influence important parameters like maximal torque, m.t.j.p. and work as well.

Another point of interest is that a comparison and analysis of both curves may illu-

Note 1: For convenience of the reader angular velocity will be expressed as degr./sec. instead of rad./sec.  
(360 degr. =  $2\pi$  rad.).



*Fig. 1.1 Example of a torque angle curve of the Cybex II.*



*Fig. 1.2 Example of a torque angle curve of the Q.D.*

strate how these curves are generated and this may contribute to a better understanding and interpretation of isokinetic torque measurements.

### 1.5 The object of strength testing.

Muscle strength testing with isometric and isokinetic dynamometers is most frequently used during the rehabilitation of traumatological, neuromuscular and joint disorders.

Dynamometry is used for preseason assessment of muscle strength of athletes, to follow the results of training or therapy and to evaluate the effectiveness of different modes of exercise.

The high incidence of knee joint injuries has stimulated the study of strength of the knee extensors and flexors. The relationship between maximal torque of the knee flexors and the knee extensors is usually reported as the flexion to extension ratio and expressed as a percentage. The flexion to extension ratios found by different authors range from 45% to 80% (Gilliam et al. 1979; Moffroid et al. 1969; Molnar and Alexander 1974; Grace et al. 1984). Some authors note that a discrepancy, between the anticipated and the actual flexion to extension ratio, predisposes to knee joint injury (Gilliam et al. 1979; Steele 1980; Coplin 1971; Slagle 1979; Burnie and Brodie 1986).

Unfortunately, hardly any normal or reference values are known and the ratios reported seem to depend to a large extent on age, sex, athletic activity, speed of testing, etc.

An imbalance (i.e. a difference between right and left) of maximal torque of the knee extensors is also considered to be related to an increased risk of knee joint injuries. Some authors recommend extra strength training as long as this imbalance exceeds 10% (Coplin 1971; Slagle 1979). Elliott (1978) recommends isokinetic dynamometry in diagnosing the extent of injuries and in determining when an athlete can return to competition. A strength difference of more than 10% indicates a defect in the injured limb.

Up to the present only one study describes a prospective evaluation of isokinetic muscle testing as a method to identify risks for joint injuries. Grace et al. (1984) determined flexion to extension ratios and right/left knee extension torque differences in 172 football players in a preseason test. They did not find a consistent pattern or a relationship between an existing preseason imbalance and a subsequent injury.

Several authors recommend isometric or isokinetic dynamometry for the comparison of different strength training methods (Lindh 1979; Delateur et al. 1972; Moffroid et al. 1969; Grimby et al. 1973; Wilmore 1979; Coyle et al. 1971; Adeyanyu et al. 1983; Pavone and Moffat 1985).

Nordesjö and Norgren (1978) point out that measuring the performance of the muscular system is useful in vocational guidance and transfer to other employ-

ment. The results of muscle strength assessment can be used to design the work or equipment in order to meet the operator's capabilities, or to select suitable personnel.

Arvidsson et al. (1981) recommend measurement of the strength of the thigh muscles in the follow-up of patients operated for knee ligament injuries since it gives a fair impression of the patient's activity and potential to use the knee joint. The authors suggest that reduced muscle strength may be caused by lack of adequate training or avoidance of normal use of the extremity as a result of pain or instability of the knee.

Not only in traumatology are isometric or isokinetic strength tests frequently applied. Several studies describe the use of dynamometry in various neurological and degenerative joint diseases and conditions.

Strength measurements can also be of use to evaluate the effect of drug therapy and to monitor the long term course of chronic disease. Several authors presented the results of isometric follow-up testing in patients suffering from dermatomyositis (Dinsdale et al. 1971; Hyde 1985), peripheral neuromuscular disorders (Wiles and Karni 1983), myasthenia gravis (v.d. Ploeg et al. 1984) and muscular dystrophy (Fowler and Gardner 1967).

Knutsson and Martensson (1976) used isometric and isokinetic strength tests in a study on the effects of dantrolene sodium, an antispasticity drug.

Armstrong et al. (1983) tested healthy subjects and patients with multiple sclerosis with an isokinetic dynamometer. They judged isokinetic testing to be a safe and reliable form of objective neuromuscular testing for ambulatory patients with multiple sclerosis.

Watkins et al. (1984) reported the results of isokinetic measurements of the quadriceps and hamstring muscles in 15 patients with hemiparesis.

Lankhorst et al. (1982; 1985) determined isometric and isokinetic torque of the knee extensors and flexors and studied the relationship between torque values, functional capacity and pain.

Strickler and Greene (1984) performed isokinetic torque measurements of the knee extensors and flexors in 47 hemiplegia patients. They found that an increasing degree of arthropathy of the knee was associated with significant decrease of both extensor and flexor torque.

Most authors agree that in neuromuscular diseases the change in strength is the ultimate manifestation of improvement or deterioration of the underlying disease. Thus dynamometry can serve as a tool to monitor the course of a disease.

Finally it is common experience that patients with muscle weakness appreciate the benefit in accuracy of attributing an absolute value to their strength, rather than relying on the doctor's recollection of it over weeks or months.

## 1.6 Factors influencing strength testing.

Even when using a strength testing method that seems to be valid and reliable, there are many sources of potential error and variability, which may affect its clinical or scientific value.

The expression of human strength can be modified by intrinsic and extrinsic factors.

The intrinsic factors are the mental or physical condition of the subject. The examiner, the testing device, the testing protocol and various environmental circumstances may be considered as extrinsic factors.

Ikai and Steinhaus (1961) claimed that the limits of performance in maximal voluntary contractions are determined by psychological rather than by physiological factors. They found significant changes in the maximal pull of forearm flexors caused by loud noises, the subject's own outcry, hypnosis and pharmacological agents such as alcohol, adrenaline and amphetamine.

The examiner may seriously influence the results of strength testing by inconsistent instructions, emotional appeals and goal setting (Westers 1982).

The importance of feedback is illustrated in a study by Peacock et al. (1981). They performed an experiment with different forms of feedback. They found that verbal encouragement, coupled with direction of the subject's attention to concurrent visual information about the achievement, resulted in a significant increase in maximal isometric strength of approximately 10% over a non-feedback condition.

Westers (1982) pointed out that, as a generalisation, pain interferes with reliable strength testing. Pain may cause a patient to refuse a test or pain may inhibit maximal output during a test. He stated that other symptoms associated with inflammatory joint disorders, such as joint swelling and stiffness, may inhibit maximal voluntary muscle contraction as well.

Other authors (De Andrade et al. 1965; Shakespeare et al. 1985) showed that swelling of the knee joint, even without pain, results in reflex inhibition and an inability to contract the knee extensor muscles voluntarily.

In a paper describing routine isometric muscle strength measurements, Kroemer and Marzas (1980) presented a table (table 1.2) that lists most of the factors mentioned above.

*Table 1.2* Factors affecting motivation and increasing (+) or decreasing (-) maximal muscular performance (Kroemer and Marzas 1980).

	Likely effect
Feedback of results	+
Instructions on how to exert strength	+
Arousal of ego involvement, aspiration	+

Pharmaceutical agents (drugs)	+
Startling noise, subject's outcry	+
Hypnosis	+
Setting of goals	+ or -
Competition	+ or -
Verbal encouragement	+ or -
Spectators	?
Deception by researcher	?
Fear of injury	-
Deception by subject	-

It is very important, when designing or performing a muscle strength test, to be aware of those circumstances that may influence the exertion of strength.

When sources of variability are recognised, testing procedures can be readily modified to allow for more objectivity in assessing a patient's progress during treatment.

### 1.7 Relationship between results of strength testing and functional variables.

A considerable loss of muscle strength may be considered a major impairment. This impairment will nearly always lead to a certain extent of disability. In other words, a subject suffering from loss of muscle strength of the lower extremities may have difficulties with standing up, walking, climbing stairs, squatting, running, etc.

If measurement of the diminished muscle strength (impairment) is meant to provide information about its consequences (disability) the question of validity should be discussed. A test is considered valid when it measures what it has to measure. A strength test is valid when it measures muscle performance (torque or work or power).

When a strength test is used to predict functional capabilities the matter of predictive validity is under discussion. The correlation coefficient ( $r$ ) between the strength test and the functional activity is often used to determine the predictive validity of the strength test.

Lankhorst et al. (1982) studied the relationship between isometric knee extension torque and functional activities like walking speed, step length and stairclimbing to evaluate the results of the treatment in osteoarthritis. They found low correlation coefficients of isometric torque and functional measurements and concluded that isometric dynamometry is not a valid method to judge the outcome of treatment.

In another paper, Lankhorst et al. (1985) presented the results of a study on the relationship of isometric and isokinetic torque and functional capacity. The conclusion was that in osteoarthritis of the knee, isometric and isokinetic maximal

torque measurements are unsatisfactory predictors of functional capacity and that the isokinetic measurements have very little advantage over the isometric tests.

Smith (1961) tested 70 college students and found a statistically non-significant correlation coefficient ( $r = .20$ ) between vertical jump performance (in inches) and isometric leg strength.

Berger and Henderson (1966) however found correlation coefficients of 0.64 and 0.71 between leg power (calculated by measuring body weight and vertical jump height) and static and dynamic leg strength respectively.

More recently, Genuario and Dolgener (1980) studied the relationship between isokinetic strength and jump height in female athletes and found a statistically non-significant correlation at an angular velocity of 30 degr./sec. and a statistically significant correlation of 0.59 at an angular velocity of 180 degr./sec.

Danneskiold-Sansoe et al. (1984) studied isometric muscle strength and functional performance in elderly people. The subjects were asked to climb up and down steps with heights of 10 to 50 cm. The highest possible step at which the subject was able to climb was registered. Knee extension strength and climbing capacity had no direct relationship. The authors concluded that other factors, such as reduced joint mobility, balance problems, anxiety, etc., also influence the ability to climb steps in old age.

Aniansson et al. (1980) found statistically significant positive correlations between walking speed and the peak values of isokinetic muscle strength of the right knee extensors at angular velocities 30, 60 and 120 degr./sec. in healthy 70-year-old women ( $p < 0.05$ ,  $r = 0.40-0.45$ ), but not in men. They also found statistically significant positive correlations in the group of women ( $p < 0.01$ ,  $r = 0.30-0.52$ ) between the results of a step test (maximal height up and down) and the maximal isokinetic muscle strength of the knee extensors at angular velocities of 30 and 60 degr./sec.

Up to the present, the relationship between muscle weakness determined by isometric or isokinetic dynamometry and the resulting diminished functional capacity (expressed by problems with standing up, walking, running, etc.) seems not to be clear.

## 1.8 Aim and general design of the study.

The purpose of this study is twofold:

1. to study torque angle curves, obtained with two different isokinetic dynamometers.
2. to study the practical usefulness of isometric and isokinetic dynamometry applied to healthy subjects and patients with decreased muscle strength.

When these two main purposes are specified in more detail the following aims can be distinguished:

1. to compare torque angle curves obtained from a Cybex II and a Q.D.
2. to study the influence of angular velocity and starting position on maximal torque and maximal torque joint position during isokinetic dynamometry.
3. to study the intra- and interindividual variability of isometric and isokinetic dynamometry.
4. to study the relationship between isometric and isokinetic dynamometry.
5. to study the practical use of isometric and isokinetic dynamometry in patients during a treatment period after meniscectomy.
6. to study the long term consequences of right/left imbalances of muscle strength of the knee extensors after meniscectomy.
7. to study the relationship between the results of dynamometry and functional activities.

The knee extensors were chosen because they are the most frequently studied muscle-group concerning isokinetic dynamometry in vivo. Besides, the knee extensors are major contributors to activities like walking, running, getting up, sitting down and jumping. Therefore, impairment of the function of the knee extensors frequently leads to disability, expressed by the patient as problems with several common daily activities. With proper positioning and strapping of the subject, disturbing movements produced by other muscles can be prevented easily.

The dynamometer used in this study (the Q.D.) was designed in order to assess muscle strength of the knee extensors during isometric, isokinetic and isotonic contraction. However, the results of isotonic dynamometry will not be presented.

In chapter 2 the technical aspects of the Q.D. are described. The Q.D. differs in many respects from the commonly used and relatively well known Cybex II dynamometer. These technical differences have important consequences for the respective torque angle curves. The most relevant parameters of the curves of both the Q.D. and the Cybex II are presented.

The Q.D. is equipped with a range of motion that can be preselected between 60 degr. (maximal flexion) and 180 degr. (maximal extension). The extra 30 degrees between 60 and 90 degr. (the Cybex starts at 90 degr.) may increase the value of the isokinetic strength test on the Q.D. On the other hand, the influence of changing the starting position on the torque angle curve is not known. We therefore studied the effect of two different starting positions in healthy men and women at three angular velocities. These results are also presented in chapter 2.

The value of measurements of muscular performance in human subjects is to a large extent determined by the variability and reproducibility of the selected parameters. In chapter 3 the intra- and interindividual variability of isometric and isokinetic measurements of healthy men and women is described. The data of this

study are at the same time used to establish the relationship between isometric and isokinetic torque measurements. A high correlation would suggest that only one way of strength testing is needed, because performance on one test will predict very accurately the result of the other test. A low correlation between isometric and isokinetic dynamometry suggests that each test requires a different neuromotor activity.

In chapter 4 the results of dynamometry during an 8 week training programme after meniscectomy are presented. Isometric and isokinetic torque of the knee extensors of both legs was measured. A group of healthy volunteers served as a control group. Strength testing results are compared with performance during a vertical jump test in order to establish the relationship between knee extensor torque, assessed on a dynamometer, and a functional activity.

In chapter 5 a follow-up study of the patients of chapter 4 is described. Special attention is paid to the strength differences of the knee extensors found at the end of the training period. The change of isometric and isokinetic torque of the knee extensors of both legs 2 years after the meniscectomy is studied.

In chapter 6 the results of a study on muscle strength in Guillain-Barré (polyradiculoneuropathy) patients is presented. Isometric and isokinetic maximal torque of the knee extensors was measured from an early stage of the disease until full recovery. At each test session the functional performance was determined with a simple test covering a wide range of activities. The results of the strength test were compared with the functional performance in order to study the relationship between impairment and disability.

A general discussion, the Summary and the ‘Samenvatting’ (in English and Dutch respectively) are presented at the end of the thesis.

Two Appendices are added. Appendix I is the technical note of the Q.D. Appendix II is the training programme of the patients of chapter 4.

## 1.9 References.

- Adeyanyu K, Crews T R, Meadows W J.  
Effects of two speeds of isokinetic training on muscular strength, power and endurance.  
*J. Sports Med.* 23: 352-356, 1983.
- Aniansson A, Rundgren A, Sperling L.  
Evaluation of functional capacity in activities of daily living in 70-year-old men and women.  
*Scand. J. Rehab. Med.* 12: 145-154, 1980.
- Armstrong L E, Winant D M, Swasey P R, Seidle M E, Carter A L, Gehlsen G.  
Using isokinetic dynamometry to test ambulatory patients with multiple sclerosis.  
*Phys. Ther.* 63: 1274-1279, 1983.
- Arvidsson I, Eriksson E, Haggmark T, Johnson R J.  
Isokinetic thigh muscle strength after ligament reconstruction in the knee joint: results from a 5-10 year follow-up after reconstructions of the anterior cruciate ligament in the knee joint.  
*Int. J. Sports Med.* 2: 7-11, 1981.
- Berger R A, Henderson J M.  
Relationship of power to static and dynamic strength.  
*Res. Quart.* 37: 9-13, 1966.
- Burnie J, Brodie D A.  
Isokinetic measurement in prae-adolescent males.  
*Int. J. Sports Med.* 7: 205-209, 1986.
- Coplin T H.  
Isokinetic exercise: clinical usage.  
*J. of the N.A.T.A.* fall 1971.
- Coyle E F, Feiring D C, Rolkis T C, Cole R W, Roby F B, Lee W, Wilmore J H.  
Specificity of power improvement through slow and fast isokinetic training.  
*J. Appl. Physiol.* 51: 1437-1442, 1981.
- Daniels L, Worthingham C.  
Muscle testing: technique of manual examination.  
4th Ed. W.B. Saunders, Philadelphia, 1980.

- Danneskiold-Samsøe B, Kofod V, Grimby G, Schnohr P, Jensen G.  
Muscle strength and functional capacity in 78-81-year-old men and women.  
*Eur. J. Appl. Physiol.* 52: 310-314, 1984.
- De Andrade J R, Grant C, Dixon A. St.J.  
Joint distension and reflex muscle inhibition in the knee.  
*J. Bone and Joint Surg.* 47A: 313-322, 1965.
- Delateur B, Lehman C G, Stonebridge J, Funita G, Coker K, Egbert H.  
Comparison of effectiveness of isokinetic and isotonic exercise in Quadriceps strengthening.  
*Arch. Phys. Med. Rehab.* 53: 60-64, 1972.
- Dinsdale S M, Cole T M, Zaki F G, Awad E A.  
Measurements of disease activity in dermatomyositis.  
*Arch. Phys. Med. Rehab.* 52: 201-206, 1971.
- Edwards R H T, Hyde S A.  
Methods of measuring muscle strength and fatigue.  
*Physiotherapy* 63: 51-55, 1977.
- Elliot J.  
Assessing muscle strength isokinetically. *J.A.M.A.* 240: 2408-2409, 1978.
- Fowler W M, Gardner G W.  
Quantitative strength measurements in muscular dystrophy.  
*Arch. Phys. Med. Rehab.* 48: 629-644, 1967.
- Genuario S E, Dolgener F A.  
The relationship of isokinetic torque at two speeds to the vertical jump.  
*Res. Quart. Exerc. Sport* 51: 593-598, 1980.
- Gilliam T B, Sady S P, Freedson P S, Villanacci J.  
Isokinetic torque levels for highschool football players.  
*Arch. Phys. Med. Rehab.* 60: 110-114, 1979.
- Grace T G, Sweetser E R, Nelson M A, IJdens L R, Skipper B J.  
Isokinetic muscle imbalance and knee joint injuries.  
*J. Bone and Joint Surg.* 66A: 734-740, 1984.

Grimby G, von Heyne C, Hook O, Wedel H.  
Muscle strength and endurance after training with repeated maximal isometric contractions.  
Scand. J. Rehab. Med. 5: 118-123, 1973.

Hettinger T.  
Physiology of strength.  
C.C. Thomas, Springfield 1961.

Hislop H J, Perrine J J.  
The isokinetic concept of exercise.  
Phys. Ther. 47: 114-117, 1967.

Hook O, Tornvall G.  
Apparatus and method for determination of isometric muscle strength in men.  
Scand. J. Rehab. Med. 1: 139-142, 1969.

Hyde S A.  
Use of the myometer for evaluation of muscle force.  
Ned. T. Fysiother. 95: 66-69, 1985.

Ikai M, Steinhaus A H.  
Some factors modifying the expression of human strength.  
J. Appl. Physiol. 16: 157-163, 1961.

Kendall H O, Kendall F F, Wadsworth G E.  
Muscles: testing and function, 2nd edition.  
Williams and Wilkins, Baltimore 1971.

Knapik J J, Ramos M U.  
Isokinetic and isometric torque relationships in the human body.  
Arch. Phys. Med. Rehab. 61: 64-67, 1980.

Knutsson E, Martensson A.  
Action of dantrolene sodium in spasticity with low dependance on fusimotor drive.  
J. Neurological Sciences 29: 195-212, 1976.

Kroemer K H E, Marzas W S.  
Towards an objective assessment of the 'maximal voluntary contraction' component in routine muscle strength measurements.  
Eur. J. Appl. Physiol. 45: 1-9, 1980.

Lamb R L.

Manual muscle testing.

From: Measurement in physical therapy.

Churchill Livingstone, New York 1985.

Lankhorst G J, v.d. Stadt R J, v.d. Korst J K, Hinlopen-Bonrath E, Griffioen F M M, de Boer W.

Relationship of isometric knee extension torque and the functional variables in osteoarthritis of the knee.

Scand. J. Rehab. Med. 14: 7-10, 1982.

Lankhorst G J, v.d. Stadt R J, v.d. Korst J K.

The relationships of functional capacity, pain and isometric and isokinetic torque in osteoarthritis of the knee.

Scand. J. Rehab. Med. 17: 167-172, 1985.

Licht S.

Therapeutic exercise. 2nd edition 1965.

E Licht.

Lindh M.

Increase of muscle strength from isometric quadriceps exercises at different knee angles.

Scand. J. Rehab. Med. 11: 33-36, 1979.

Mayhew T P, Rothstein J M.

Measurement of muscle performance with instruments.

From: Measurement in physical therapy.

Churchill Livingstone, New York 1985.

Medical Research Council.

Aids to the investigation of the peripheral nervous system.

Her Majesty's Stationary Office, London 1975.

Mendler H M.

The hydraulic isometric force testing unit K-100.

Phys. Ther. 52: 393-398, 1972.

Moffroid M, Whipple R, Hofkosh J, Lowman E, Thistle H.

A study of isokinetic exercise.

Phys. Ther. 49: 735-747, 1969.

- Moffroid M T, Kusiak E T.  
The power struggle.  
Phys. Ther. 55: 1098-1104, 1975.
- Molnar G E, Alexander J.  
Development of quantitative standards for muscle strength in children.  
Arch. Phys. Med. Rehab. 55: 490-493, 1974.
- Nordesjo L O, Nordgren B.  
Static and dynamic measuring of muscle function.  
Scand. J. Rehab. Med. suppl. 6: 33-42, 1978.
- Pavone E, Moffat M.  
Isometric torque of the quadriceps femoris after concentric, eccentric and isometric training.  
Arch. Phys. Med. Rehab. 66: 168-170, 1985.
- Peacock B, Westers T, Wals S, Nicholson K.  
Feedback and maximum voluntary contraction.  
Ergonomics 24: 223-228, 1981.
- v.d. Ploeg R J O, Oosterhuis H J G H, Reuvekamp J.  
Measuring muscle strength.  
J. Neurology 231: 200-203, 1984.
- Pronk C N A, Niesing R.  
Technical note: apparatus for measuring the functional capacity of the knee extensors and flexors.  
Med. Biol. Eng. Comput. 21: 764-767, 1983.
- Rompe G.  
Beurteilung der Muskelkraft in Gutachten.  
Z. Ortop. 110: 392-395, 1972.
- Rothstein J M, Delitto A, Sinacore D R, Rose S J.  
Electromyographic, peak torque and power relationships during isokinetic movement.  
Phys. Ther. 63: 926-933, 1983.

Shakespeare D T, Stokes M, Sherman K P, Young A.  
Reflex inhibition of the quadriceps after meniscectomy: lack of association with pain.  
Clin. Physiol. 5: 137-144, 1985.

Slagle G W.  
The importance of pretesting of the knee joint.  
Athletic Training 14: 225-226, 1979.

Smidt G L, Rogers M W.  
Factors contributing to the regulation of clinical assessment of muscular strength.  
Phys. Ther. 62: 1283-1290, 1982.

Smith L E.  
Relationship between explosive leg strength and performance in the vertical jump.  
Res. Quart. 32: 403-408, 1961.

Steele V.  
Rehabilitation of the injured athlete.  
Physiotherapy 66: 251-255, 1980.

Strickler E M, Greene W B.  
Isokinetic torque levels in hemophiliac knee musculature.  
Arch. Phys. Med. Rehab. 65: 766-770, 1984.

Thistle H G, Hislop H J, Moffroid M, Lowman E W.  
Isokinetic contraction: a new concept of resistive exercise.  
Arch. Phys. Med. Rehab. 48: 279-282, 1967.

Vos J A.  
Statische en dynamische krachtmeting. (Static and dynamic strength testing).  
Ph.D. Thesis in Dutch, Gent, 1976.

Watkins M P, Harris B E, Kozlowski B A.  
Isokinetic testing in patients with hemiparesis.  
Phys. Ther. 64: 184-189, 1984.

Westers B M.  
Factors influencing strength testing and exercise prescription.  
Physiotherapy 68: 42-44, 1982.

W.H.O. 1980.

International Classification of Impairments, Disabilities and Handicaps.  
Genève 1980.

Wiles C M, Karni Y.

The measurement of muscle strength in patients with peripheral neuromuscular disorders.

J. Neurol. Neurosurg. Psych. 46: 1006-1013, 1983.

Williams M, Stutzman L.

Strength variation through the range of joint motion.

Phys. Ther. Rev. 39: 145-152, 1959.

Wilmore J H.

Alteration in strength, body composition and anthropometric measurements consequent to a 10 week weight training program.

Med. Sci. Sports 6: 133-138, 1974.

## CHAPTER 2

### THE QUADRICEPS DYNAMOMETER: DESIGN AND TORQUE ANGLE CURVES

#### 2.1 General design and use of the Q.D.

In this study the measurements of the knee extensor torque are performed on a Q.D., a dynamometer, described by Pronk and Niesing (1983).

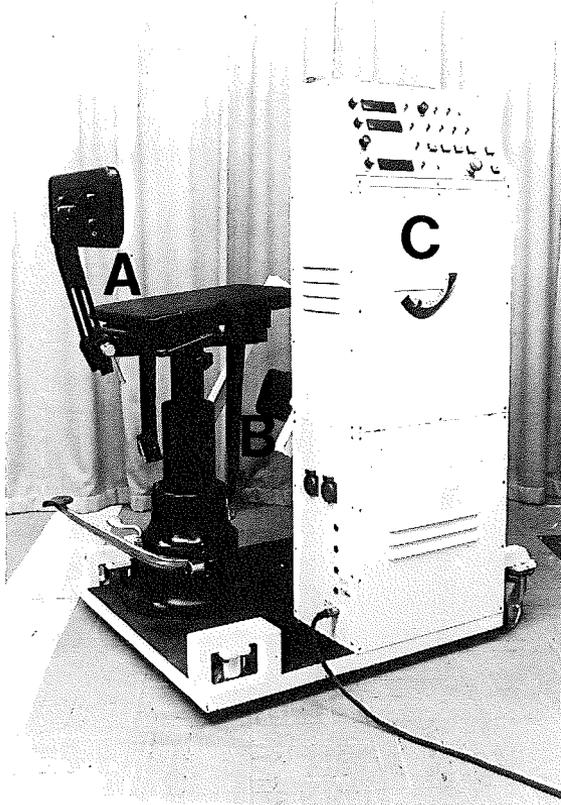
The Cybex dynamometer, most frequently used in research on human muscular strength, was considered too expensive and technically not appropriate for this study.

Although the Q.D. is designed to measure the torque under isometric, isokinetic and isotonic conditions, the latter way of strength testing will not be presented.

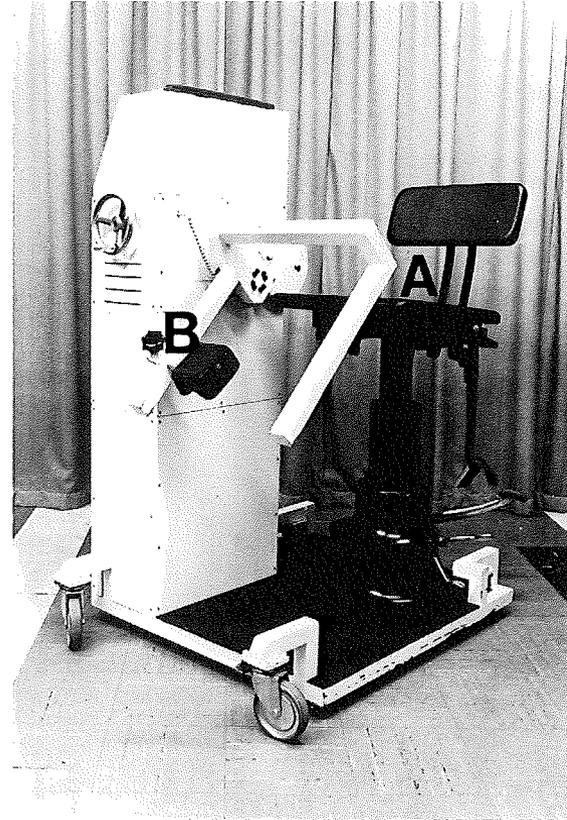
The Q.D. is composed of an adjustable chair (a), a leverarm (b) connected with an electric driving system and a control panel (c) (fig. 2.1).

The chair on which the subject is seated is adjustable in height (from 45 to 65 cm) and can be rotated (around a vertical axis) in order to allow for easy transfer of the subject in and out of a wheelchair. The subject's trunk is supported by a back rest which is adjustable in a horizontal and vertical direction. The subject is leaning against the back rest inclined at some 15 degrees from the vertical position. The subject is positioned according to the principles described by Goslin and Charteris (1979):

- parallel alignment:  
the moving limb segment is aligned parallel to the leverarm of the dynamometer.
- rotational alignment:  
the axis of rotation of the joint and the axis of rotation of the leverarm coincide. This is achieved by adjusting the height of the chair in a vertical direction and/or by adjusting the axis of the leverarm in a horizontal direction.
- stabilisation:  
limb segments that are not supposed to contribute to the force exerted on the leverarm are not allowed to participate. In the case of dynamometry of the knee extensors, the tendency for the pelvis to lift during an all-out effort is prevented by having subjects hold on to side handles on the seatbase (Perrine and Edgerton 1978) and by strapping the upper legs with a belt of 5 cm in width.



*Fig. 2.1a The Quadriceps Dynamometer (Q.D.)  
(For further information: see text).*



*Fig. 2.1b The Quadriceps Dynamometer (Q.D.)  
(For further information: see text).*

After proper positioning, the strength of the knee extensors is measured by having the subject exert force (with the distal end of the tibia) against a padded block, attached to the distal end of the leverarm. Strength is expressed in units of torque (Nm). Torque is the product of force multiplied by its perpendicular distance from the axis of rotation (Moffroid et al. 1969). The Q.D. measures torque with a torque transducer, placed between the leverarm and the driving system.

Underestimation of the knee extensor torque due to the effect of gravity acting on the leverarm is prevented by a weight, counterbalancing the weight of the leverarm and the padded block.

The Q.D. is operated by a high instantaneous torque a.c. motor (power = 0.6 kW). The available torque of the motor (2.6 Nm at 2400 r.p.m.) is sufficient to measure torque at a maximal angular velocity of 90 degr./sec. The angular velocity range is therefore limited and corresponds with 0 - 90 degr./sec.

The range of motion of the leverarm and knee joint is limited by electrical switches and mechanical stops and can be preselected anywhere between 60 degrees of flexion and 180 degrees of extension.

Angle, speed and torque are simultaneously recorded on a four-channel pen recorder (W + W 314).

Calibration of the torque transducer is performed under isometric conditions with known weights.

A more detailed description of the Q.D. is provided by Appendix I, which contains the Technical Note of this dynamometer.

## **2.2 Isometric and isokinetic dynamometry with the Q.D.**

Isometric dynamometry.

An isometric contraction is a muscular contraction against a load which is immovable. The length of the muscle remains constant and no joint movement is allowed (Hislop and Perrine 1967).

The Q.D. is able to measure isometric torque at every 5 degrees between 60 degr. (knee flexion) and 180 degr. (knee extension).

Before actual testing, the subject is informed about the aim of the measurement and instructed to perform a maximal voluntary contraction.

Subsequently, the subject is allowed to exert several submaximal contractions in order to become familiar with the testing procedure.

Finally, the subject is asked to exert maximal tension against the padded block during about 3 or 4 seconds. Maximal torque is recorded and the best of three contractions is registered. Rest periods of 1 minute are allowed between each maximal contraction in order to prevent mental or physical fatigue.

No visual feedback is given during the test session, but the subject is verbally encouraged.

Isokinetic dynamometry.

In isokinetic dynamometry torque is measured during a concentric muscle contraction (i.e. the muscle shortens), while the angular velocity of the limb segment is held constant throughout the range of motion (r.o.m.). The constant angular velocity is provided by the dynamometer.

The r.o.m. of the dynamometer is preselected and adjusted anywhere between 60 and 180 degr. Usually a r.o.m. of 105 degr. (75 - 180 degr.) is chosen.

After getting used to the isokinetic way of testing by performing some submaximal tests, actual maximal strength testing takes place. The subject is instructed to extend the knee as fast and as powerful as possible. The best of 3 contractions is registered and 1 minute rest intervals are allowed between the maximal contractions.

Torque (Nm) and angular velocity (degr./sec.) are registered on a pen recorder, resulting in a torque angle curve as shown in fig. 2.2. The torque angle curve of the Q.D. is composed of an isometric and an isokinetic part, separated by a short period in which acceleration to the preset angular velocity takes place.

The isometric phase is the result of a torque threshold (usually about 10 Nm) and the time needed for relay-switching. This isometric phase takes about 150 msec. The torque threshold is meant to synchronize the start of the contraction of the knee extensors and the start of the leverarm of the dynamometer. The isometric phase allows the knee extensors to build up a considerable part of their force before the actual dynamic phase begins. The consequences of this way of testing will be discussed later.

After the isometric phase the leverarm accelerates to the preset angular velocity. Acceleration amounts to 300 degr./sec.sec.

A constant angular velocity is reached after a certain angular displacement. This means, for example, that in case of a preset angular velocity of 90 degr./sec. and a starting position at 75 degr., the real isokinetic phase starts at  $(75 + 18 =) 93$  degr. of the knee angle (fig. 2.2).

Maximal torque, recorded during the isokinetic phase, is the parameter most frequently used in isokinetic dynamometry.

Maximal torque joint position (m.t.j.p.) is the angle in the r.o.m. where maximal torque occurs.

After the isokinetic phase the deceleration phase occurs in which the angular velocity decreases rapidly and the torque registration drops to zero.

## 2.3 Torque angle curves of the Q.D. and the Cybex II.

### 2.3.1 Introduction.

Most studies concerning isokinetic dynamometry are done with the Cybex II dynamometer, which differs in some technical respects from the Q.D.

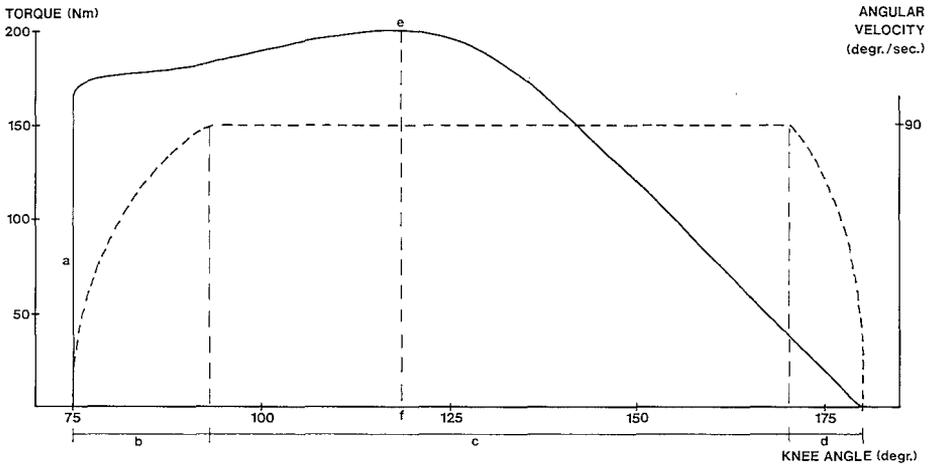


Fig. 2.2 Example of a torque angle curve of the Q.D.

- a = isometric phase;
  - b = acceleration phase;
  - c = isokinetic phase;
  - d = deceleration phase;
  - e = maximal torque;
  - f = m.t.j.p.
- Angular velocity is indicated by a broken line.

After the introduction of the isokinetic principle by Hislop and Perrine (1967), several authors have described the consequences of the technical design of the Cybex II (Gransberg and Knutsson 1983, Nelson and Duncan 1983, Sapega et al. 1982, Sinacore et al. 1983, Winter et al. 1981).

The torque angle curve of the Cybex II (fig. 2.3) is characterized by an initial phase of uncontrolled acceleration. In this phase, when the subject increases the speed of the lower leg and the leverarm from zero to a preselected angular velocity, no torque is registered (Gransberg and Knutsson 1983, Winter et al. 1981). After acceleration to the preset velocity, torque rapidly builds up. In this early phase of the isokinetic movement, after transition from the unresisted (uncontrolled acceleration) to the resisted (isokinetic phase) contraction, large oscillations in the torque recording may be seen. The accelerating lower leg is abruptly inhibited from further acceleration and there is an impact between accelerating mass and resisting leverarm. The impact is followed by a period of oscillations which may interfere with accurate interpretation of the torque angle curve (Sapega et al. 1982). The Cybex II is equipped with a system to damp the effects of the impact of the accelerating limb. The oscillations fade away by the damp system and a smooth curve, with a maximal torque that can be easily identified, is generated (Sinacore et al. 1983).

The most relevant features of the Q.D. and the Cybex II are listed in table 2.1.

*Table 2.1* Technical features of the Q.D. and the Cybex II.

	Q.D.	CYBEX II
r.o.m.	60-180 degr.	90-180 degr.
starting position	anywhere between 60-175 degr.	circa 90 degr.
end of r.o.m.	anywhere between 65-180 degr.	circa 180 degr.
starting threshold	0-250 Nm.	non existing
acceleration	300 degr./sec.sec. (controlled by dynamometer)	uncontrolled (dependent on subject)
angular velocity	0-90 degr./sec.	0-288 degr./sec.

It may be expected that the technical differences of the Q.D. and the Cybex II result in different torque angle curves. The results of strength testing with the Q.D. can only be compared with other studies when the torque angle curves of both dynamometers are determined in one test session. Therefore the purpose of this study is to compare the torque angle curves and the most important parameters of the curves of the Q.D. and the Cybex II.

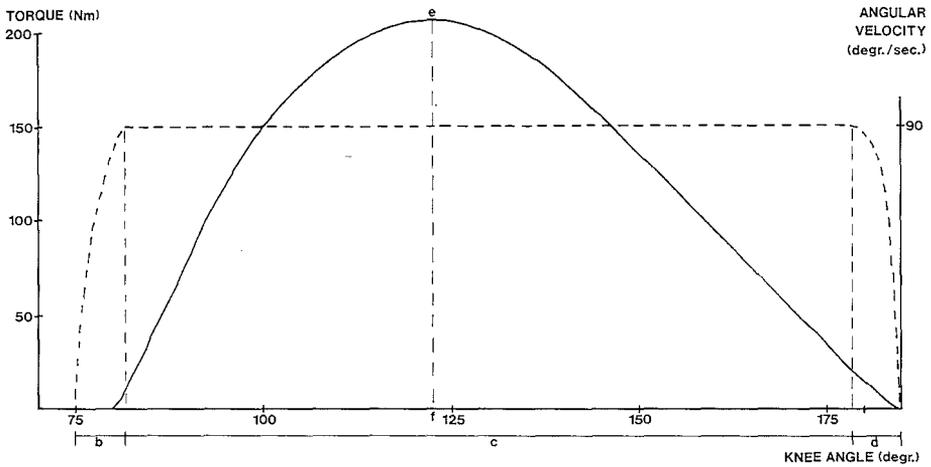


Fig. 2.3 Example of a torque angle curve of the Cybex II.

b = acceleration phase;                      c = isokinetic phase;  
 d = deceleration phase;                      e = maximal torque;  
 f = m.t.j.p.

Angular velocity is indicated by a broken line.

### 2.3.2 Materials and methods.

Twenty healthy volunteers (11 men and 9 women), with a mean age of 30 years (range 25 - 38) participated in the study.

Each subject was tested on both dynamometers in one test session and the sequence of the first and second dynamometer was changed for every new subject. Instruction, positioning and warming-up contractions were performed as described in 2.1 and 2.2. Isokinetic contractions were performed at angular velocities of 60 and 90 degr./sec. The sequence of the angular velocities did not alternate. The r.o.m. was 105 degr. i.e. from 75 degr. flexion to 180 degr. extension. On the Cybex II the subject had to bend the knee actively to reach the starting position of 75 degr.

Each maximal contraction was repeated three times at one minute intervals. The highest torque angle curve was used for calculations.

Work produced during the maximal contraction was determined by measuring the area under the torque angle curve with a planimeter (Moffroid and Kusiak 1975).

The Student-paired-t-test was used to test the differences between the mean maximal torque, mean m.t.j.p. and mean torque at certain knee angles. Statistical significance of the differences was accepted at the 0.05 confidence level.

### 2.3.3 Results.

Means and (S.D.) of the most relevant curve parameters are presented in table 2.2, together with results of the Student-paired-t-test.

*Table 2.2* Means, (S.D.) and statistical significance of maximal torque, m.t.j.p. and work of men and women at angular velocities of 60 and 90 degr./sec. on the Cybex II and the Q.D. (S = statistically significant,  $p < 0.05$ ).

		CYBEX II		Q.D.
men 60 degr./sec.				
mean max. torque	(Nm)	222(39)	- S -	202(37)
mean m.t.j.p.	(degr.)	115 (8)		117 (6)
mean work	(Joule)	273(54)		268(48)
men 90 degr./sec.				
mean max. torque	(Nm)	207(33)	- S -	180(31)
mean m.t.j.p.	(degr.)	123 (7)	- S -	114(13)
mean work	(Joule)	254(47)		246(40)
women 60 degr./sec.				
mean max. torque	(Nm)	154(25)	- S -	137(22)
mean m.t.j.p.	(degr.)	126 (8)		120(13)
mean work	(Joule)	192(27)		184(31)
women 90 degr./sec.				
mean max. torque	(Nm)	139(25)	- S -	120(17)
mean m.t.j.p.	(degr.)	124 (4)		120(17)
mean work	(Joule)	168(26)		168(27)

Mean maximal torque produced on the Cybex II is significantly higher than on the Q.D. in both men and women. This difference amounts to about 10%.

With the exception of the men at an angular velocity of 90 degr./sec., no statistically significant differences of m.t.j.p. are found between both dynamometers.

Work produced during the maximal contraction does not differ significantly on the Cybex II and the Q.D.

Mean maximal torque of the male subjects is about 30 - 35% higher than the mean maximal torque of the female subjects. There are some differences between the male and female subjects concerning m.t.j.p., but these differences are small and not statistically significant.

In order to simplify the further discussion on the shape of the curves the data of

men and women are combined and mean torque angle curves of the whole group are composed of the individual curves. Mean torque at certain positions in the r.o.m. (with 10 degrees intervals) is calculated. The results are presented in figure 2.4.

The Cybex II torque recording shows a phase where no torque is registered during the initial part of the r.o.m. Subsequently, torque rapidly builds up.

The torque angle curves of the Q.D. and the Cybex II coincide at about 97 and 103 degr. at the respective angular velocities.

During the second part of the r.o.m. mean torque registered on the Cybex II is higher than on the Q.D.

Statistical analysis resulted in significant differences in torque at the selected joint angles, with the exception of the joint angles of 95 and 105 degr. at angular velocities of 60 and 90 degr./sec. respectively.

#### 2.3.4 Discussion.

When the mean values of maximal torque, measured on both dynamometers, are compared, a difference of about 10% is found. This difference has to be taken into account when the results of strength testing with the Q.D. are compared with literature on the Cybex II.

Although important parameters of the torque angle curve, like maximal torque, m.t.j.p. and the area under the curve (work), are to a certain degree comparable, the curves of the Cybex II and the Q.D. show some striking differences especially during the initial phase of the contraction.

These differences can be partially explained by the way the isokinetic contraction is started. In the case of the Q.D. an isometric phase, resulting from a torque threshold and the relay-switching (see par. 2.2), causes the high torque during the first part of the curve. The low initial torque readings of the Cybex II are caused by the absence of a torque threshold and the uncontrolled acceleration, during which no torque is registered. The Cybex II seems to 'underestimate' the strength of the knee extensors, between 75 and 95 degr. The curve of the Q.D. shows that the knee extensors are capable of producing a considerable amount of force between 75 and 95 degr. under dynamic conditions.

Williams and Stutzman (1959), describing the isometric strength variation through the range of joint motion, found a knee extensor torque angle curve that is very well comparable with the isokinetic curve produced by the Q.D.

Knapik et al. (1983) presented the results of maximal torque measurements with the Cybex in 16 healthy young men (mean age 26 years). They left the initial phase out of their torque angle curve. This resulted in torque angle curves that are almost identical to the curves produced with the Q.D.

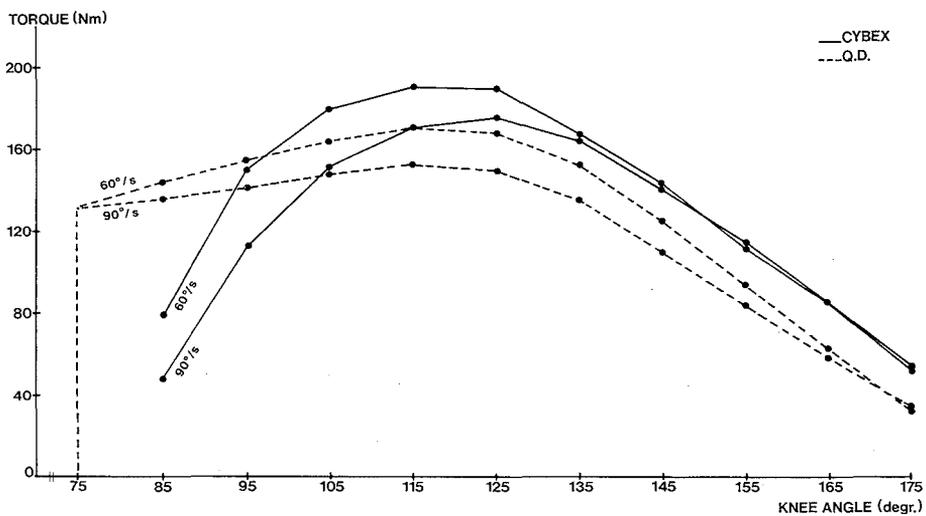


Fig. 2.4 Mean torque angle curves of the Q.D. and the Cybex II at angular velocities of 60 and 90 degr./sec.

The second half of the curve of the Q.D. is lower than the Cybex curve. This could be explained by the fact that with the Q.D. a considerable amount of energy is used up in the isometric and early isokinetic phase.

The low initial torque of the Cybex II leaves more energy for the second half of the contraction, which results in a higher torque.

It is not clear to what extent overshoot (i.e. an erroneously high reading in electro-mechanical systems) contributes to the higher maximal torque and the higher second half of the curve of the Cybex II. This overshoot is an artefact and consists of a torque tracing that occurs when the subject reaches the preset velocity after the unresisted acceleration (Sapega et al. 1982). Unlike the Cybex dynamometer the Q.D. is provided with a controlled acceleration and this kind of overshoot does not occur.

The conclusion of this study is that the first part of the torque angle curve of the Q.D. and the Cybex II differs considerably. The second part of the curves shows about the same shape. The technical design of the Cybex II and the Q.D. is, to a large extent, responsible for the different torque angle curve. Maximal torque of the knee extensors measured with the Q.D. is about 10% lower than the results of this test performed with a Cybex II.

Provided that these differences are taken into account, the results of isokinetic tests of the knee extensors obtained with the Q.D. can be very well compared with the data presented by other authors.

## **2.4 The influence of angular velocity and starting position.**

### **2.4.1 Introduction.**

The inverse relationship between the speed of contraction and the force produced by a muscle is common knowledge. This relationship can be presented by a curve with the shape of a rectangular hyperbola.

Fenn and Marsh (1935) and Hill (1983) described the shape of this so-called force velocity curve and developed empirical equations. Their experiments, however, were done on isolated muscles. Later Wilkie (1950) showed that the equations described by Hill were valid in human muscles *in vivo*, too.

After the introduction of isokinetic dynamometry, several authors have described the relationship between isokinetic torque and angular velocity (Ingemann-Hansen and Halkaer-Kristensen 1979, Knapik et al. 1983, Moffroid et al. 1969, Parker and Ruhling 1983, Perrine and Edgerton 1978, Scudder 1980, Thorstenson et al. 1976, Wickiewicz et al. 1984). Most of them confirmed that the inverse relationship between force (torque) and velocity (angular velocity) does exist in isokinetic contractions of the knee extensors as well. Only Moffroid et al. (1969) and Perrine and Edgerton (1978) presented somewhat different torque velocity curves.

All studies on isokinetic dynamometry mentioned above are performed with a Cybex dynamometer and in most of them the r.o.m. is not exactly defined. The knee angle of the subject tested with the Cybex is about 90 degr. when the knee extensors are relaxed. The r.o.m. can be increased by actively flexing the knee joint, but the chair of the dynamometer prevents further flexion above 75 degr. The r.o.m. of the Cybex is not determined by the dynamometer, but by the subject tested.

The Q.D., on the contrary, is equipped with electrical switches which allow of exact limitation of the r.o.m. anywhere between 60 degr. of flexion and 180 degr. of extension of the knee.

This study was performed with the following purposes:

- to determine the relationship between isokinetic torque and angular velocity in the range of angular velocities covered by the Q.D.
- to establish the effect of the starting position on maximal torque and m.t.j.p.

#### 2.4.2 Materials and methods.

Forty-four healthy volunteers were tested. The anthropometric data of the subjects are presented in table 2.3.

*Table 2.3* Means and (range) of age, height and bodymass of the male and female subjects.

		males (n=22)	females (n=22)[
age	(years)	27.7 (20-37)	27.8 (22-34)
height	(m)	1.81 (1.72-1.93)	1.71 (1.59-1.80)
bodymass	(kg)	72 (63-87)	64 (50-78)

Instruction, positioning and warming-up contractions were performed as described in 2.1 and 2.2.

Isokinetic contractions were performed with angular velocities of 30, 60 and 90 degr./sec. and at starting positions of 90 and 60 degrees.

The Wilcoxon-t-test of paired data was used to test the differences of maximal torque and of maximal torque joint position (m.t.j.p.). Statistical significance of the differences was accepted at the 0.05 confidence level.

### 2.4.3 Results.

In table 2.4 the means and standard deviations of maximal torque are presented.

*Table 2.4* Means and (S.D.) of maximal torque (Nm) at different angular velocities and starting positions.

(S = statistically significant,  $p < 0.05$ ).

starting position (degr.)		men		women	
		60	90	60	90
angular velocity (degr./sec.)	30	228(43) - S -	254(54)	144(26) - S -	169(31)
		S	S	S	S
	60	207(30) - S -	234(41)	134(24) - S -	149(29)
		S	S	S	S
	90	183(26) - S -	214(37)	116(24) - S -	135(27)

The relationship between angular velocity and maximal torque is presented in figure 2.5.

At both starting positions an increase of the angular velocity results in a decrease of mean maximal torque. These differences are statistically significant.

Starting the contraction at 60 degr. instead of 90 degr. results in a statistically significant decrease of the mean maximal torque values.

Table 2.5 shows the means and standard deviations of m.t.j.p.

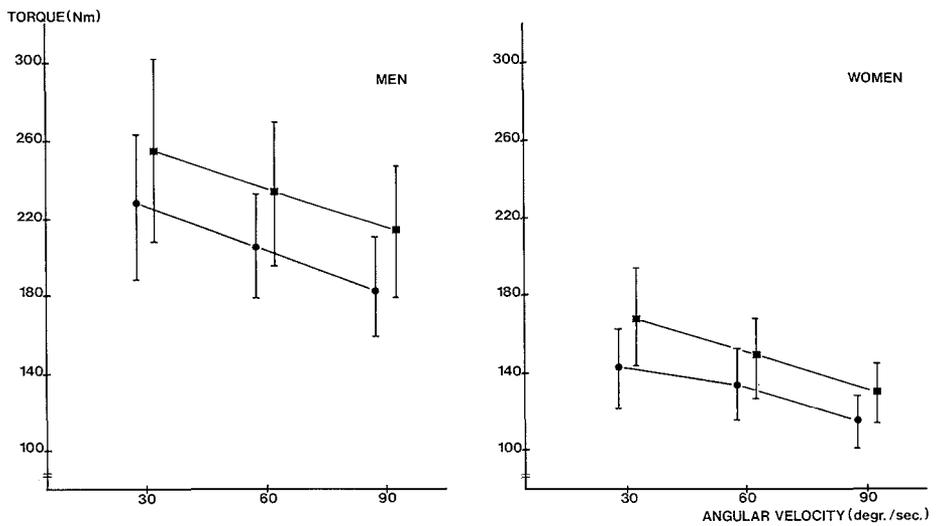


Fig. 2.5 Means and S.D. of maximal torque (Nm) of different angular velocities (degr./sec.) and starting positions (■ at 90 degr.; ● at 60 degr.).

Table 2.5 Means and (S.D.) of m.t.j.p. (degr.) at different angular velocities and starting positions.  
(S = statistically significant,  $p < 0.05$ ).

starting position (degr.)		men		women	
		60	90	60	90
angular velocity (degr./sec.)	30	110(9.5) - S -	106(8.3)	112(6.9) - S -	110(5.4)
		S	S	S	S
	60	114(8.5) - S -	110(8.7)	116(8.2) - S -	114(6.5)
		S	S		
	90	116(9.1) - S -	112(7.3)	117(8.4) - S -	114(5.2)

Mean m.t.j.p. shifts towards extension at higher angular velocities. The differences of m.t.j.p. are statistically significant, except for the difference between 60 and 90 degr./sec. at both starting positions in women.

When the starting position changes from 90 to 60 degr. mean m.t.j.p. shifts to a more extended position in the r.o.m. These differences of m.t.j.p. are statistically significant too, except for the women at an angular velocity of 30 degr./sec.

#### 2.4.4 Discussion.

Angular velocity and maximal torque.

There is an negative relationship between angular velocity and maximal torque, as shown in table 2.4 and figure 2.5.

This negative relationship may be explained by the mechano-chemical features of the muscle fiber. The amount of force developed by a muscle is determined by the number of cross bridges formed between the actin and myosin filaments. In an isometric contraction there is sufficient time for a maximum of cross bridges to be formed. In a shortening (concentric) contraction the speed of contraction is thought to limit the number of cross bridges and this decreases the force that can be developed by the muscle. It is therefore suggested that time is an important factor in cross bridge formation and consequently explains the decrease of torque at increasing angular velocities.

It should be remembered that in the isokinetic studies only a small part of the complete torque velocity curve is covered. The interference of an isokinetic dyna-

momometer causes that only at relatively slow angular velocities torque can be measured. Much higher velocities occur in daily life and during sport activities. Despite the limitation of the low angular velocities, most authors (Ingemann-Hansen and Halkaer-Kristensen 1979, Moffroid et al. 1969, Parker and Ruhling 1983, Scudder 1980, Thorstensson et al. 1976) agree that the decline of maximal torque is in accordance with the *in vitro* force velocity relationship described by Hill (1938) and Fenn and Marsh (1935).

In general, the results described in this chapter correspond rather well with the data presented in the other studies mentioned before. The data presented in table 2.4 are very well comparable with the mean maximal torque values of Thorstensson et al. (1976), Ingemann-Hansen and Halkaer-Kristensen (1979) and Scudder (1980). Moffroid et al. (1969) found a plateau in the torque velocity curve between 0 and 54 degr./sec. and a decline of maximal torque between 54 and 108 degr./sec. They attributed this plateau to a reluctance of the subject to exert more force at the slower speeds of shortening.

Perrine and Edgerton (1978) also presented a somewhat different torque velocity curve. They found an increase of mean torque between 0 and 96 degr./sec., followed by a decrease at higher velocities. Torque, however, was measured at 150 degr. in the r.o.m. and the subjects were asked to exert maximal force only at the end of the contraction at the slower angular velocities. In the studies mentioned before, the subjects are instructed to extend the knee as fast as possible and to complete the entire r.o.m. Furthermore, Perrine and Edgerton used no immobilisation of the subject on the chair and used a footplate for subject-machine coupling instead of a padded block against the ankle. These methodological differences most probably cause the biphasic torque velocity curve of Perrine and Edgerton.

#### Angular velocity and m.t.j.p.

The increase of angular velocity also influences the joint position at which maximal isokinetic torque occurs (m.t.j.p.). In this study, at increasing speeds of contraction and at both starting positions, m.t.j.p. is found later in the r.o.m. (table 2.5).

Other authors agree that, as the isokinetic velocity increases, the angle at which maximal torque occurs shifts to a point later in the r.o.m. However, they are not very specific in the explanation of the influence of increasing angular velocities on m.t.j.p. and their discussion remains rather vague.

Moffroid et al. (1969) considered time as an important factor in the explanation of the shift of m.t.j.p. At slower velocities, maximal torque occurs at a certain joint position where the muscle performs optimally because of leverage and muscle length. There is enough time to develop force and with increasing angular velocities the point in the r.o.m. where maximal torque occurs remains constant. At

higher velocities, however, the knee joint passes the point of optimal biomechanical circumstances by the time the contractile component attains maximum tension and as a result maximal torque tends to occur later in the r.o.m. Unfortunately, the authors do not specify the angular velocity at which m.t.j.p. starts shifting towards extension.

Knapik et al. (1983) added an alternative explanation and stated that the inherent mechanical characteristics of the Cybex dynamometer and the machine-subject coupling contribute to the shift of m.t.j.p. At higher angular velocities the limb completes a certain part of the r.o.m. as it accelerates to the preset velocity. Only when the preset velocity is reached, the muscle starts developing torque and the leg completes a further part of the r.o.m. Thus increasing lag time as the limb accelerates to the preset velocity and increasing time for the muscle group to develop torque account for the shift of the position of maximal torque.

Basically, Moffroid and Knapik both consider time (needed to develop force) the most important factor in the explanation of the shift of m.t.j.p. Our data seem to support their hypotheses. The different design of the Q.D. provides a starting threshold, which results in an initial isometric phase. Consequently, the knee extensor muscles are allowed to build up force before the dynamic phase of the contraction begins. No time is lost during the acceleration or during the first part of the isokinetic phase. If the explanation of Knapik is correct we would expect that mean m.t.j.p. of the torque angle curve found with the Q.D. occurs at an earlier part of the r.o.m. than m.t.j.p. found by authors using a Cybex II. In this study m.t.j.p. is found about 6 to 10 degr. earlier than m.t.j.p. determined by Thorstensson et al. (1976) and Scudder (1980). The results of the previous study (chapt. 2.3.3) seem to support the observation that the design of the dynamometer causes the differences of m.t.j.p. When m.t.j.p. is measured in one test session with both the Cybex II and the Q.D. there is a tendency to find the m.t.j.p. of the Cybex later in the r.o.m. (table 2.2). A statistical significant difference is found only in the male subjects at 90 degr./sec.

It is concluded that the hypothesis that a shortage of time causes the shift of m.t.j.p. at increasing angular velocities seems to be supported by the results of isokinetic measurements performed with the Q.D.

#### Starting position and maximal torque.

In figure 2.5 and table 2.4 the influence of the starting position on maximal torque at the three angular velocities is shown. The torque velocity relationship itself is not essentially changed by the starting positions, but in both the male and the female subjects the torque velocity curve descends to a lower level when the isokinetic contraction starts at a position of 60 degr. instead of 90 degr. These experiments cannot be compared with the results of other authors because their studies

have been performed with a Cybex dynamometer which only has a starting position of about 90 degr.

The observation that the shapes of the torque velocity curves show no essential differences at both starting positions is not surprising if we assume that the mechano-chemical characteristics of the muscle determine the relationship between torque and velocity. The starting position does not affect the diminishing time available to form cross bridges at the increasing angular velocities, resulting in a lower maximal torque.

However, the explanation of the lower level of the entire torque velocity curve produced at a starting position of 60 degr. is more complicated. Starting the contraction at 60 degr. instead of 90 degr. causes an increase of the time available to complete the isokinetic contraction, lengthening of the knee extensor muscles and a change of the mechanical circumstances of the knee joint.

In figure 2.6 the consequences of the change of the starting position are illustrated. In order to make the discussion less complex the torque time relationship of the male subjects at both starting positions is schematically illustrated in a simplified form. Mean torque at the end of the initial isometric phase, mean torque at a joint position of 90 degr. and mean maximal torque are determined from the individual torque angle curves and related to the time elapsed since the onset of the dynamic contraction. The angular velocity of 60 degr./sec. is left out. Finally, because in the female subjects the influence of the starting position is the same as in the male subjects, the assumption is made that the torque time relationships (and the discussion which is based upon this relationship) are essentially the same in both sexes.

This schematical approach of the torque time relationship reveals that the mean isometric torque ( $t = 0$  sec.), produced during the initial isometric phase of the contraction, is considerably lower when the contraction starts at 60 degr. The time available to build up torque in this initial phase is the same at both starting positions (150 msec.).

The vertical bars indicate the end of the acceleration phase. At a starting position of 90 degr. and an angular velocity of 90 degr./sec. maximal torque is reached very soon after the end of the acceleration phase. At a starting position of 60 degr. and an angular velocity of 90 degr./sec. the acceleration phase ends just before a joint position of 90 degr. is reached. Subsequently, torque increases rapidly to its maximum in a short time.

At the angular velocity of 30 degr./sec. and a starting position of 60 degr., torque increases before a joint position of 90 degr. is reached. Between 90 degr. and maximal torque the increase of torque runs parallel with the torque increase found at a starting position of 90 degr.

The explanation for the lower isometric torque at a starting position of 60 degr. is most probably that the length of the knee extensor muscles and the mechanical circumstances of the knee joint (e.g. the direction of the force exerted by the ex-

tensor muscles with regard to the position of the patella and of the patellar tendon and its insertion to the tibia) are less favourable for producing torque than at a starting position of 90 degr. Williams and Stutzman (1959) also showed that maximal isometric torque of the knee extensors at 90 degr. is higher than maximal torque at a position earlier in the r.o.m.

The consequence of the lower torque at the end of the isometric phase at a starting position of 60 degr. is that the muscle has to make up for the difference. Despite the increase of the time available to complete the isokinetic contraction the muscle appears not to be capable of making up for the considerable lower torque level existing at the beginning of the contraction at 60 degr. Thus the difference of maximal torque at an angular velocity of 30 degr./sec. seems to result primarily from the relatively low initial torque of the contraction starting at 60 degr.

At an angular velocity of 90 degr./sec. it is more difficult to use this explanation for the lower maximal torque of the contraction starting at 60 degr. If the contraction starts at 90 degr. the acceleration to the preset velocity of 90 degr./sec. takes half a second and maximal torque is reached when the isokinetic phase just starts. There is hardly time to build up torque. If the contraction starts at 60 degr. the acceleration phase ends well before a joint position of 90 degr. and an increase of torque is found between 90 degr. and m.t.j.p. This increase, however, is not sufficient to make up for the difference of torque present at the beginning of the contraction.

It is concluded that the lower mean maximal torque values, which are found when the starting position is changed from 90 to 60 degr., seem to be primarily caused by the lower initial torque of the contraction that starts at a joint position of 60 degr.

#### Starting position and m.t.j.p.

Except for the influence on maximal torque, the starting position has consequences for m.t.j.p. as well. Table 2.5 shows that in both the male and female subjects m.t.j.p. shifts to a more extended position in the r.o.m. when the starting position is changed from 90 to 60 degr.

This observation conflicts with the explanation Moffroid et al. (1969) gave for the shift of m.t.j.p. at increasing angular velocities. They stated that at higher angular velocities the knee joint passes by the point of optimal biomechanical performance by the time the contractile component attains maximal tension and as a result maximal torque tends to occur later in the r.o.m. Starting the isokinetic contraction at 60 degr. instead of 90 degr. increases the time to develop torque. It was therefore expected that the shift of m.t.j.p. (caused by increasing the angular velocities) of the contraction starting at 60 degr. would be less than the shift at a starting position of 90 degr. The opposite effect was found. Increasing the time available to develop torque brings about a further shift of m.t.j.p. towards extension.

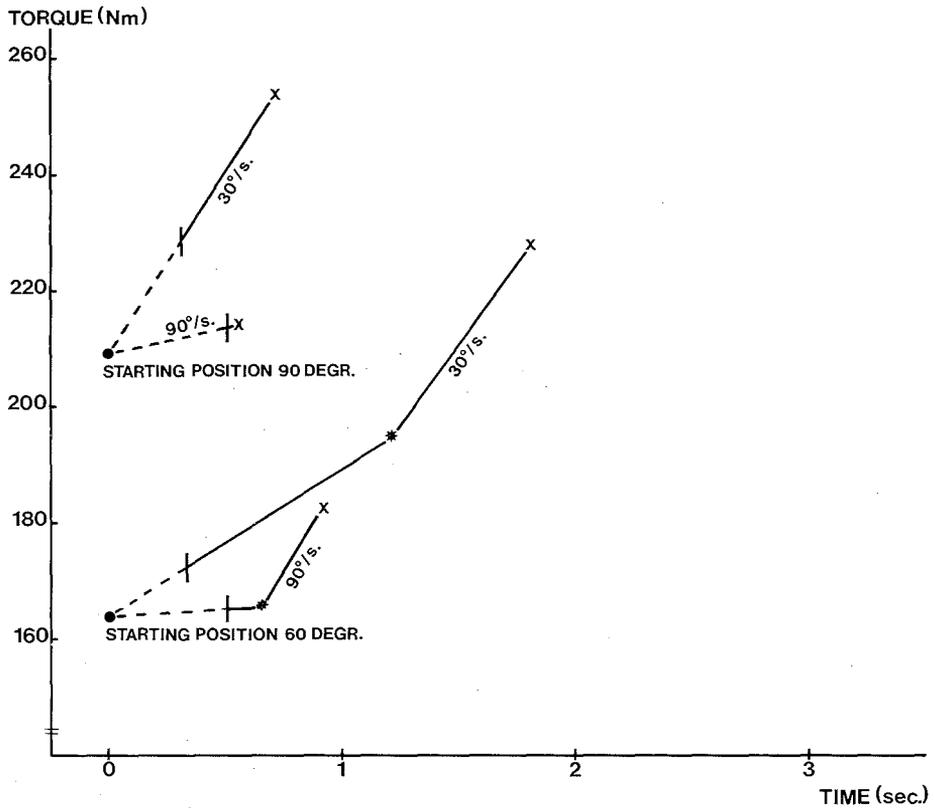


Fig. 2.6 Schematical representation of the torque time relationship at both starting positions and at angular velocities of 30 and 90 degr./sec.

- = mean torque at end of isometric phase
- \* = mean torque at 90 degr.
- × = mean maximal torque
- = acceleration phase

Obviously other factors than the relatively simple biomechanical explanation of Moffroid et al. (1969) must play an important role.

The results of this study do not allow for a decision upon the fundamental processes underlying the phenomena described above. It is not sure to what extent the design of the Q.D. is responsible for the decrease of maximal torque and for the shift of m.t.j.p. caused by changing the starting position from 90 to 60 degr. Certainly also factors like intrinsic biomechanical and biochemical characteristics of the knee extensors and neuromuscular processes have their influence on maximal torque and the position in the r.o.m. where maximal torque occurs.

## 2.5 References.

Fenn W O, Marsh B S.

Muscular force at different speeds of shortening.

J. Physiol. (Londen) 85: 277-297, 1935.

Goslin B R, Charteris J.

Isokinetic dynamometry: Normative data for clinical use in lower extremity (knee) cases.

Scand. J. Rehab. Med. 11: 105-109, 1979.

Gransberg L, Knutsson E.

Determination of dynamic muscle strength in men with acceleration controlled isokinetic movements.

Acta Physiol. Scand. 119: 317-320, 1983.

Hill A V.

Heat of shortening and dynamic constants in muscle.

Proc. Roy. Soc. London (B) 126: 136-195, 1938.

Hislop H J, Perrine J J.

The isokinetic concept of exercise.

Phys. Ther. 47: 114-117, 1967.

Ingemann-Hansen T, Halkaer-Kristensen J.

Force velocity relationships in the human quadriceps muscles.

Scand. J. Rehab. Med. 11: 85-89, 1979.

Knapik J J, Wright J J, Mawdsley R H, Braun J.

Isometric, isotonic and isokinetic torque variations in four muscle groups through a range of joint motion.

Phys. Ther. 63: 938-947, 1983.

Moffroid M, Whipple R, Hofkosh J, Lowman E, Thistle H.

A study of isokinetic exercise.

Phys. Ther. 49: 735-747, 1969.

Moffroid M, Kusiak E T.

The power struggle.

Phys. Ther. 55: 1098-1104, 1975.

Murray M P, Gardner G M, Mollinger L A, Sepic S B.  
Strength of isometric and isokinetic contractions.  
Phys. Ther. 60: 412-419, 1980.

Nelson S G, Duncan P W.  
Correction of isokinetic and isometric torque recordings for the effects of gravity.  
Phys. Ther. 63: 674-676, 1983.

Williams M, Stutzman L.  
Strength variation through the range of joint motion.  
Phys. Ther. Rev. 39: 145-152, 1959.

Winter D A, Wells R P, Orr G W.  
Errors in the use of isokinetic dynamometers.  
Eur. J. Appl. Physiol. 46: 397-408, 1981.

## CHAPTER 3.

### ISOMETRIC AND ISOKINETIC DYNAMOMETRY: VARIABILITY AND SPECIFICITY.

#### 3.1 Introduction.

The inter- and intraindividual variability of muscle strength, like other parameters of human performance, is generally known.

Knowledge of the variability of strength measurements is necessary in order to interpret the results of dynamometry of individual subjects during a follow-up study or when comparing individual strength with a reference group. For example, when a patient is tested during a training program an improvement of maximal torque may be caused by real strength gain and/or by the intraindividual variation of strength over days or weeks. Data of interindividual variability of groups are needed to decide whether an individual strength test is normal or not.

The variability of strength consists mainly of a biological and a methodological part, which are difficult to distinguish.

The biological variability in a group of subjects is to a large extent influenced by sex, height, bodymass, age and general health and is the most important cause of interindividual variability.

The type of dynamometer, testing position, testing protocol and sort of feedback contribute to the methodological variability. The influence of these methodological factors can be restricted by taking the necessary precautions during dynamometry.

Intraindividual variability is often studied by determination of the reproducibility. Reproducibility means to what extent a test, repeated after a certain interval, produces the same results. When the circumstances are held constant it theoretically represents the biological variability of an individual subject. Reproducibility is usually expressed as a correlation coefficient of two consecutive tests (test-retest correlation =  $r$ ) or as the coefficient of variation (C.V.), which is the ratio of the standard deviation and the mean expressed in a percentage. A high reproducibility is one of the main criteria for acceptance of a parameter in a test-battery (Viitasalo et al. 1980).

Data of the inter- and intraindividual variability of torque measurements performed on the Q.D. are not available. In this study the variability of strength, measured during test-sessions in consecutive weeks, is determined.

Furthermore, the relationship between isometric and isokinetic torque measurements is studied to determine to what extent both ways of strength testing measure the same phenomenon and to decide whether to use only one or both strength testing modes in future studies.

### 3.2 Materials and methods.

Thirty-four healthy volunteers (18 males and 16 females) participated in this study.

Group data, concerning age, bodyheight and bodymass, are presented in table 3.1.

*Table 3.1* Means and (S.D.) of age, height and bodymass of the male and female subjects.

	males (n=18)	females (n=16)
age (years)	22.3 (1.37)	22.5 (4.79)
height (m)	1.80 (0.10)	1.72 (0.06)
bodymass (kg)	67.3 (7.69)	64.1 (6.6)

None of the subjects had a history of knee-injury or knee-malfunction. The subjects had no experience with isometric or isokinetic dynamometry. Before actual testing took place the aim and procedure of the study were explained.

One session was spent on theoretical and practical instruction of the subjects. Three test sessions took place with one week intervals. This frequency was chosen arbitrarily. Each subject was tested on the same time of the day as the week before.

The dominant leg was submitted to testing and dominance was determined by asking the subject which leg he preferred for kicking a ball.

In order to prevent competition, information on the results of other subjects was not given. No visual feedback was given, but the subjects were verbally encouraged to perform at their best. All sessions were supervised and executed by the same two assistants.

Positioning on the Q.D. was the same as described in 2.1.

The angular velocities were 0 (isometric), 45 and 90 degr./sec. (isokinetic).

Two maximal contractions were performed at each angular velocity and the second torque angle curve was used for calculations.

Isometric torque was always tested first. Subsequently isokinetic tests at 45 and 90 degr./sec. were performed.

Isometric torque was measured at a knee angle of 120 degr. Isokinetic torque was obtained from the torque angle curve at an angle of 120 degr. This joint position was chosen in order to measure torque in the isokinetic phase and to compare torque values produced isometrically and at both isokinetic angular velocities. In this way torque was measured at the same position in the r.o.m. and therefore at the same muscle length.

The range of motion was from 75 to 180 degr.  
One minute rest periods were allowed between maximal contractions.

#### Statistical analysis.

Means, standard deviations and coefficients of variation of torque registered at a joint position of 120 degr. were calculated.

A two-way analysis of variance was used to determine the contribution to variability of the subjects (interindividual variability) and of time (intraindividual variability during week 1, 2 and 3).

The absolute torque values (of the male and female subjects separately), recorded at the respective angular velocities (0, 45 and 90 degr./sec.) were transformed into percentages. For example: the mean of the torque values of the male subjects, recorded at 0 degr./sec. in week 1, 2 and 3 was fixed at 100%. Subsequently, the absolute torque values (in Nm) of each subject during week 1, 2 and 3 could be expressed as a percentage of this mean value. The reason for transformation of the absolute numbers into percentages was to create the possibility to use a two-way and a three-way analysis of variance.

Using absolute torque values in the analysis of variance would introduce an over-estimation of the angular velocity as a source of variability.

Using percentages reduces the influence of angular velocity on torque output and creates the possibility to compare variability at the three testing speeds more accurately.

The three-way analysis of variance, using angular velocity, subjects and weeks as sources, was chosen to study variability in more detail.

Pearson correlation coefficients were calculated to assess the specificity of isometric and isokinetic dynamometry of the knee extensors.

### 3.3 Results.

The results are presented in table 3.2, 3.3, 3.4 and 3.5.

Table 3.2 shows the means, standard deviations and coefficients of variation of the torque measurements expressed in Nm and percentage.

*Table 3.2* Means, (S.D.) and C.V. of torque (Nm) at a knee angle of 120 degr., in the group of male and female subjects, in week 1, 2 and 3 and at angular velocities of 0, 45 and 90 degr./sec.

		week			mean
		1	2	3	
males	0	202 (44)	205 (40)	211 (44)	206 Nm
		98	100	103	100 %
		22	20	21	21 C.V.
	45	158 (33)	160 (29)	171 (35)	140 Nm
		97	98	105	100 %
		21	18	20	20 C.V.
	90	135 (39)	138 (22)	148 (25)	140 Nm
		96	98	105	100 %
		29	16	17	21 C.V.
females	0	170 (27)	162 (23)	167 (26)	166 Nm
		102	98	100	100 %
		16	14	16	15 C.V.
	45	123 (39)	124 (26)	120 (24)	122 Nm
		101	102	98	100 %
		32	21	20	24 C.V.
	90	105 (23)	103 (22)	102 (22)	103 Nm
		102	99	99	100 %
		22	21	22	22 C.V.

The mean torque values appear to be rather the same at the weeks of testing. Only in the male group there is a tendency of an increase of mean isokinetic torque from

week 1 till week 3. The C.V.'s also remain at about the same level in both groups. The results of the two-way analysis of variance are presented in table 3.3.

*Table 3.3* Inter- and intraindividual variability (%) of the group of male and female subjects and at angular velocities of 0, 45 and 90 degr./sec.

		interindividual	intraindividual variability
angular velocity			
degr./sec.			
males	0	19.8	6.9
	45	17.6	9.9
	90	16.1	10.9
females	0	13.2	7.4
	45	19.7	9.8
	90	19.1	9.0

The interindividual variability is substantial and ranges from 13.2 to 19.8%. The intraindividual variability ranges from 6.9 to 10.9%. The isometric torque values show a smaller intraindividual variability when compared with the isokinetic values.

Table 3.4 and 3.5 show the results of the three-way analysis in male and female subjects respectively.

*Table 3.4* Three-way analysis of variance of the male subjects.

(\* =  $p < 0.05$ , \*\* =  $p < 0.01$ , \*\*\* =  $p < 0.001$ , NS = not significant).

source	df	SS	MS	F	P
angular velocity	2	0	0	0	
subjects	17	44092	2594	66.5	***
weeks	2	1645	822	5.48	**
ang. veloc. x subjects	34	7825	230	5.90	***
ang. veloc. x weeks	4	113	28	<1	NS
subjects x weeks	34	5116	150	3.85	***
rest	68	2649	39		
total	161	61440			

*Table 3.5* Three-way analysis of variance of the female subjects.

(\* =  $p < 0.05$ , \*\* =  $p < 0.01$ , \*\*\* =  $p < 0.001$ , NS = not significant).

source	df	SS	MS	F	P
angular velocity	2	0	0	0	
subjects	15	35357	2357	42.9	***
weeks	2	188	94	<1	NS
ang. veloc. x subjects	30	9855	329	5.98	***
ang. veloc. x weeks	4	194	49	<1	NS
subjects x weeks	30	3751	125	2.27	**
rest	60	3300	55		
total	143	52645			

The correlation matrix of the respective testing modes (isometric = 0 degr./sec. and isokinetic = 45 and 90 degr./sec.) is presented in table 3.6

*Table 3.6* Correlation coefficients of torque measurements at angular velocities of 0, 45 and 90 degr./sec. at a knee angle of 120 degr.

angular velocity	0	45	90
0	1	.70	.56
45	.70	1	.92
90	.56	.92	1

The correlation coefficients of the isometric and the isokinetic contractions of 45 and 90 degr./sec. amount to .70 and .56 respectively and are statistically significant ( $p < 0.05$ ). Both isokinetic contractions show a high correlation coefficient of .92.

### 3.4 Discussion.

Absolute torque values.

When the results of table 3.2 are compared with those of other authors, some differences are found. This may be explained by differences in age, bodymass, height, testing device, testing protocol, etc.

Larsson et al. (1979) and Thorstensson et al. (1976) tested populations of about the same age and found similar isometric and isokinetic torque values of the knee

extensors as presented in table 3.2. Unfortunately, they did not present S.D.'s and therefore variability in their studies cannot be compared.

Goslin and Charteris (1979) determined maximal isokinetic torque of the knee extensors of 60 young adult male and female subjects. C.V.'s in their study ranged from 9 to 25% in the men and from 15 to 23% in the women.

Knapik (1980) tested the knee extensors of 352 male soldiers and found a mean isometric torque (at a knee angle of 120 degr.) of 230 Nm (S.D. = 50) and a mean isokinetic peak torque at 90 degr./sec. of 130 Nm (S.D. = 30). The rather high C.V.'s (22 and 23% respectively) probably result from the fact that he studied a large population in which age, bodymass and height varied considerably.

Murray et al. (1980) studied a group of men with an age of 20-35 years and found a maximal isometric torque of 272 Nm at a joint position of 120 degr. The C.V. was 3.5%.

In general the mean torque values and the C.V.'s of this study are in agreement with the data presented by other authors using a Cybex II dynamometer.

#### Two-way analysis of variance.

Whereas the coefficient of variation in table 3.2 represents overall variability, the two-way analysis of variance of table 3.3 gives information about the interindividual and the intraindividual variability separately. The results of this analysis show that the interindividual variability ranges from 13.2 to 19.8%.

Thorstensson et al. (1976) found an overall variation of 13.7% of duplicate maximal torque determinations of the knee extensors. These tests were done on two separate days and at angular velocities between 0 and 180 degr./sec. However, his population, 25 male subjects, was more homogeneous with regard to height and bodymass.

The intraindividual variability in table 3.3 ranges from 6.9% to 10.9%. The smaller intraindividual variability of isometric torque values in both male and female subjects may be explained by the simplicity of an isometric contraction compared to the relatively more difficult task of an isokinetic contraction.

The intraindividual variability shows that, when the results of a strength test of the knee extensors performed on the Q.D., have to be interpreted a large margin has to be taken into account.

If, for example a subject, submitted to a strength training program, shows an increase in knee extensor torque of 5-10%, the effectiveness of the training program is not proven. The higher torque may as well be the result of the intraindividual variability.

### Three-way analysis of variance.

The three-way analysis of variance (table 3.4 and 3.5) gives more detailed information on the sources of variability. Angular velocity, subjects and weeks represent the sources. As a result of the reduction of the absolute torque values to percentages the SS (sum of squares) and the MS (mean of squares) of angular velocity equals zero.

The subjects contribute significantly ( $p < 0.001$ ) to variability in both the male and the female group. This corresponds, as could be expected, with the results of the two-way analysis of variance.

The weeks contribute to variability significantly ( $p < 0.01$ ) in the male, but not in the female subjects. This finding, the different influence of time on torque measurements in the male and female group, corresponds with the results presented in table 3.2 Mean torque in the male group tends to increase gradually from week 1 to week 3.

Angular velocity x subjects is a significant source ( $p < 0.001$ ) of variability. This indicates that the individual subject performs differently at the respective angular velocities. For example, the subject with the highest isometric torque value is only the sixth best in isokinetic testing at 45 degr./sec. and ninth best at 90 degr./sec. This finding will be worked out in more detail when the correlations between the different testing speeds are discussed.

Angular velocity x weeks is no significant source. This means that the influence of weeks is the same at each angular velocity. The increase of torque values in the male subjects from week 1 to week 3 is found in the isometric test as well as in both isokinetic tests.

Subjects x weeks is a significant source of variability in both the male ( $p < 0.001$ ) and the female subjects ( $p < 0.01$ ). Although in the male subjects the mean torque values increase from one week to the next, this does not apply to the same extent to every individual subject. One subject may show a larger increase than the other. It is even possible that some subjects produce decreasing torque values. The mean torque measurements of the female subjects stay at about the same level from week 1 to week 3. The three-way analysis of variance reveals that this does not apply to all female subjects. Whereas one female shows increasing torque output the other may show a decrease from one week to the other.

The general conclusion of the analysis of variance is that there is a considerable variability in the way that individual subjects perform when torque of the knee extensors is measured in an isometric or isokinetic way on a Q.D., with one week intervals.

## The relationship between isometric and isokinetic dynamometry.

The correlation coefficients ( $r$ ) between isometric and both isokinetic contractions (45 and 90 degr./sec.) amount to .70 and .56 respectively (table 3.6). These are significant positive correlations.

The specificity of isometric and isokinetic dynamometry can be determined by calculating the common and specific variance of these two types of muscular contraction. Squaring the derived correlation coefficients results in a common variance ( $r^2$ ) of 49% (0 and 45 degr./sec.) and 31% (0 and 90 degr./sec.). This means that only 49% and 31% of the variability of the isometric test is explained by the variability of the isokinetic test at 45 and 90 degr./sec. respectively.

The specific variance of 69% ( $1-r^2$ ) indicates a higher degree of specificity of isometric and isokinetic torque measurements at 90 degr./sec. This means, for example, that an isometric test cannot simply be used to predict the outcome of an isokinetic test.

The common variance of both isokinetic measurements amounts to 85%. Thus the specificity of the test at 45 and 90 degr./sec. is low (15% specific variance). Both tests probably measure the same aspect of strength.

Knapik (1980) found correlation coefficients of .77 and .76 between isometric torque and isokinetic torque at 30 and 90 degr./sec. respectively. The correlation coefficients between both isokinetic torque values was .85. In that study the author tested 352 male volunteers and used maximal torque readings for his calculations. In a later study (Knapik et al. 1980) on 16 male volunteers he found correlation coefficients of .83 and .82 between isometric maximal torque and isokinetic maximal torque at an angular velocity of 36 and 108 degr./sec. respectively. Knapik et al. concluded that one mode of strength testing may be adequate to predict a large portion of the strength in a second mode of testing.

Lankhorst et al. (1985) studied 42 patients with osteoarthritis of the knee and present correlation coefficients of .90, .86 and .84 between isometric knee extensor torque and isokinetic torque at 30, 60 and 120 degr./sec.

The interpretation and comparison of correlation coefficients presented in various studies is very difficult and sometimes even impossible. The  $r$ -value is influenced by several factors like the number of subjects, the composition of the population and variability. One or two exceptionally high or low values may increase the  $r$ -value substantially and lead to false conclusions. Therefore, the results of this study are not necessarily comparable with or contradictory to the results of other authors.

It is concluded that isometric torque values cannot be used to predict accurately the performance in an isokinetic test. The common and specific variance, based on the correlation coefficients, indicates that isometric and isokinetic torque measurements should both be used in strength testing.

### 3.5 References.

Armstrong L E, Winant D M, Swasey P R, Seidle M E, Carter L A, Gehlsen G.  
Using isokinetic dynamometry to test ambulatory patients with multiple sclerosis.

Phys. Ther. 63: 1274-1279, 1983.

Goslin B R, Charteris J.

Isokinetic dynamometry: normative data for clinical use in lower extremity (knee) cases.

Scand. J. Rehab. Med. 11: 105-109, 1979.

Knapik J J.

Isokinetic and isometric torque relationships in the human body.

Arch. Phys. Med. Rehabil. 61: 64-67, 1980.

Knapik J J, Wright J E, Mawdsly R H, Braun J M.

Isometric, isotonic and isokinetic torque variations in four muscle groups through a range of joint motion.

Phys. Ther. 63: 938-947, 1983.

Knapik J J, Wright J E, Mawdsly R H, Braun J M.

Isokinetic, isometric and isotonic strength relationships.

Arch. Phys. Med. Rehabil. 64: 77-80, 1983.

Lankhorst G J, v.d. Stadt R J, v.d. Korst J K.

The relationships of functional capacity, pain and isometric and isokinetic torque in osteoarthritis of the knee.

Scand. J. Rehab. Med. 17: 167-172, 1985.

Larsson L, Grimby G, Karlsson J.

Muscle strength and speed of movement in relation to age and muscle morphology.

J. Appl. Physiol. 46: 451-456, 1979.

Murray M P, Gardner G M, Mollinger L A, Sepic S B.

Strength of isometric and isokinetic contractions.

Phys. Ther. 60: 412-419, 1980.

Thorstensson A, Grimby G, Karlsson J.  
Force-velocity relations and fiber composition in human knee extensor muscles.  
J. Appl. Physiol. 40: 12-16, 1976.

Viitasalo J T, Sankkonen S, Komi P V.  
Reproducibility of measurements of selected neuromuscular performance variables in man.  
Electromyogr. Clin. Neurophysiol. 20: 487-501.

## CHAPTER 4.

# DYNAMOMETRY OF THE KNEE EXTENSORS OF MENISCECTOMY PATIENTS.

### 4.1 Introduction.

Most studies on dynamometry of the knee extensors describe torque measurements of healthy subjects or elite athletes. In rehabilitation medicine, however, clinicians are usually more interested in an objective quantification of strength in patients.

The reliability of strength test results with patients is, more than with healthy subjects, influenced by inhibiting factors, such as pain, joint swelling, joint stiffness and fear of injury (Westers 1982).

Another matter that may affect the clinical application of dynamometry is the relation between deterioration of muscle strength and decrease of functional capabilities. It is, for example, very difficult to predict, on the basis of a low torque value, to what extent an individual will have problems with standing, walking, jumping, etc. (Lankhorst et al. 1982).

Even in healthy subjects the relationship between torque measurements and functional capabilities is not always clear (Aniansson et al. 1980; Danneskiold-Samsoe et al. 1984).

It is not known whether isometric torque measurements have the same validity in the prediction of functional capabilities as isokinetic torque measurements.

The observation, described in chapter 3, that the correlation between isometric and isokinetic torque is low and that both ways of strength testing measure a different aspect of force development, implies that their relationship with functional capabilities and their predictive validity may be different.

The purpose of the study, presented in this chapter, is:

- to study the strength of the knee extensors with isometric and isokinetic dynamometry during a training period of patients after meniscectomy.
- to study the predictive validity of isometric and isokinetic dynamometry of the knee extensors.

### 4.2 Materials and methods.

Subjects.

The patient group consisted of military personnel referred to an army rehabilitation centre for aftertreatment of meniscectomy of the knee. Surgery was done by the orthopaedic surgeons of the Military Hospital 'Dr. A. Mathijssen'. Menis-

cectomy was carried out only after arthrographic and/or arthroscopic proof of a torn meniscus. The post surgical regime consisted of bedrest, gradual mobilisation with crutches and a knee splint and isometric strength training of the leg muscles. The patients were referred to the rehabilitation centre 10 to 14 days after surgery. All military personnel is obliged to submit to aftertreatment of a meniscectomy in this rehabilitation centre.

Reasons to exclude patients from the study were:

- the use of antiflogistic or analgetic drugs.
- recurrent arthrotomy of the knee.
- ligamental instability of the knee.
- damage to the cartilage of the knee joint.

This medical information was obtained from the written discharge report provided by the orthopaedic surgeon. No further selection took place and every patient, not excluded by the criteria mentioned above, was tested.

Twenty-two patients participated in the study.

In order to be able to distinguish between the effect of repeated measurement of knee extensor torque and the effect of treatment, a control group was formed. The control group consisted of conscripts temporarily employed in the rehabilitation centre. The subjects of this group had no history of serious general diseases nor of any knee complaints or dysfunction. They were not actively involved in a training or treatment programme and had to be available for strength testing during a period of 8 weeks. No other selection criteria were used. The control group consisted of eleven subjects.

Informed consent was obtained, before the first testing session, from each patient and each subject in the control group.

Training programme.

All patients were submitted to a standard training programme of 8 weeks. This programme is described in detail in appendix II. From week 1 to week 6 the patients completed an exercise programme consisting of static and dynamic exercises of the operated leg, five times a week. Resistance was applied by the physiotherapist or by weights on an exercisebench and was gradually increased. In week 7 the physiotherapy programme was partially replaced by sporting activities. In week 8 only sporting activities were prescribed. No isokinetic devices were used in the training programme.

Testing protocol.

All tests of the patients and the control group were carried out on Fridays to reduce the influence of weekend activities. The conscripts were allowed to spend their weekends out. During the week they all lived at the rehabilitation centre.

The first test was done on the Friday of the week of admittance to the rehabilitation centre (week 0). The mean time elapsed between the meniscectomy and the

first test was 16.5 days (S.D. = 4.4). The tests were repeated 2, 4, 6 and 8 weeks later.

Three physiotherapists were instructed and trained to examine the patients and to supervise the tests.

Before the first test session the following data were collected:

- personal data such as name, address, date of birth, etc.
- date of first test.
- date of surgery.
- date of admission to the rehabilitation centre.
- dominance of the legs.
- site of the meniscectomy (right/left knee and medial/lateral).

Bodymass and height were assessed before the first test.

During every test session pain, swelling and the active range of motion of the knees were registered.

#### Pain.

The subjects were asked to report their complaints of pain in general (i.e. during the week) and during the test respectively. In both cases pain was scored on a 5-point scale:

- 0 = no pain.
- 1 = occasional moderate pain.
- 2 = continuous moderate pain.
- 3 = occasional severe pain.
- 4 = continuous severe pain.

#### Swelling.

Swelling of the knee was scored by the physiotherapist before strength testing took place. A 4-point scale was used:

- = no clinical signs of intra-articular effusion.
- + - = clinical signs of intra-articular effusion without a patellar tap sign.
- + = patellar tap sign after compression of the supra-patellar pouch.
- + + = patellar tap sign without compression of the supra-patellar pouch.

This semiquantitative method to determine the swelling of the knee is subjective, but the physiotherapists were very experienced in using this scale in consequence of a previous study on the treatment of effusion of the knee (Stam et al. 1982).

#### Range of motion.

Traumatic arthritis of the knee is often accompanied by a restricted active and passive r.o.m. The capsular pattern consists of a great limitation of flexion and a

slight limitation of extension (Cyriax 1978). The active r.o.m. was determined by the physiotherapist before testing took place. The patient was positioned supine on an examination bench and was requested to bend and extend the knee. Maximal flexion and extension of both knees were determined with a goniometer.

#### Dynamometry.

In the patient group isometric and isokinetic torque of the knee extensors of both legs were measured with the Quadriceps Dynamometer (Q.D.). Dynamometry of the non-operated leg was performed in order to obtain a torque value to which the result of the measurement of the operated leg for each subject could be compared. In this way individual loss of strength could be determined. The non-operated leg was always tested first.

Only the dominant leg was tested with the Q.D. in the control group. Dominance of the leg was determined by asking the subject which leg he preferred when kicking a ball.

Isometric torque was measured at a joint position of 115 degr. (180 degr. = full extension).

Isokinetic torque was always tested after the isometric contraction and was carried out at an angular velocity of 90 degr./sec. Only one isokinetic test speed was used to prevent mental or physical fatigue caused by repeated maximal contractions.

The r.o.m. was 100 degr. (i.e. from 75 degr. flexion to 175 degr. extension). Several submaximal contractions were allowed to get accustomed to the test and to warm up for the maximal contractions.

Three maximal voluntary contractions were performed at 0 and 90 degr./sec. and the highest torque reading was used for calculations.

Positioning on the Q.D. was the same as described in chapter 2.

#### Functional test.

All patients were able to walk, to stand, to climb stairs, etcetera. A more difficult test was therefore used to test the knee extensors under functional circumstances. The vertical jump test may be considered as a simple test for explosive leg strength in which the knee extensors play an important role. Gray et al. (1962) showed that the test-retest reliability of the vertical jump test is high ( $r = .975$ ).

The subject was standing sideways by a blackboard hanging from the ceiling with the arm extended above the head and next to the board. The height of the extended arm was marked on the board with a piece of chalk. After adopting a squat position, the subject jumped upward and marked the maximum height of the jump on the board by means of the piece of chalk. Jump height was defined as the difference between both marks on the blackboard and expressed in centimeters. Three attempts were made and the best was scored (Berger and Henderson 1966).

If only jump height is used to measure vertical jump performance, the body-mass of a subject is not taken into consideration. A subject with a bodymass of 80 kg and a jump height of 50 cm performs better (more work is done) than a subject of 60 kg and a jump height of 50 cm. Therefore jump height was converted to external work in terms of Joule by the formula:

$$\text{bodymass (kg)} \times \text{jump height (m)} \times 9.81 \text{ m/sec}^2 = \text{external work (Joule)}.$$

Statistical analysis.

The statistical analysis was descriptive and correlative. Means and standard deviations of the anthropometric data, the torque curve parameters and functional test results were calculated. Pearson correlation coefficients assessed the relationships between knee extensor torque and jumping performance.

A p-value of less than 0.05 was considered significant.

### 4.3 Results.

One subject of the patient group was excluded from the study retrospectively because of taking indomethacine without notifying his physician. The results of 21 patients and 11 control subjects were used for calculations.

In week 8, 7 patients and 3 subjects of the control group were not available for testing because they were ordered back to their army units. The consequences of this smaller number of subjects in week 8 are discussed in paragraph 4.4. Age, height and bodymass of the patients and the control group are presented in table 4.1.

*Table 4.1* Means and (S.D.) of age, height and bodymass of the patients and the control group.

		patients (n=21)	control group (n=11)
age	(years)	20.4 (1.5)	23.0 (1.4)
height	(m)	1.82 (0.06)	1.83 (0.07)
bodymass	(kg)	73.2 (8.2)	73.6 (8.5)

The mean age of the control group is slightly higher than the mean age of the patients. Only small differences between the groups are found in length and body-mass.

Table 4.2 shows the location of the meniscectomy.

*Table 4.2* Location of the meniscectomy.

	right knee	left knee	totals
medial meniscus	7	5	12
lateral meniscus	7	2	9
totals	14	7	21

In the patient group no subject scored 2, 3 or 4 when asked to fill in the pain scale. Complaints of occasional moderate pain (pain score 1) were distributed as shown in table 4.3.

*Table 4.3* Distribution of pain score 1 (occasional moderate pain).

week	0	2	4	6	8
pain in general	4	2	2	3	3
pain during testing	9	4	2	1	2

A considerable number of patients experienced pain during dynamometry and/or jumping, especially in the first week. The subjects of the control group had no complaints of any discomfort or pain.

Table 4.4 presents the results of the examination of swelling of the operated knee.

*Table 4.4* Swelling of the operated knee. (See text for explanation).

week	0	2	4	6	8
intra-articular effusion	-		2	5	9
	+ - 2	12	12	13	3
	+ 15	9	7	3	2
	+ + 4				
totals	21	21	21	21	14

In the first week of testing (week 0) 19 out of 21 patients had moderate to severe symptoms of intra-articular effusion of the knee. During the period of training there is a tendency of gradual reduction of the swelling of the knee.

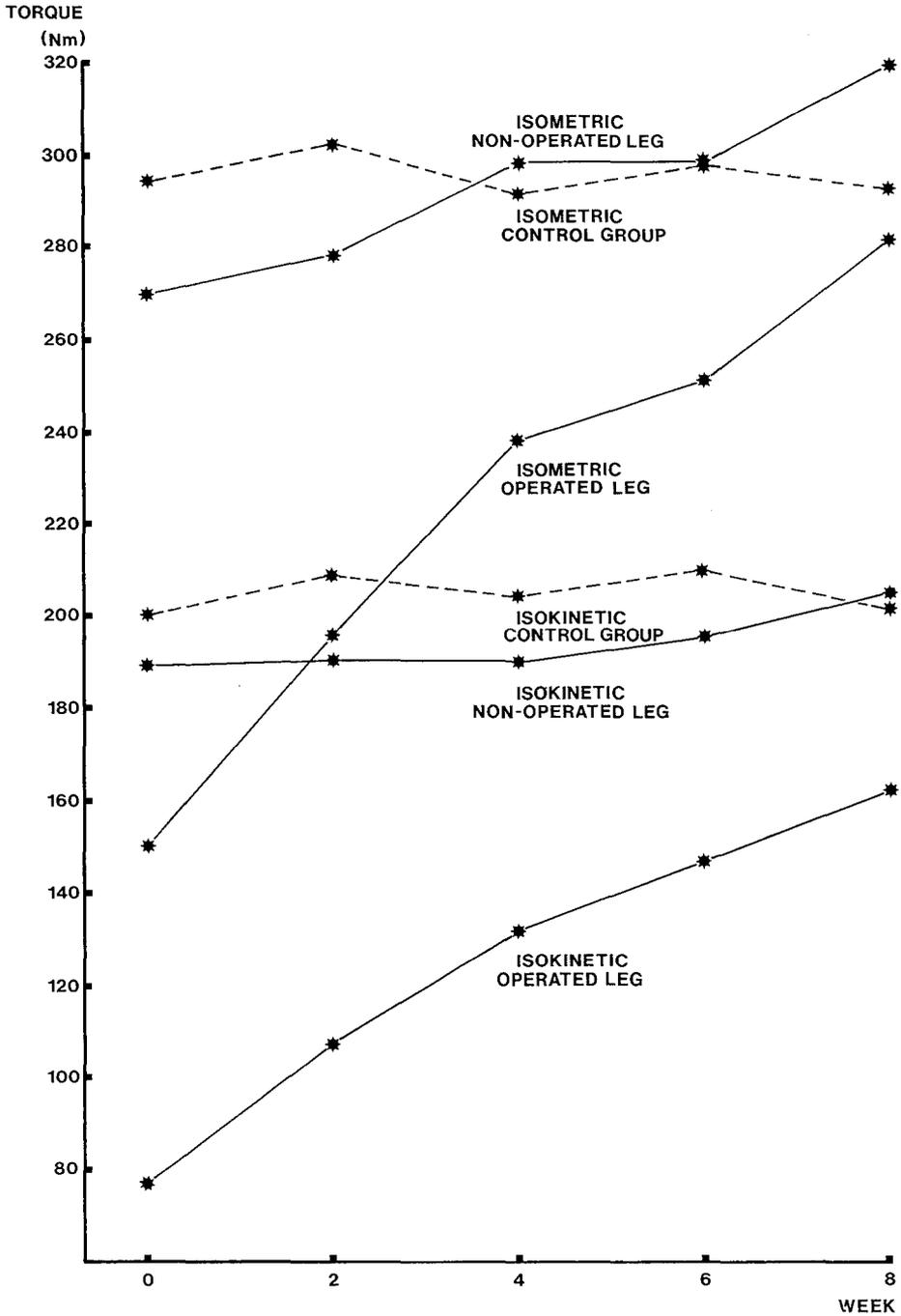


Fig. 4.1 Mean maximal isometric and isokinetic torque of the knee extensors of each legs in the patient group and the dominant leg of the control group.

Knee extension was limited in only 6 patients in week 0. In one of these patients extension was reduced by 20 degrees. In the other 5 cases the deficit was less than 10 degrees. In week 2 all patients had a symmetrical normal knee extension.

The limitation of active knee flexion was determined by comparing the operated and the non-operated knee. Differences were rounded down to every 5 degrees. In table 4.5 the mean differences found at the respective weeks are presented.

*Table 4.5* Knee flexion limitation (degr.). Mean differences and (S.D.) between operated and non-operated leg.

week	0	2	4	6	8
limitation of knee flexion (degr.)	17.4 (11.8)	3.6 (4.1)	1.9 (2.9)	0.7 (1.8)	0.2 (1.4)

The results of maximal isometric and isokinetic torque measurements of the patients and the subjects of the control group are presented in table 4.6.

*Table 4.6* Means and (S.D.) of maximal isometric (Nm) and isokinetic torque (Nm at 90 degr./sec.) of patients and control group.

week	0	2	4	6	8
mean max. isometric torque (Nm)					
operated knee	151 (50)	196 (47)	239 (42)	252 (47)	282 (50)
non-operated knee	270 (53)	279 (53)	299 (48)	299 (51)	319 (57)
control group	294 (37)	302 (41)	293 (56)	298 (45)	292 (47)
mean max. isokinetic torque (Nm at 90 degr./sec.)					
operated knee	77 (32)	112 (33)	132 (24)	147 (28)	164 (28)
non-operated knee	188 (32)	191 (29)	191 (26)	197 (25)	207 (30)
control group	200 (36)	209 (32)	204 (26)	210 (42)	201 (35)

A graphical representation of the mean maximal torque values is shown in figure 4.1. It is obvious that both isometric and isokinetic maximal torque of the operated leg are very low, when compared with the non-operated leg, during week 0. In the successive weeks the isometric and isokinetic torque values of the operated leg gradually increase. There is also a notable improvement of maximal torque of the non-operated leg. This improvement is especially clear in the isometric measurements. The maximal torque values of the subjects of the control group stay at about the same level from week 0 to week 8.

The maximal torque joint position (m.t.j.p.) was determined from the individual isokinetic torque angle curves of the patients and the subjects of the control group. These data are presented in table 4.7.

*Table 4.7* Means and (S.D.) of m.t.j.p. (degr.) of patients and control group.

week	0	2	4	6	8
mean m.t.j.p. operated knee	104 (14)	110 (13)	109 (10)	107 (10)	109 (7)
mean m.t.j.p. non-operated knee	111 (6)	109 (7)	109 (9)	107 (8)	105 (7)
mean m.t.j.p. control group	111 (10)	112 (11)	108 (8)	106 (11)	107 (9)

In order to construct the mean isokinetic torque angle curves torque was determined from the individual curves at every 15 degrees, starting at a joint position of 75 degrees. Mean torque at every joint position was calculated. In figures 4.2, 4.3 and 4.4, the mean torque angle curves of the knee extensors of the operated, the non-operated and the control legs are presented.

The gradual increase over the weeks of the mean torque values of the non-operated leg (table 4.6) interferes with the expression of the strength of the operated leg in a percentage of one normal torque value. The Quadriceps Ratio (Q.R.) of each patient in the respective weeks was therefore calculated. The Q.R. is the ratio (expressed in %) of maximal torque of the operated leg to maximal torque of

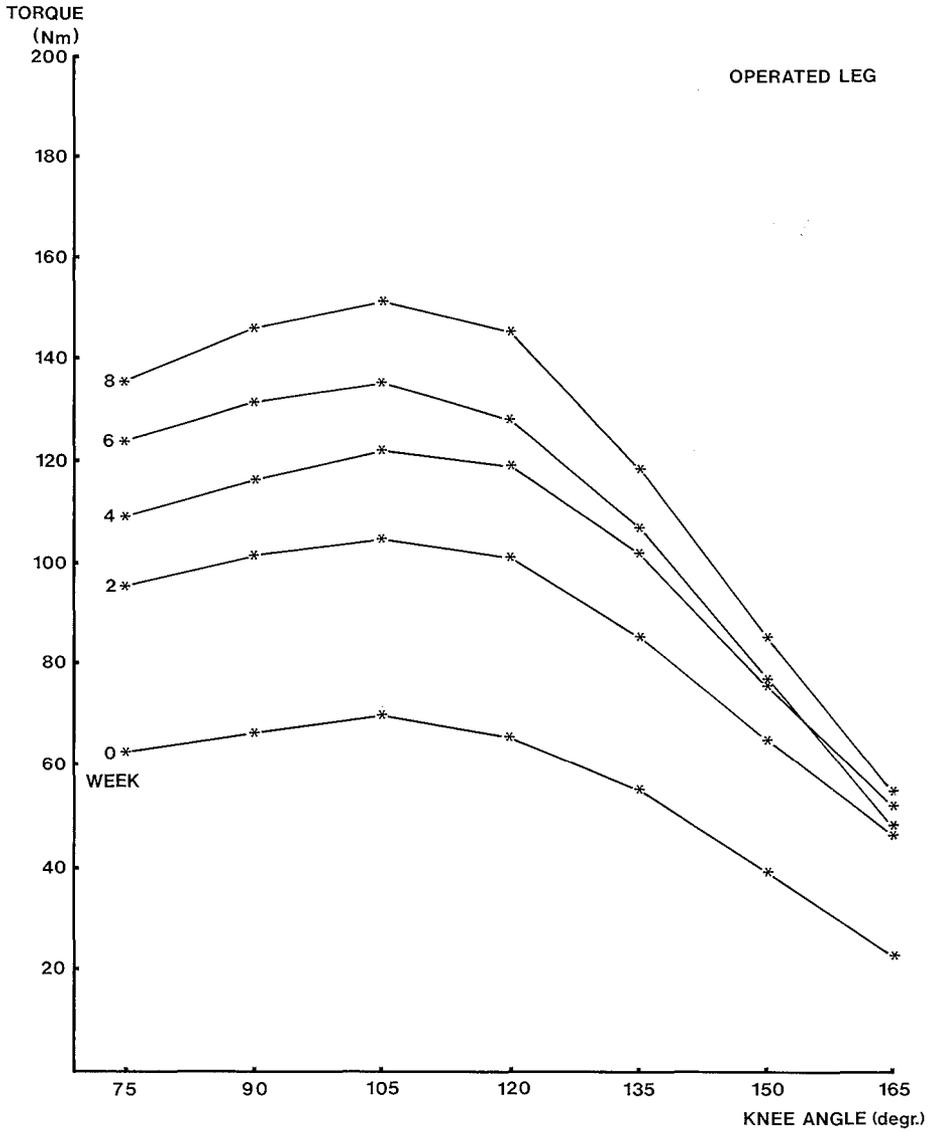


Fig. 4.2 Mean torque angle curves of the knee extensors of the operated leg from week 0 till week 8.

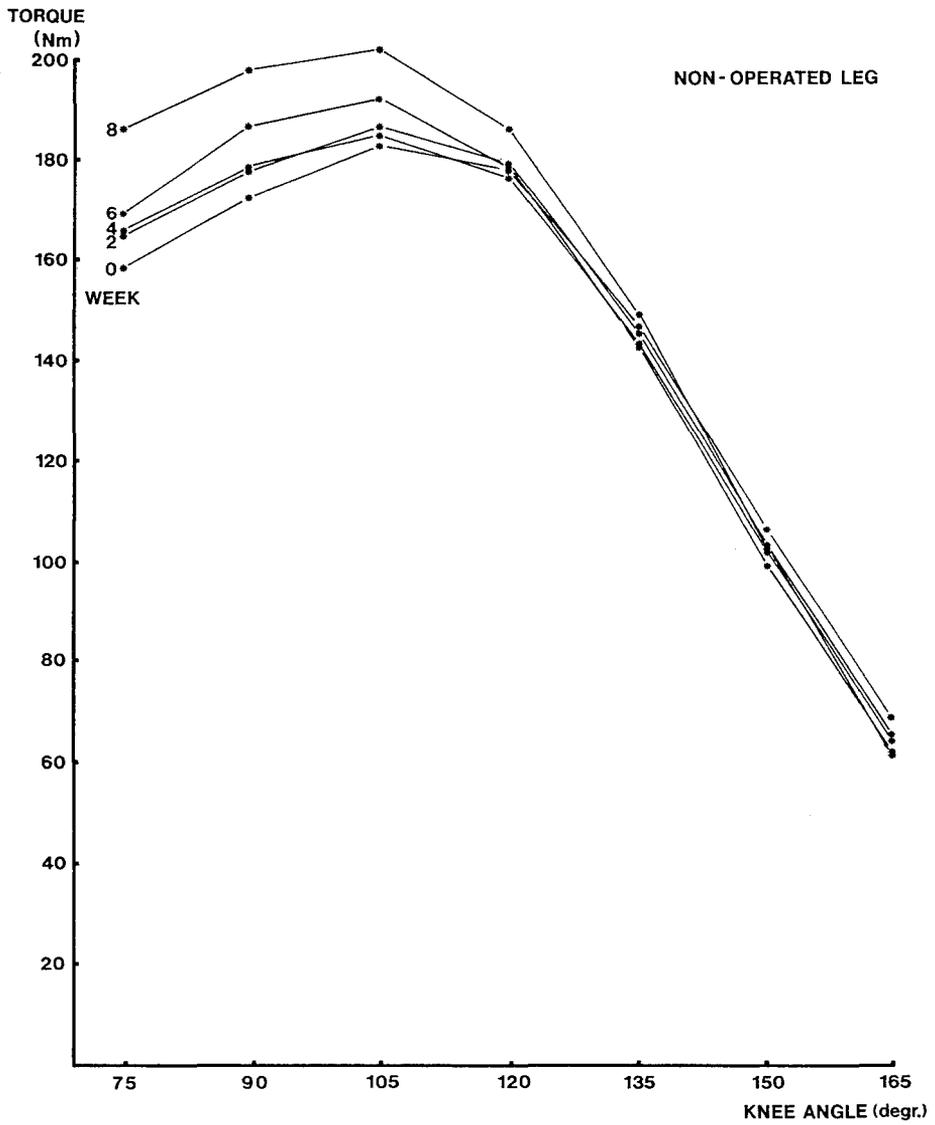


Fig. 4.3 Mean torque angle curves of the knee extensors of the non-operated leg from week 0 till week 8.

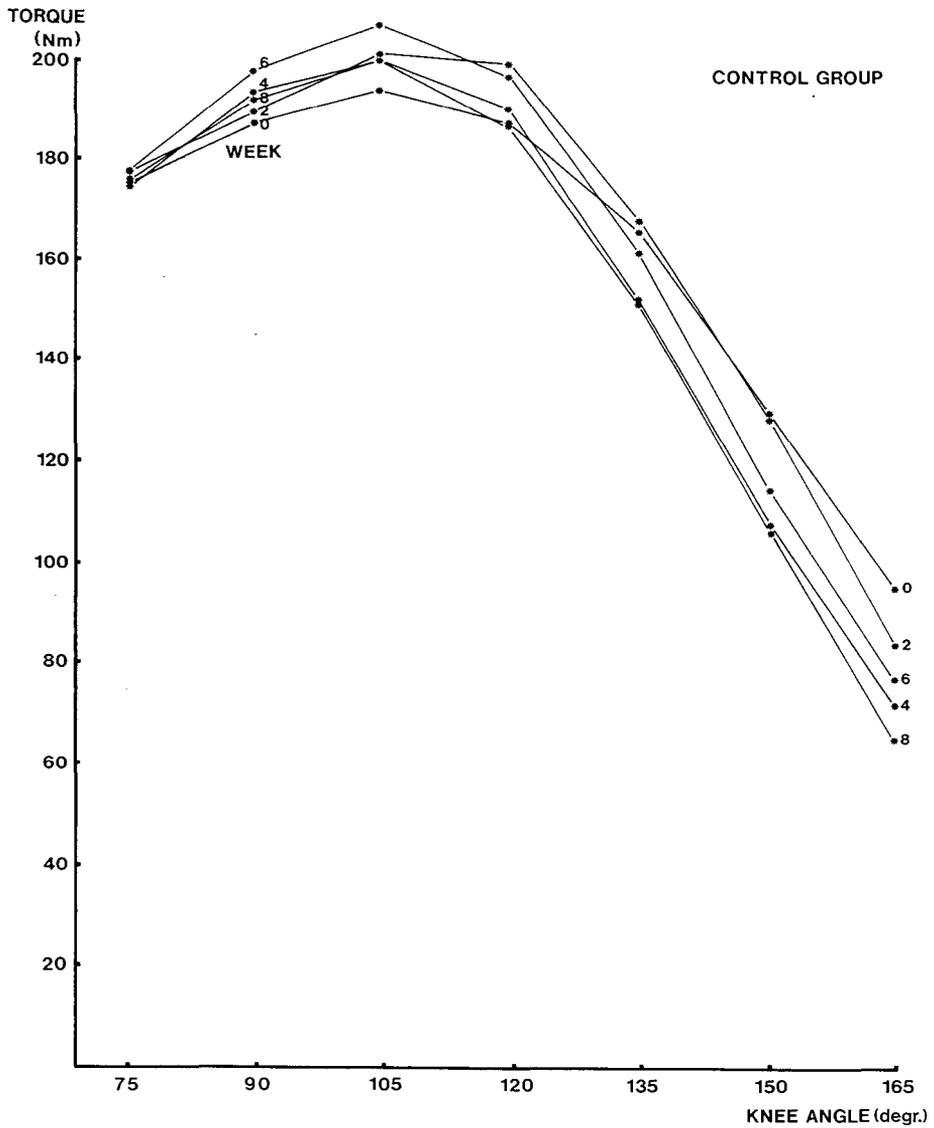


Fig. 4.4 Mean torque angle curves of the knee extensors of the control group from week 0 till week 8.

the non-operated leg. The mean isometric and isokinetic Q.R. values of the patients are presented in table 4.8 and figure 4.5.

*Table 4.8 Means and (S.D.) of the Quadriceps Ratio of the patients.*

week	0	2	4	6	8
mean isometric Q.R. (%)	57 (19)	71 (15)	80 (12)	85 (12)	88 (9)
mean isokinetic Q.R. (%)	42 (20)	59 (16)	70 (12)	74 (11)	79 (11)

The maximal torque differences between the operated and the non-operated leg are more pronounced in the isokinetic than in the isometric Q.R., especially in weeks 0 and 2. In week 4, 6 and 8 the isometric Q.R. remains about 10% higher than the isokinetic Q.R.

The results of the jump test, expressed in jump height and as work, are presented in table 4.9.

*Table 4.9 Means and (S.D.) of jump height and jump work of the patients and the control group.*

week	0	2	4	6	8
patients					
mean jump height (cm.)	33.5 (7)	41.1 (6)	42.5 (8)	43 (7)	44 (8)
mean jump work (Joule)	244 (49)	298 (49)	311 (49)	313 (49)	327 (49)
control group					
mean jump height (cm.)	50.4 (7)	50.9 (6)	51.6 (7)	51.7 (6)	52.6 (4)
mean jump work (Joule)	363 (69)	369 (78)	379 (69)	373 (69)	384 (59)

Between week 0 and 2 there is a notable improvement of jump height and jump work in the patient group. In week 8 there is still a mean jump height difference

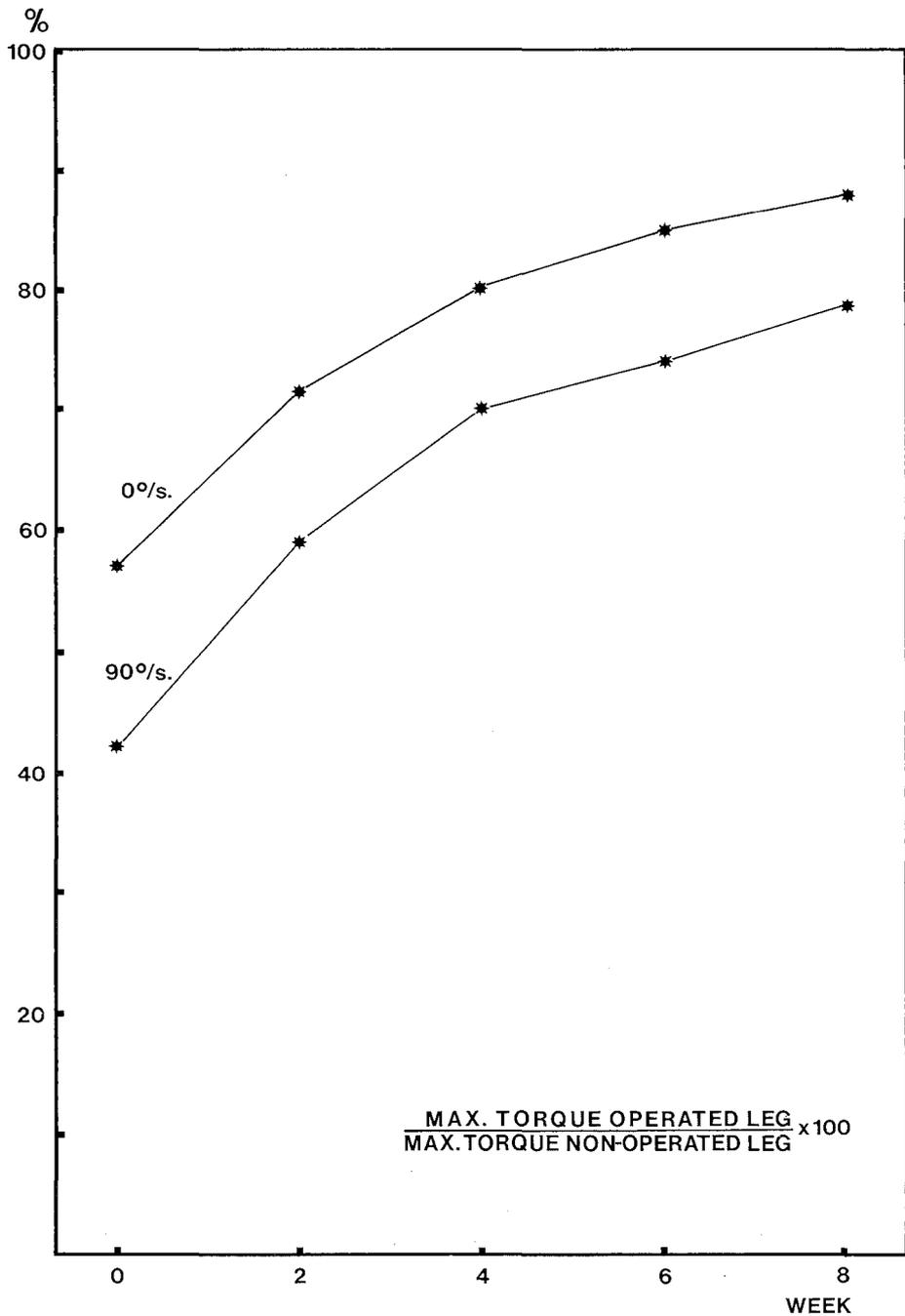


Fig. 4.5 *Quadriceps Ratio.*  
*Isometric and isokinetic ratio of maximal torque of the operated leg to maximal torque of the non-operated leg.*

of 9 cm between the patients and the control group. The correlation coefficients of the torque measurements and jump performance are presented in table 4.10.

*Table 4.10* Correlation coefficients of maximal isometric and isokinetic (90 degr./sec.) torque and jump performance of the patients and the control group.  
 (\* =  $p < 0.05$ , \*\* =  $p < 0.01$ , \*\*\* =  $p < 0.001$ ).

week	jump height					jump work				
	0	2	4	6	8	0	2	4	6	8
operated leg										
max. isom.torque	.25	.20	.15	.07	.08	.30	.40	.44	.50	.57
							*	*	*	
max. isokin.torque	.30	.26	.17	.08	.16	.26	.43	.37	.46	.67
							*		*	**
non-operated leg										
max. isom.torque	.20	.29	.42	.38	.31	.43	.63	.67	.55	.63
			*	*		*	**	***	**	**
max. isokin.torque	.31	.61	.48	.34	.43	.49	.82	.66	.56	.80
		**	*			*	***	***	**	***
control group										
max. isom.torque	.26	.42	.31	.02	.29	.58	.66	.52	.42	.77
						*	*	*	*	*
max. isok.torque	.39	.62	.50	.49	.63	.69	.80	.60	.67	.81
		*				**	**	*	*	*

The correlation coefficients of maximal torque and jump work are in general higher than those of maximal torque and jump height. As the weeks pass by, the relationship between maximal torque of the knee extensors of the patients and jump work tends to get stronger. The relationship between maximal torque of the non-operated leg and jump work is stronger than the relationship between maximal torque of the operated leg and jump work. The correlation coefficients in the control group are comparable with the correlation coefficients of the non-operated leg. When isometric and isokinetic maximal torque values are compared about

the same low positive correlation with jump work is found. In week 8 in the patient group and during all testing weeks in the control group the isokinetic maximal torque measurements have a higher correlation with jump work than the isometric values.

#### 4.4 Discussion.

##### Subjects.

From week 0 till week 6 the patient and the control group consisted of 21 and 11 subjects respectively. In week 8 it appeared that 7 patients and 3 subjects of the control group had been ordered back to their army units. In order to exclude that other factors, e.g. better recovery, had caused their advanced departure, the measurements of the group that stayed and the group that was not available in week 8 were statistically compared in week 6. It appeared that there were no statistically significant differences between maximal isometric torque, maximal isokinetic torque, jump height or body mass of both groups. Extrapolation of the mean values in week 0, 2, 4 and 6 indicated that in the final testing week the group of dismissed subjects would have shown the same results as the group that was actually tested in week 8. It was therefore decided that the results of the tests in week 8, although based on a smaller number of subjects, were representative of the whole patient and control group.

##### Anthropometric data.

The differences in age, height and body mass of the patient group and the control group (table 4.1) are small and statistically not significant. Other factors that might cause strength differences between the groups, such as professional or athletic activities, were not screened.

##### Location of the meniscectomy.

The location of the meniscectomy (table 4.2) indicates that the right knee is involved twice as often as the left knee. Veth (1978) studied the late results of meniscectomy in 211 Dutch military men and found a right/left ratio of 54.5/45.5%. In our patient group the right sided meniscectomies seem to be overrepresented. The frequency of lateral meniscectomy was 24.2% in the study of Veth and 43% in our patient group. The small sample size of our group does not allow conclusions with regard to the right/left and the medial/lateral ratios.

##### Dominance.

In the patient group the determination of dominance of the leg, defined as the leg preferred for kicking a ball, revealed that only one patient had a left leg dominance. This patient had a left sided meniscectomy. Thus 6 of the 21 patients had a meniscectomy of the knee of their non-dominant (left) leg. Mean isometric and

mean isokinetic maximal torque of the knee extensors of the operated leg in this group did not differ statistically significantly from the torque measurements of the operated leg of the patients who had had a meniscectomy of the knee of their dominant leg.

In the control group all subjects had a dominance of the right leg and therefore their right knee extensors were tested on the dynamometer.

Because strength differences between dominant and non-dominant operated legs could not be demonstrated, it was assumed that dominance of the leg is no useful information in this type of study. This assumption is supported by the observations of Holmes and Alderink (1984) and Giliam et al. (1979) who demonstrated that no difference exists between strength of the dominant and the non-dominant legs in highschool students and young male athletes.

### Pain.

Contrary to expectation it appeared that pain was not a common finding in the patient group (table 4.3). Some patients experienced occasional moderate pain in general. Especially pain during strength testing was expected to be present in the first weeks of training. However, none of the patients scored a 2, 3 or 4 on the pain scale. During the first test session 9 patients experienced occasional moderate pain. In week 2 this number was reduced to 4. During the following weeks only 1 or 2 patients complained of pain during the strength tests.

Pain, as far as it concerns the pain that is experienced consciously, does not seem to play an important role in the patient group.

### Swelling of the knee.

Swelling of the knee, following to arthrotomy, is most times caused by intra-articular fluid and is considered as a sign of traumatic arthritis. In the patient group, 19 out of 21 patients had moderate to severe symptoms of intra-articular effusion (table 4.4) in week 0.

During the next weeks the knees showed a gradual decrease of the degree of swelling. Even in week 8 clinically detectable signs of intra-articular fluid were present in 5 patients. In the patient group swelling of the knee was more pronounced than pain.

De Andrade et al. (1965) have shown that isolated joint swelling, irrespective of pain, inhibits voluntary muscle contraction.

Shakespeare et al. (1985) tested 14 men after meniscectomy and measured reflex inhibition, as a percentage reduction from the preoperative ipsilateral value, in the integrated surface EMG during maximal isometric contraction of the knee extensors. The authors recorded pain on a linear analogue scale. They showed a 30 to 50% inhibition 2 weeks postoperatively. Local anaesthesia caused less pain but did not influence inhibition.

Thus the swelling of the knees of the patients in this study may be considered as an important cause of inhibition of the maximal voluntary contraction of the knee extensors.

#### Range of motion (r.o.m.).

The results of the measurements of the active r.o.m. of the knee (table 4.5) support the observation of Cyriax (1987) concerning the greater limitation of flexion and the smaller limitation of extension in a capsular pattern of the knee.

Only in week 0, 6 patients had a limited knee extension, whereas only 1 patient had a clinically relevant limitation of extension of 20 degr. The symmetrical knee extension of all patients in week 2 illustrates the rapid improvement of extension.

The limitation of active knee flexion was considerable in week 0 (mean difference = 17.4 degr.). In week 2 only 3.6 degr. remained as the mean difference in knee flexion between operated and non-operated legs.

The limited active r.o.m. did not interfere with the isokinetic torque measurements. The leg was not attached to the leverarm. Before the contraction the leg was resting against the leverarm and the knee was bent passively to the position of 75 degr. At the end of the isokinetic contraction the leverarm just stopped at 175 degr. If active extension was limited the lower leg could not follow the last part of the movement and a drop in torque was registered in the torque angle curve.

#### Dynamometry.

Isometric and isokinetic maximal torque of the subjects of the control group remained rather constant from week 0 to week 8 (table 4.6 and figure 4.1).

Maximal torque of the non-operated leg increased gradually and this improvement was especially clear in the isometric measurements. This may be partially explained by the fact that during the time before the meniscectomy, when the patient had clinical signs and complaints of a torn meniscus, his overall activity probably was less than usual. During the week following the meniscectomy the patient was ordered to keep to bed, which restricted the activity of the non-operated leg also and caused further loss of strength. The gradual return to normal activities, following a period of relative inactivity and rest, may explain to a certain extent the increase of torque output of the non-operated leg.

Another explanation may be that there is a transfer of gain in muscle strength from the operated leg to the non-operated leg. This improvement of strength of a leg, which is not primarily subjected to strength training, has been noted by Stevens et al. (1980), who found increasing muscle strength and endurance following isokinetic training of the contralateral leg.

Maximal torque of the operated leg was very low in week 0 and improved rapidly during the 8 weeks of training. There was an increase of about 100% in mean maximal isometric and isokinetic torque at the end of the training period.

This substantial improvement in such a short time might partly be explained by increasing muscle mass and increasing neuromuscular coordination, and partly by reduction of pain and joint swelling.

The shape of the curves of mean maximal torque of the operated leg (fig. 4.1) indicates that a final level is not reached when the training programme of 8 weeks is over. This observation will be discussed later.

Not only maximal torque, but also the shape of the isokinetic torque curve may change after a meniscectomy. The maximal torque joint position (m.t.j.p.), the angle in the r.o.m. where maximal torque is reached, is one of the parameters that determines the shape of an isokinetic torque curve to a large extent.

Mean m.t.j.p. of the operated knee (table 4.7) amounted to about 108 degr. Only between week 0 and 2 a statistically significant change of mean m.t.j.p. was observed. In general, m.t.j.p. does not seem to be influenced by muscle weakness and strength training after meniscectomy.

Strickler and Greene (1984) demonstrated that, despite large differences in torque output between haemophilia patients and able bodied subjects, the m.t.j.p. of the knee extensors did not differ.

Moffroid and Whipple (1970) studied healthy volunteers during a 6 weeks strength training programme (a slow and a high velocity training group) and found that the m.t.j.p. of the knee extensors did not change.

Another approach to the study of isokinetic data is to determine torque at certain intervals in the individual torque angle curves. In this way mean torque at each selected joint position is calculated and mean isokinetic torque curves are constructed (fig. 4.2, 4.3 and 4.4). The general shape of the mean isokinetic torque curves of the operated and non-operated leg did not show striking differences. Torque of the operated leg (fig. 4.2) at 75 degr. gradually increased from week 0 to week 8. The same improvement was seen in the initial and middle part of the r.o.m. Towards the end of the contraction the torque differences became smaller. The mean torque angle curves of the non-operated leg also revealed that the differences occurred in the first half of the curves (fig. 4.3). Towards the end of the r.o.m., the torque values produced during the successive weeks converged.

The increase of strength of the knee extensors of both the operated and the non-operated leg is mainly found in the first part of the contraction. The relatively small (operated leg) and absent (non-operated leg) improvements of torque during the second half of the isokinetic contraction are difficult to explain. It is not likely that the training programme is the cause of the low torque readings at 150 and 165 degr. The exercises covered the whole r.o.m. Perhaps the knee flexors act as active and/or passive antagonists when the knee joint is extended while the subject is in an erect sitting position.

The mean torque angle curves of the dominant legs of the control subjects (fig. 4.4) changed in a different pattern from week 0 to week 8, when compared to the curves of the patients. In the first half of the r.o.m. the torque values, measured

during the respective weeks, concurred and intertwined. In the second part of the r.o.m. minor differences became apparent, but no definite pattern could be discerned.

The last parameter of the torque angle curves that is discussed is work. Work was calculated in weeks 0, 4 and 8 and correlated to maximal torque of the knee extensors of the operated leg. Correlation coefficients of .93, .82 and .92 were found. These high and statistically significant correlation coefficients result from the rather uniform shape of the torque angle curves.

Moffroid and Kusiak (1975) showed that in an isokinetic contraction of maximum effort and with a good stabilisation technique the maximal torque reliably reflects work. They found correlation coefficients of about .90 for elbow flexion and extension and knee flexion and extension.

It was decided not to use work as a parameter in this study

#### Quadriceps Ratio.

The quadriceps ratio (Q.R.), the ratio of maximal torque of the operated leg to maximal torque of the non-operated leg, indicates the relative loss of knee extensor strength of the operated leg. The isokinetic Q.R. values are smaller than the isometric Q.R. values (fig. 4.5, table 4.8). This difference is most pronounced in weeks 0 and 2. During the second half of the training period the isometric Q.R. remains about 10% higher than the isokinetic Q.R. Even in week 8, when the conscript is supposed to be recovered and ready for military duty, isometric and isokinetic torque of the knee extensors of the operated leg still show a deficit of 12 and 21% respectively.

The practical value of the Q.R. is of course limited by the observation that maximal torque of the non-operated leg is used as a reference point while this maximal torque increases gradually during the training period.

If one assumes that the 'normal' strength of the non-operated leg is not yet reached (fig. 4.1) the relative loss of strength of the operated leg becomes even more pronounced.

Although this study was not meant to evaluate the training programme, it will be obvious that after 8 weeks of daily training an imbalance of the knee extensors of more than 10% remains. Such an imbalance is considered by several authors to render subjects injury prone (Abbott 1969; Bender 1964; Steele 1980). If, following an injury of the knee, an imbalance is found, they advise a strength training regime before the subject is allowed to return to sports activities. Considering the Q.R. values in week 8 it may be concluded that the training programme prescribed to the conscripts, that who have to resume heavy physical activities, is insufficient.

The observation that diminished muscle strength, expressed in an isometric Q.R., shows higher values than the isokinetic Q.R. seems to support the conclusion of chapter 3 that isometric and isokinetic dynamometry both measure a diffe-

rent aspect of strength. During an isometric contraction a subject has sufficient time to build up tension to its maximum. However, when the available time is shorter, as in isokinetic testing, the effects of inactivity and inhibition become more pronounced and the difference of strength between the knee extensors of the operated and the non-operated leg increase.

These results suggest that isokinetic dynamometry may be a more sensitive test than isometric dynamometry in demonstrating impairment of the knee extensors.

#### Jump test.

In the patient group jump height and jump work improve mainly from week 0 to week 2. Subsequently, a smaller increase is observed (table 4.9). The gradual improvement of jump performance in the control group indicates that the results of the jump test may be influenced by a learning effect. It is therefore not entirely clear to what extent the increasing jump height and jump work between week 2 and 8 in the patient group are caused by improving strength of the knee extensors or by a learning process. Both increasing muscle strength and better neuromuscular coordination probably are important factors.

At the end of the training programme in week 8 the jump performance of the patients is still considerably lower than in the control group. This is in accordance with the results of the maximum torque measurements which indicate that in week 8 strength of the knee extensors of the operated leg has not yet reached the level of the non-operated leg.

The reason to convert jump height to jump work was to be able to take the body-mass of the subjects into consideration. However, the expression of jump performance in work, instead of height, does not contribute any new information to the discussion of the individual course of the jump test during the training period. The increase of jump height runs parallel with the increase of jump work.

Another objection to work, as an expression of jump performance, might be that the time needed to produce work was not measured. If this time could be determined, one would dispose of jump power in the physical sense ( $\text{power} = \text{force} \times \text{distance}/\text{time}$ ). This approach is rather complicated and time consuming for a clinical study. Gray et al. (1962) developed such a test in which the vertical jump was established in the physical sense of power. Subsequently, they presented a modification in which time was neglected and work rather than power was measured. They showed that all correlations with the original vertical power were higher for work performed than distance covered. Thus, if jump performance is used as a functional test, jump work appears to be a better parameter than jump height.

#### Dynamometry and jump performance.

Several authors studied the relationship between vertical jumping and torque of the knee extensors in healthy volunteers. Some of them used jump work as the parameter of jump performance, while others used jump height.

Genuario and Dolgener (1980), using a Cybex dynamometer, determined correlation coefficients in 29 female athletes. In their study the correlation coefficients of vertical jump work and maximal isokinetic torque of the knee extensors at 30 and 180 degr./sec. were .51 and .59 respectively.

Berger and Henderson (1966) studied 66 male students and determined jump work in the same way as in this study. A dynamometer was used for the isometric tests and dynamic strength was tested with barbells. The authors found correlation coefficients of .64 and .71 between jump work and isometric and dynamic strength respectively.

Smith (1961) studied 70 college students and found a low positive correlation between the isometric strength of the leg muscles, assessed with a conventional leg strength dynamometer, and jump height (correlation coefficient .20).

Considine and Sullivan (1973) tested 38 male students for leg power, using seven tests, including a vertical jump test, and leg strength by means of a cable tensiometer. Vertical jump was expressed in inches and correlations with strength of the dominant knee extensors were low (.27).

In this study (table 4.10) it is found that in all cases (healthy subjects as well as patients) the correlation coefficients of maximal torque and jump work are higher than those of maximal torque and jump height. In general this is in accordance with the results of the studies mentioned above, although different testing methods were used. Therefore, in the discussion of the relationship between maximal torque of the knee extensors and vertical jump performance, jump work will be used instead of jump height.

In the studies mentioned above, healthy subjects were tested and the conclusions do not necessarily have to be valid in patients.

Only one study on the relationship between strength and functional tests is available to be compared with the results of this study.

Lankhorst et al. (1985) studied the relationship between torque of the knee extensors and functional capacities in patients suffering from osteoarthritis of the knee. Functional capacity was among others determined by asking the patients questions about problems experienced with getting up from a chair, standing, walking and stairclimbing in the week before the test. A 0-10 numerical scale was used to score at each item and the mean functional capacity was calculated. A correlation coefficient of .49 was found between the mean functional capacity and isokinetic torque at 120 degr./sec. The authors also presented a walking test under standardized conditions and found a correlation coefficient of .46 between isokinetic torque at 30 degr./sec. and walking time. They concluded that both the isometric and isokinetic torque measurements of the knee extensors of osteoarthrotic patients are of little value in the prediction of functional capacity.

In the patient group of this study maximal torque of the operated leg shows considerably lower correlation coefficients with jump work than the non-operated leg

(table 4.10). Especially in week 0 the correlation coefficients of both legs are low compared with week 2 till week 8.

The correlation coefficients of the operated leg tend to increase gradually between week 2 and 8, whereas in the non-operated leg the correlation coefficients remain at about the same level after week 2.

The low correlation coefficients in week 0 probably result from the presence of inhibiting factors such as pain, swelling of the knee and fear of injury. These factors negatively influence the maximal torque output as well as the jump performance. This negative influence is more pronounced in the operated than in the non-operated leg. The effect of the inhibiting factors becomes smaller as the training programme progresses.

From these results it is concluded that the predictive validity of the torque measurements of the operated leg is rather small in the initial phase of the training programme. Only at the end, in weeks 6 and 8, the correlation coefficients become comparable with the non-operated leg and the control group.

On the basis of the low predictive validity one could decide not to carry out maximal torque measurements in the first weeks after meniscectomy, when swelling and other inhibiting factors are present. On the other hand, maximal torque measurements during the initial training phase may have a certain value if they are carefully used and interpreted. The steady increase of maximal torque values can be a stimulus for the patient and a contribution to the motivation for the physical therapy programme. Furthermore, the difference between the torque values of both legs of an individual patient is an indication for the examiner on which he determines the status of the knee and the progress that is made. It is therefore concluded that, with restrictions, the measurement of maximal torque of the knee extensors in the initial phase of the training programme can produce useful information.

The correlation coefficients of the patients in week 8 and of the control group range between .57 and .80 and .42 and .81 respectively. Consequently, the common variances (the square of  $r$ ) range from 32-64% and from 18-66% respectively. This means, for the individual subject, that the result of the measurement of maximal torque of the knee extensors provides only limited information about the performance of the same individual in a jump test. Apparently other factors such as strength of the hip extensors, the plantar flexors, coordination, etc. also determine the performance of the jump test.

The isokinetic maximal torque measurements show in most cases a higher correlation coefficient with jump work than the isometric values. This supports the assumption that isokinetic torque measurements are better predictors of jumping performance than isometric torque measurements.

The most important conclusions of this study are:

- both isometric and isokinetic maximal torque of the knee extensors of the operated leg increase, but after 8 weeks the strength level of the non-operated leg is not yet reached.
- the difference between maximal torque of the operated and the non-operated leg is demonstrated most distinctly in the isokinetic test. This suggests that isokinetic torque measurement is a more sensitive way of strength testing than isometric dynamometry.
- the relationship between maximal torque of the knee extensors and a functional activity such as jumping is low.

#### 4.5 References.

Abbott H G.

Preconditioning in the prevention of knee injuries.

Arch. Phys. Med. Rehab. 50: 326-333, 1969.

Aniansson A, Rundgren A, Sperling L.

Evaluation of functional capacity in activities of daily living in 70-year-old men and women.

Scand. J. Rehab. Med. 12: 145-154, 1980.

Bender J A.

Factors affecting the occurrence of knee injuries.

J. Assoc. Phys. Mental Rehab. 18: 130-134, 1964.

Berger R A, Henderson J M.

Relationship of power to static and dynamic strength.

Res. Quart. 37: 9-13, 1966.

Considine W J, Sullivan W J.

Relationship of selected tests of leg strength and leg power on college men.

Res. Quart. 44: 404-413, 1973.

Cyriax J.

Textbook of orthopaedic medicine, Volume 1. 7th edition.

Bailliere Tindall 1978.

Danneskiold-Samsøe B, Kofod V, Munter J, Grimby G, Schnohr P, Jensen G.

Muscle strength and functional capacity in 78-year-old men and women.

Eur. J. Physiol. 52: 310-314, 1984.

De Andrade J R, Grant J R, Dixon St J.

Joint distension and reflex muscle inhibition in the knee.

J. Bone and Joint Surg. 47A: 313-322, 1965.

Genuario S E, Dolgener F A.

The relationship of isokinetic torque at two speeds to vertical jump.

Res. Quart. 51: 593-598, 1980.

Gilliam T B, Sady S P, Freedson P S, Villanacci J.  
Isokinetic torque levels for highschool football players.  
Arch. Phys. Med. Rehab. 60: 110-114, 1979.

Gray R K, Start K B, Glencross D J.  
A test of leg power.  
Res. Quart. 33: 44-50, 1962.

Gray R K, Start K B, Glencross D J.  
A useful modification of the vertical power jump.  
Res. Quart. 33: 230-235, 1962.

Holmes J R, Alderink G J.  
Isokinetic strength characteristics of the quadriceps femoris and hamstring muscles in highschool students.  
Phys. Ther. 64: 914-918, 1984.

Lankhorst G J, v.d. Stadt R J, v.d. Korst J K, Hinlopen-Bonrath E, Griffioen F M M, de Boer W.  
Relationship of isometric knee extension torque and functional variables in osteoarthritis of the knee.  
Scand. J. Rehab. Med. 14: 7-10, 1982.

Lankhorst G J, v.d. Stadt R J, v.d. Korst J K.  
The relationships of functional capacity, pain and isometric and isokinetic torque in osteoarthritis of the knee.  
Scand. J. Rehab. Med. 17: 167-172, 1985.

Moffroid M T, Whipple R H.  
Specificity of speed of exercise.  
Phys. Ther. 50: 1692-1699, 1970.

Moffroid M T, Kusiak E T.  
The power struggle.  
Phys. Ther. 55: 1098-1104, 1975.

Shakespeare D T, Stokes M, Sherman K P, Young A.  
Reflex inhibition of the quadriceps after meniscectomy: lack of association with pain.  
Clin. Physiol. 5: 137-144, 1985.

Smith L E.

Relationship between explosive strength and performance in the vertical jump.  
Res. Quart. 32: 403-408, 1961.

Stam H J, v. Gorcom P, v.d. Wurff P.

Pulserende U.K.G., het effect op hydrops van het kniegewricht na meniscectomie. (Pulsating U.S.W., the effect on effusion in the knee joint after meniscectomy).

Ned. Tijdschr. Fysiotherapie 92: 183-185, 1982.

Steele V.

Rehabilitation of the injured athlete.

Physiotherapy 66: 251-255, 1980.

Stevens C J, Costill D L, Benham D, Whitehead T.

Transfer of gains in muscle strength and endurance following unilateral isokinetic training (abstract).

Med. Sci. Sports Exerc. 12: 121, 1980.

Strickler E M, Greene W B.

Isokinetic torque levels in hemophiliac knee musculature.

Arch. Phys. Med. Rehab. 65: 766-779, 1984.

Veth R P H.

Over de resultaten van de meniscectomie van de knie. (On the results of meniscectomy of the knee).

Ph.D. thesis in Dutch, Groningen, 1978.

Westers B M.

Factors influencing strength testing and exercise prescription.

Physiotherapy 68: 42-44, 1982.

## CHAPTER 5.

### A FOLLOW-UP STUDY OF MENISCECTOMY OF THE KNEE.

#### 5.1 Introduction.

One of the most interesting observations of the study described in chapter 4 was that, after a training period of 8 weeks, 10 weeks after the meniscectomy, still a mean maximal torque difference of 12% (with isometric testing) and 21% (with isokinetic testing) existed between the operated and the non-operated leg (fig. 4.5). Such an imbalance of strength of the knee extensors is considered as a sign that complete recovery is not yet reached and as a risk of further damage of the knee joint (Abbott 1969; Bender 1964; Steele 1980).

The curves of mean maximal torque of the operated and the non-operated leg at the respective testing weeks (fig. 4.1) indicated that at the end of the training period no final level had been reached.

The subjects of the patient group were sent back to their army units without further instruction or therapy. At that time there was no opportunity to continue the tests in order to determine the time and level of a possible complete recovery. Such a recovery could not even be taken for granted.

Campbell and Glenn (1979) found that mean maximal torque of the knee extensors of the operated leg was 10 to 12% less than the mean maximal torque of the contralateral knee. The time elapsed in their study between the knee surgery and the strength testing ranged from 5 to 15 months.

Grimby et al. (1980) studied a group of 30 subjects after surgery for knee ligament injuries. The athletes (n=29) went back to athletic training after a mean training time of 14 weeks. The mean time from the operation to the study was 14 (range 3 to 36) months. The authors reported a maximal torque difference between the operated and the non-operated leg of about 10% in isometric and of about 20% in isokinetic (42 degr./sec.) strength testing.

These studies indicate that resumption of normal physical activities and even of athletic training not always results in a symmetrical knee extensor torque.

The purpose of the study presented in this chapter was to investigate the long term effects of meniscectomy, with special attention to:

- resumption of professional and sports activities.
- knee extensor torque of both legs.
- vertical jump performance and its relationship with the torque values.
- physical signs of knee damage.

## 5.2 Materials and methods.

The subjects of the patient group, described in chapter 4, were requested about 2 years later to report to our department. (Department of Rehabilitation Medicine of the University Hospital Dijkzigt Rotterdam).

The purpose of the follow-up test was explained in order to achieve the largest possible attendance.

Before the actual strength test the subject was interviewed to collect data concerning the condition of the knees and the resumption of professional and recreational activities. After the dynamometry and the vertical jump test, both legs were physically examined.

During the interview attention was paid to pain and discomfort, swelling, instability and locking of the knees. The subjects were questioned about the present state of their professional and recreational activities and this was compared with the situation before the meniscectomy.

Furthermore, they were asked about any medical or physical treatment, in relation to knee complaints, during the period between the last test in the training phase and the follow-up test.

Dynamometry consisted of torque measurements of both knee extensors. The Q.D. was used to determine isometric and isokinetic torque. The non-operated leg was tested first. Isometric torque was measured at a joint position of 115 degr. (full extension = 180 degr.). Subsequently, the isokinetic torque angle curves were determined at an angular velocity of 90 degr./sec. and with a range of motion of 100 degr. (from 75 degr. flexion to 175 degr. extension). After several submaximal-warming up contractions, 3 maximal contractions were performed at both angular velocities and the highest recordings were used for calculations. Instructions and positioning on the Q.D. were the same as used during the training phase and are described in chapter 2.

The vertical jump test was performed following to the strength test and was executed as described in chapter 4. The results were expressed in cm and converted to external work (Joule) by multiplying bodymass (kg) and jump height (m) and  $9.81 \text{ m/sec}^2$ .

The follow-up session was concluded with the physical examination of the knees. Attention was paid to knee flexion and extension, swelling, instability and muscular atrophy of the knee extensors. Bodymass was assessed subsequently.

Means and standard deviations of maximal torque, jump height, jump work and bodymass were calculated. A Student-t-test of paired data was used to determine the statistical significance of the differences found between week 8 of the training programme and of the follow-up study. A p-value of less than 0.05 was considered significant.

### 5.3 Results.

For the follow-up study 16 out of 21 subjects of the patient group were available. The 5 subjects who did not respond to the request for attending the test gave the following reasons:

- the distance between their place of residence and our hospital was too great (2 subjects).
- indispensability to his job (1 subject).
- fracture of the leg (1 subject).

One subject could not be invited because his address could not be retrieved.

The mean time elapsed between the meniscectomy and the follow-up test was 27.75 (S.D. = 1.1) months.

#### Interview.

Eight subjects experienced occasional pain in their operated knee. The character of these complaints was described as shooting or burning and the pain was in most cases related to physical activities such as climbing stairs and sporting.

Two subjects reported the occurrence of swelling of the knee for one occasion only. Another four subjects had more than one period of knee swelling related to sports activities.

Only two subjects mentioned feelings of instability of their operated leg.

Locking of the knee did not occur in any subject in the period between the meniscectomy and the follow-up study.

Three subjects experienced a limitation of their knee flexion during squatting.

Comparison of professional activities before and after the meniscectomy was not possible because most subjects were students before they were drafted. However, the subjects did not report any problems during their daily work caused by knee complaints and all were of the opinion that the choice of their jobs was not influenced by their meniscectomy.

The influence of the meniscectomy on sports activities was more complex. Three subjects played soccer on a higher level than before the operation. Four subjects reported no change in their sports activities and played soccer at the same competitive level. Seven subjects had continued playing soccer on a lower level or had stopped entirely. Prevention of further damage of the knee and knee complaints resulting from playing soccer were the most frequently reported causes for the decision to stop. One subject changed from judo to badminton because of preventive considerations. One subject was not involved in any sports at all before or after the meniscectomy. Most subjects did not receive a special training programme or physical therapy after the 8 weeks' training programme. Only three subjects reported being treated by a physiotherapist after discharge from the rehabilitation centre.

Dynamometry and jumptest.

The results of strength testing with the Q.D. are shown in table 5.1 and figure 5.1.

*Table 5.1* Means and (S.D.) of maximal isometric and isokinetic torque of the knee extensors of both legs of the patient group (p.g., n=14) in week 8 of the training programme, of the follow-up group (f.u.g., n=16) in week 8 and of the f.u.g. during the follow-up test > 2 years later. (S = statistically significant, p<0.05).

	week 8 p.g.	week 8 f.u.g.		>2 years f.u.g.
max. isom. torque operated knee	282 (50)	277 (48)	- S -	318 (47)
		,		
		S		
		,		
max. isom. torque non-operated knee	319 (57)	319 (54)		324 (49)
max. isokin. torque operated knee	164 (28)	159 (29)	- S -	223 (31)
		,		
		S		
		,		
max. isokin. torque non-operated knee	207 (30)	206 (28)	- S -	225 (30)

No statistically significant differences were found between maximal torque of the patients in week 8 and maximal torque in week 8 of the 16 subjects that entered the follow-up study.

The mean maximal isometric torque of the operated leg showed statistically significant improvement whereas the non-operated leg remained at about the same level.

Mean maximal isokinetic torque of both legs increased statistically significant in the follow-up group.

The differences between mean maximal (isometric and isokinetic) torque of the operated and the non-operated leg, found in week 8 were very small in the follow-up study and not statistically significant. Jump height and jump work improved statistically significantly between the last week of the training period and the follow-up test. This is presented in table 5.2.

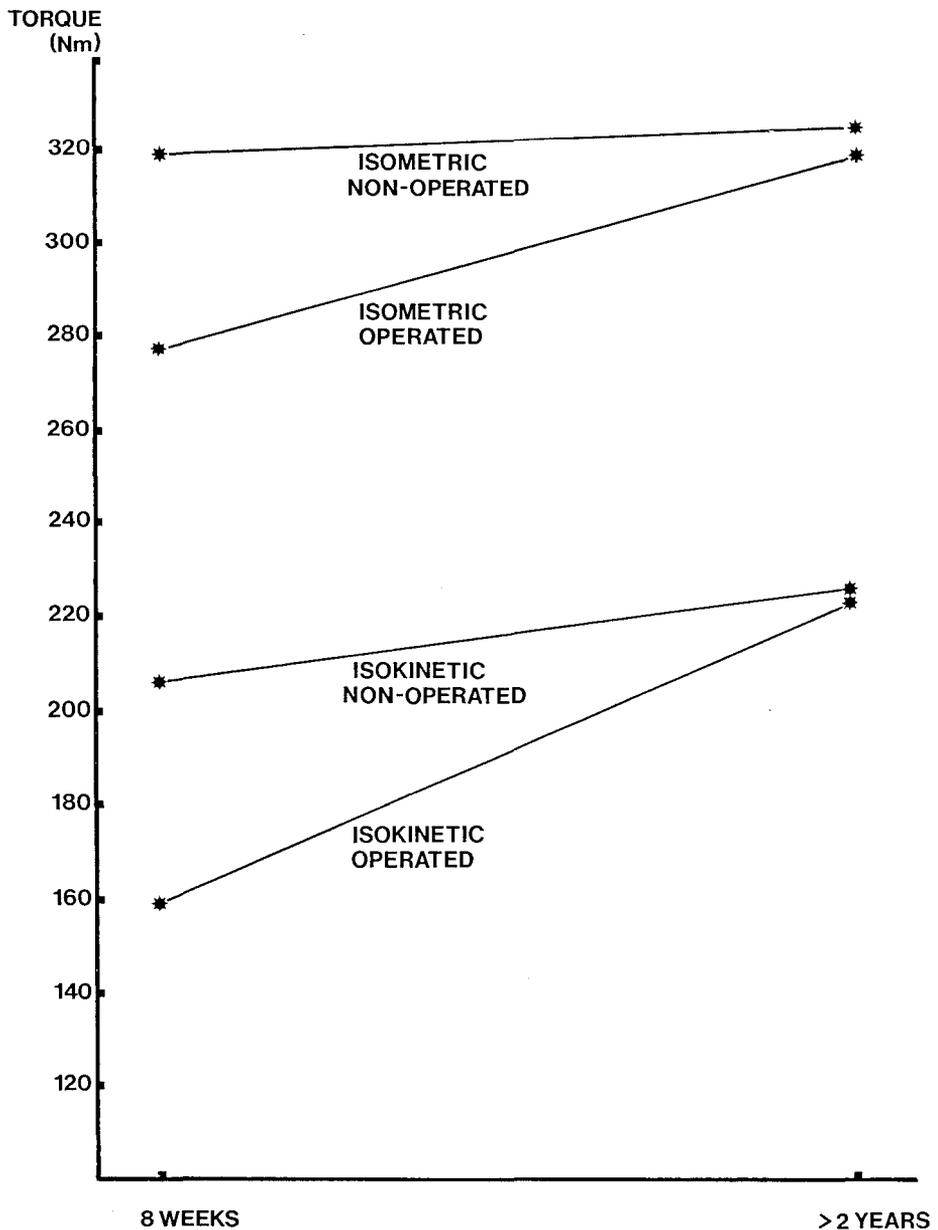


Fig. 5.1 Mean maximal isometric and isokinetic torque of the knee extensors of both legs of the subjects of the follow-up group in week 8 of the training programme and >2 years later.

*Table 5.2* Means and (S.D.) of jump height and jump work. For further explanation see table 5.1.

	week 8 p.g.	week 8 f.u.g.	>2 years f.u.g.
jump height (cm)	44 (8)	46 (6)	49 (8)
jump work (Joule)	327 (49)	332 (45)	- S - 370 (58)

For the purpose of calculating the correlation coefficients between maximal torque of the knee extensors and jump work, the maximal torque values of both legs were added up. The correlation coefficients between maximal isometric and isokinetic torque and jump work are presented in table 5.3.

*Table 5.3* Correlation coefficients of maximal isometric and isokinetic torque of both legs and jump work in the patient group (p.g.) in week 8 of the training programme and in the follow-up group (f.u.g.) >2 years after meniscectomy.

(\* =  $p < 0.05$ , \*\* =  $p < 0.01$ , \*\*\* =  $p < 0.001$ ).

	jump work p.g	jump work f.u.g.
max. isom. torque	.61 **	.42 *
max. isokin. torque	.77 ***	.81 ***

#### Physical examination.

The physical examination showed only minor abnormalities. All subjects, but one, had a normal symmetrical active and passive knee flexion.

In all but two subjects a normal symmetrical knee extension was found. Inspection of the knee extensor muscles and measurement of the circumference of the thighs revealed no signs of muscular atrophy.

Swelling of the knee was not found in any of the subjects.

A minor anterior cruciate ligament instability was found in 9 patients. No evident lateral instability could be detected in the follow-up group.

The mean bodymass increased from 74.2 kg (in week 8 of the training programme) to 77.8 kg at the time of follow-up. This difference is statistically significant.

## 5.4 Discussion.

The number of 16 (out of 21) subjects who attended the follow-up test is considered sufficient to obtain a judgment about the follow-up results of the meniscectomy and the training period of the patient group described in chapter 4.

The data presented in table 5.1 and 5.2 indicate that the subjects of the follow-up test are not different from the 14 patients tested in week 8 of the training programme as far as mean maximal torque and jump performance are concerned.

The data collected during the interview preceding the strength test, are rather more subjective and qualitative. The reason to present these data after all is that they provide a fair notion of the status of the knee during the two years before the follow-up study.

### Interview.

The complaints about pain, swelling, instability and locking of the knee are, generally spoken, rather mild. This finding is supported by the fact that all subjects report that the meniscectomy and eventual knee complaints did not influence their professional activities or the choice of their jobs.

The sports activities on the other hand show a different picture. Seven subjects reported playing soccer on the same or a higher level than before the meniscectomy. Another seven subjects continued playing soccer on a lower level or stopped all together. It was not possible to detect the most prevalent cause for this decision (preventive considerations and/or knee complaints).

The study of Veth (1978) is the most recent and appropriate study to compare with the results of the interview. Veth studied the late outcome of 211 meniscectomies of Dutch military men. The time elapsed between surgery and follow-up was 1 to 10.5 years. Pain and swelling was reported by 57% and 34% of his subjects respectively. Feelings of instability were mentioned by 42%, which is higher than in this study.

In the population of Veth 10% of the patients were not able to return to their former job and 40% stopped sporting. Although this follow-up time is shorter it seems that, generally spoken, the results in the follow-up group, as far as they are reflected by the interview, are somewhat better than in the study of Veth.

### Dynamometry.

The non-operated leg shows a small and non-significant increase of mean maximal isometric torque whereas the mean maximal isokinetic torque of this leg improves considerably between week 8 and the follow-up study (table 5.1, fig. 5.1). Thus in week 8 the isometric strength of the non-operated leg seems to have reached its definitive level whereas the isokinetic strength will still improve about 10%.

Isometric and isokinetic mean maximal torque of the operated leg increases substantially (15 and 40% respectively) between week 8 and the follow-up test.

These results support the observation of chapter 4 that isokinetic maximal torque measurement is a more sensitive instrument to detect strength differences of the knee extensors.

It is surprising that at the time of the follow-up test an almost equal mean maximal torque of the knee extensors is found despite the absence (except for 3 subjects) of any training programme. Apparently the resumption of normal activities after a training period of 8 weeks is sufficient to restore the strength of both legs. The general opinion that a training programme, prescribed after meniscectomy, can be finished only as soon as a balanced state of muscular strength of the knee extensors has been reached, is not confirmed by this study.

Unfortunately, it was not possible to determine exactly at what time a symmetrical knee extensor torque was reached. The study of Campbell and Glenn (1979) suggests that it takes rather a long time. They measured maximal torque of both legs in 8 patients 5 to 15 months after a meniscectomy and found a 10% deficit for isometric and 16% deficit for isokinetic (60 degr./sec.) knee extension.

Other studies that describe the follow-up of a meniscectomy (Gear 1967; Perey 1962; Tapper 1962; Veth 1978) do not present data on the strength of the knee extensors.

Studies that do describe late knee torque measurements (Arvidsson 1981; Grimby et al. 1980) discuss the results of knee ligament reconstructions and are therefore not comparable with the follow-up results of a meniscectomy.

The improvement of knee extensor torque of both legs in this study is also reflected by the increased jump height and jump work (table 5.2). The differences between week 8 and the follow-up test are statistically significant. After 2 years jump work has reached the level of the control group (see chapter 4), which might indicate that from a functional point of view at the time of the follow-up study a complete recovery has been attained.

The correlation coefficients (table 5.3) of maximal torque and jump work are in agreement with the results of chapter 4.

The common variance of maximal torque of both legs and jump work (calculated by squaring  $r$ ) amounts to 17.6% and 65.6% for the isometric and isokinetic tests respectively. This might indicate that the isokinetic maximal torque values are better predictors of a functional activity such as vertical jumping than isometric maximal torque.

#### Physical examination.

The physical examination reveals that, except for a minor anterior instability (9 patients), no serious signs of damage of the operated knee are found more than two years after the meniscectomy. These results correspond rather well with the data presented by Veth (1978). He found ligamentous instability in 42% of his pa-

tients. Muscular atrophy, however, was found in 25% of his cases whereas in this study no atrophy was found.

#### Conclusions:

- despite a large isometric and isokinetic knee extensor torque imbalance at the end of the training period, the strength of both legs is restored more than 2 years later, without additional training.
- the results 27 months after the meniscectomy in the patient group are, as far as represented by the interview, resumption of professional and sports activities or by the results of the physical examination of the knee, satisfying and comparable with the data presented by other authors.

## 5.5 References.

Abbott H G.

Preconditioning in the prevention of knee injuries.

Arch. Phys. Med. Rehab. 50: 326-333, 1969.

Arvidsson I, Eriksson E, Haggmark T, Johnson R J.

Isokinetic thigh muscle strength after ligament reconstruction in the knee joint.

Int. J. Sports Med. 2: 7-11, 1981.

Bender J A.

Factors affecting the occurrence of knee injuries.

J. Assoc. Phys. Mental Rehab. 18: 130-134, 1964.

Campbell D E, Glenn W.

Foot-pounds of torque of the normal knee and the rehabilitated post meniscectomy knee.

Phys. Ther. 59: 418-421, 1979.

Gear M W L.

The late results of meniscectomy.

Brit. J. Surg. 54: 270-272, 1967.

Grimby G, Gustafsson E, Peterson L, Renstrom P.

Quadriceps function and training after knee ligament surgery.

Med. Sci. Sports Exerc. 12: 70-75, 1980.

Perey O.

Follow-up results of meniscectomy with regard to the working capacity.

Acta Orthop. Scand. 32: 457-460, 1962.

Steele V.

Rehabilitation of the injured athlete.

Physiotherapy 66: 251-255, 1980.

Tapper E M.

Late results after meniscectomy.

J. Bone Joint Surg. 51A: 517-526, 1969.

Veth R P H.

Over de resultaten van de meniscectomie van de knie. (On the results of meniscectomy of the knee).

Ph.D. Thesis in Dutch, Groningen, 1978.

## CHAPTER 6.

### MUSCLE STRENGTH IMPAIRMENT AND DISABILITY IN GUILLAIN-BARRÉ PATIENTS.

#### 6.1 Introduction.

Dynamometry of healthy subjects is a method to measure strength as a function. When this function is interfered by diseases, trauma or congenital deviations, one speaks of muscle weakness, which may be considered as an impairment.

In rehabilitation medicine one is not only interested in (measuring) impairment itself, but also in the consequences of this impairment: disability. In the case of muscle weakness of the knee extensors, disability may consist of a diminished ability to stand up, to walk, to climb stairs, etc.

The practical usefulness of strength measurements in patient's is to a certain extent determined by its ability to measure a patients impairment and to predict the resulting disability i.e. the problems the patient will experience during normal daily activities. In this perspective the question of practical usefulness is in fact a question of predictive validity.

Predictive validity has been studied by Aniansson et al. (1980) and Lankhorst et al. (1982, 1985). Aniansson et al. related the results of isometric and isokinetic torque measurements to the results of functional tests such as walking speed and stepping up in 70-year old men and women. Lankhorst et al. studied the relationship between isometric and isokinetic torque measurements and functional activities (such as rising from a chair, standing, walking, stair climbing) in osteoarthritis patients.

In the previous chapters (chapter 4 and 5) the results of maximal torque measurements of the knee extensors and the relationship with a functional activity such as vertical jumping were presented.

The methods used to determine the relationship between strength test results and functional activities in patients have some distinct disadvantages. Usually a correlational approach is chosen. It is well known that a correlation coefficient is highly dependent on the number of subjects and on the homogeneity of the group. If the number of patients is small one or two accidental high or low measurements may have a disproportionate influence on the coefficient.

Furthermore, the functional test itself may disturb the reliability of a study. The inter-individual variability of tests such as walking speed and chair climbing is considerable and a normal value, for the individual or for the whole group, is not available. The results of such tests are usually expressed in absolute values. In this way the relative gravity of the disability remains uncertain.

The pilot study presented in this chapter was undertaken to investigate the relationship between decreased muscle strength (impairment) of the knee extensors

and decreased functional performance (disability) in Guillain-Barré (a polyradiculo- neuropathy) patients.

A method was chosen in which the major disadvantages of the correlational approach were avoided.

## 6.2 Materials and methods.

### Subjects.

Five patients with a Guillain-Barré syndrome (G.B.) were tested from an early stage of their disease till full recovery was achieved. G.B. patients were chosen because the syndrome usually results in a complete recovery of the muscle weakness. The G.B. was diagnosed by E.M.G. and the patients were referred by the neurologist.

In table 6.1 the most important data of the patients are listed.

*Table 6.1* Sex, age and bodymass of the G.B. patients.

Patient	1	2	3	4	5
Sex	male	male	male	female	male
Age (years)	35	21	46	19	62
Bodymass (kg)	86	80	82	52	78

### Dynamometry.

Isometric and isokinetic torque of the knee extensors of both legs was measured with the Q.D.

Isometric maximal torque was determined at a joint position of 115 degr. (180 degr. = full extension).

Consequently isokinetic maximal torque was determined at an angular velocity of 90 degr./sec. The range of motion was 100 degr. i.e. from 75 degr. flexion to 175 degr. extension. Several submaximal contractions were allowed for warming-up. At both testing speeds three maximal contractions were performed with one minute intervals. The highest contraction was used for calculations. Isometric maximal torque and isokinetic maximal torque were defined as the mean of the maximal torque values of both legs.

Positioning and instruction of the patients were the same as in chapter 2.

### Functional test.

The functional testbattery had to cover a wide range of activities. Therefore, ten activities, which can be tested simply and quickly, were arbitrarily chosen. They are presented in table 6.2 in the order of assumed difficulty.

*Table 6.2* Functional activities.

1. Standing up from a chair with the support of one arm.
2. To stand with the knees slightly bent.
3. Standing up from a chair without support or compensatory movements.
4. Walking with canes (10 metres within 12 sec. = >3 km/hour).
5. Walking without canes (>3 km/hour).
6. Walking without canes (10 metres within 6 sec. = >6 km/hour).
7. Climbing stairs (5 steps with support of one arm).
8. Walking stairs (5 steps without support).
9. Horizontal jump (with both legs together) across a line on the floor.
10. Squatting (taking a squatting position and rising up to a standing position again).

The patients were requested to perform the activities listed in table 6.2 from 1 to 10. Each activity had to be carried out one time properly. The patient was allowed to rest between the respective test items. The result was judged by one observer. The end result of the functional test was expressed as a number corresponding with the number of activities the patient was able to perform properly.

### **6.3 Results.**

In figures 6.1 and 6.2 the isometric and isokinetic (90 degr./sec.) maximal torque values are plotted against the time elapsed since the first test. The last test was performed by the time the patient had resumed all his former activities. All patients reported at the time of the last test they did not experience any after-effects of their G.B.

The individual maximal torque values were converted to a percentage of the last values which were set at 100%.

The results of the functional test, determined at every test session, are presented in the curves of the individual patients.

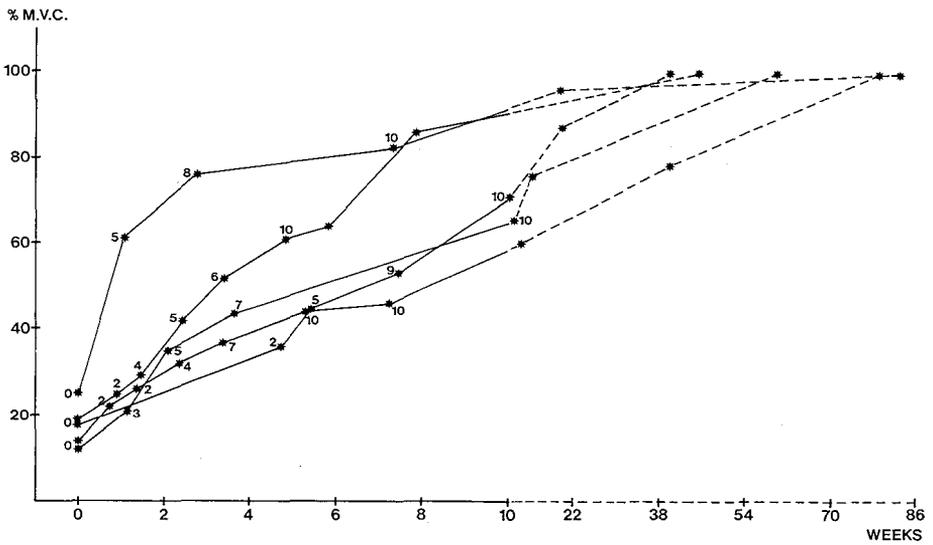


Fig. 6.1 Maximal isometric torque of the knee extensors of the individual patients. The result of the functional test is presented at every strength test.

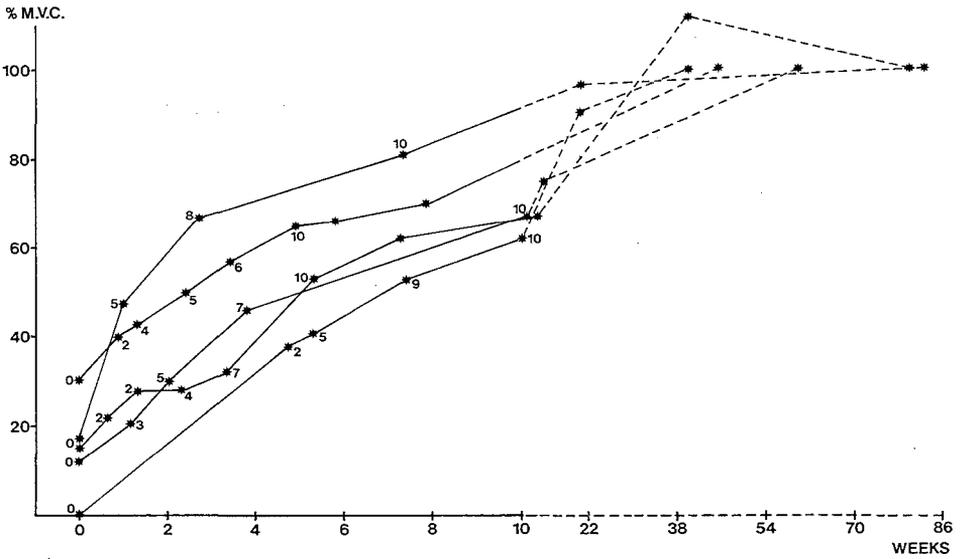


Fig. 6.2 Maximal isokinetic torque (90 degr./sec.) of the knee extensors of the individual patients. The result of the functional test is presented at every strength test.

## 6.4 Discussion.

The group of patients described in this chapter is small and rather heterogeneous as far as age and bodyweight are concerned. It was however not possible to form a larger population because of the fact that the patients had to be followed from a very early stage of their disease till full recovery.

This study should therefore be considered as a pilot study in which an attempt is made to find a different approach for the relationship between impairment and disability.

The patients performed strength tests and a functional test until they no longer experienced subjective differences in strength and in daily life, compared with their situation before the G.B. As a result of this procedure the absolute values of the measurements could be expressed as a percentage of the last test and each patient provided its own reference values.

There is no absolute proof that the results of the last test are identical with the strength level present before the G.B., but there are some indications that full recovery has been achieved.

In the first place all subjects stated that at the time of the last test they did not experience any restrictions in daily life and they subjectively felt that their strength was the same as before.

Secondly, maximal torque of the G.B. patients has reached a level which is higher than the data presented in chapter 3 (table 3.2) in which the results of healthy young volunteers are described. Mean isometric torque at the final test of the patients amounted to 259 Nm and mean isokinetic torque was 166 Nm.

In figures 6.1 and 6.2 the functional level of the patients is presented in relation to maximal torque. It appears that the patients are capable to perform all functional tests (score 10) when they have not yet reached their 'normal', definitive strength level. In figure 6.1 the first score of 10 is found at an isometric maximal torque ranging from 45 to 85%. In figure 6.2 the first score of 10 is reached between 53 and 80% of the normal isokinetic maximal torque at 90 degr./sec.

Thus, maximal torque may still be decreased considerably whereas the patient does not experience this weakness during the functional activities anymore.

In this group of G.B. patients about 30 to 40% decreased muscle strength of the knee extensors is found, while the patients are capable of performing all 10 functional tests.

Especially at the beginning of a progressive neuromuscular disease or at the end of a recovery of muscle weakness it seems more appropriate to measure muscle strength in order to monitor deterioration or recovery instead of evaluating the patient on the basis of practical activities such as walking, squatting, jumping, etc. In the area, between about 60 and 100% of normal strength, it is not possible to assess a simple relationship between impairment (muscle weakness) and disability.

In the initial phase of recovery, when the patients experience definitive functional restrictions (score <10), the relationship between maximal torque and functional score appears to be different for each individual patient. The improvement of the functional score and the increase of maximal torque coincide, but at a different individual rate.

For example: score 5 is reached at an isometric maximal torque between 30 and 60% (fig. 6.1) or at an isokinetic (90 degr./sec.) maximal torque between 30 and 50% (fig. 6.2). In figure 6.2 at a torque level of 30% one patient still shows a score of 0, whereas another patient already reached a functional score of 5.

Another approach of the data is to look for minimal levels of strength required to be able to perform certain activities. With proper reservations one may state that under a 20% level of maximal isometric or isokinetic torque these patients are not able to perform any of the 10 functional activities used in this study.

Standing and walking at a slow speed (score <5) are possible under a 30% strength level, but for more difficult activities, such as squatting and jumping or stairclimbing, more strength is required.

In order to perform all 10 activities a strength level of at least 45% is needed. The first 10 score is reached at 45% isometric maximal torque and at 53% isokinetic torque (fig. 6.1 and 6.2).

It is of course not possible to come to definitive, general conclusions about the relationship between impairment and disability on the basis of this small, heterogeneous group of patients. The population should be much larger and ideally the strength test should be done at every stage of improvement in the functional score.

## 6.5 References.

Aniansson A, Grimby G, Rundgren A.

– Evaluation of functional capacity in activities of daily living in 70-year-old men and women.

Scand. J. Rehab. Med. 12: 145-154, 1980.

– Isometric and isokinetic quadriceps muscle strength in 70-year-old men and women.

Scand. J. Rehab. Med. 12: 161-168, 1980.

Lankhorst G J, v.d. Stadt R J, v.d. Korst J K, Hinlopen-Bonrath E, Griffioen F M M, de Boer W.

Relationship of isometric knee extension torque and functional variables in osteoarthritis of the knee.

Scand. J. Rehab. Med. 14: 7-10, 1982.

Lankhorst G J, v.d. Stadt R J, v.d. Korst J K.

The relationships of functional capacity, pain and isometric and isokinetic torque in osteoarthritis of the knee.

Scand. J. Rehab. Med. 17: 167-172, 1985.

## GENERAL DISCUSSION.

The two main purposes of the studies presented in this thesis were:

- to study the isokinetic torque angle curve of the knee extensors.
- to study the practical usefulness of isometric and isokinetic dynamometry of the knee extensors in healthy subjects and in patients with decreased muscle strength.

The shape of the torque angle curve of the knee extensors, measured with the Q.D., is characterized by an initial isometric phase, followed by the dynamic phase in which torque rises slowly to a maximal level and subsequently decreases until maximal extension is reached.

This shape is partly caused by the biomechanical circumstances of the knee joint and its muscles and partly by the design of the dynamometer. Especially the first part of the curve seems to be influenced by the dynamometer. This becomes more evident when the isokinetic curve of the Q.D. is compared with the curve measured with the Cybex II (chapter 2.3). The maximal torque values of both dynamometers differ about 10% maximally and the second half of the curves are rather similar. Large differences, however, are found at the beginning of the curve and these are caused by the design of the dynamometers. In contrast with the Q.D. the acceleration of the Cybex II is unresisted and torque is recorded only as soon as the preselected angular velocity is reached.

The influence of the dynamometer on the isokinetic curve is also illustrated by the results of the experiment in which the starting position is changed (chapter 2.4). Starting the isokinetic contraction at 60 degr., instead of 90 degr., results in lower maximal torque values, found later in the r.o.m. Again the design of the dynamometer seems to be responsible for these effects.

It is not possible to discern exactly which feature of the curve should be contributed to the dynamometer or to the biomechanical characteristics of the muscles and the knee joint. However, the results of this study suggest that one should be very cautious in contributing too much value to the first part of the isokinetic curve. Maximal torque is the most frequently used parameter in other studies, but, when isokinetic curves are interpreted or other studies are compared, one should be aware that this parameter is also influenced by the design of the dynamometer. The question whether isometric and isokinetic dynamometry have any practical use may be approached in several ways:

- is the strength test reliable?
- does isokinetic dynamometry have any advantages over the isometric tests or do both methods measure the same function?
- does isokinetic dynamometry have any predictable value? Can the results of a strength test of the knee extensors predict the ability to perform activities such as walking, jumping, etc.?

- should the effect of a therapy programme or the progress of a disease be monitored by dynamometry or by testing the functional activities?

The reliability of a test is to a large extent reflected by its variability (chapter 3). The intraindividual variability of isometric and isokinetic dynamometry of healthy subjects is considerable. When tests are done with the Q.D. in 3 consecutive weeks some subjects improve, while others show decreasing torque values. Some subjects score better on one and others better on another angular velocity. The consequence is that individual strength test results are only reliable when several measurements are performed. It is unlikely that there would be a learning effect over a longer period. The healthy subjects that were tested five times, with 2 weeks intervals, remained at the same level of maximal isometric and isokinetic torque (chapter 4).

The correlation coefficients of isometric and isokinetic maximal torque of the knee extensors are statistically significant, but rather low (chapter 3). Only 31% of the variability of the isometric test can be explained by the variability of the isokinetic test (at 90 degr./sec.). This means that the result of the isometric test cannot be used to predict the result of the isokinetic test accurately and that both ways of strength testing probably measure other aspects of strength of the knee extensors. During the isometric test torque is measured at one joint angle under static conditions, whereas during the dynamic (isokinetic) test the knee extensors shorten and torque is measured through the complete r.o.m.

The advantage of isokinetic dynamometry is that this way of strength testing seems to be more sensitive to small strength differences than isometric dynamometry (chapter 4 and 5). The difference of maximal torque of the operated and the non-operated leg (after meniscectomy) was larger when tested isokinetically. The isometric deficit was 12% after 8 weeks of training, but the isokinetic deficit amounted to 21%.

Furthermore, isokinetic dynamometry shows somewhat higher correlation coefficients with jump performance in the healthy subjects. This is found in the control group (chapter 4) and in the patients after full recovery (chapter 5). The predictive validity (for the whole group) of isokinetic maximal torque seems to be better than that of isometric maximal torque.

For the individual patient in a clinical situation it seems to be impossible to predict the functional abilities on the basis of the maximal isometric or isokinetic torque values. The correlation coefficients of maximal torque and jump performance are low (chapter 4) and the interindividual differences high (chapter 6).

It is possible that a patient, recovering from a neuro-muscular disease, is able to perform all single functional tests that are frequently used in a clinical situation, whereas muscle strength, measured with a dynamometer, has not yet reached the normal level (chapter 6). In this case a physical examination is not enough and has to be followed by a dynamometer test. If not, increase or decrease of strength will

not be registered and the wrong conclusions about the progress of the disease or the effect of therapy may be drawn.

The practical usefulness of isometric and isokinetic dynamometry is limited. It is not possible to give a judgment of the functional level of an individual patient on the basis of the results of the strength test alone. Most functional activities are rather complex and not only muscle strength, but also coordination, endurance, absence of pain, motivation, unrestricted motion of the joints, etc. determine the functional performance.

The results of a strength test should therefore be interpreted very carefully and with proper reservation.

## SUMMARY.

In rehabilitation medicine one is concerned with the consequences of diseases, congenital deformations and trauma.

On the level of functions and structures the consequences consist of impairments of muscle strength, sensibility, co-ordination, etc.

These impairments may cause disabilities like restricted ambulation, problems with self-care, etc.

In rehabilitation one feels a need to measure the impairments in a reliable way, in order to assess the effects of certain training programmes or to register the course of a chronic disease objectively.

The tests used to measure the impairment have to be reliable. The variability of a test is a useful indication of the reliability.

Furthermore, a test has to be valid, i.e. the test measures what it is supposed to measure. The validity of a test becomes acceptable if there is a relationship between the impairment itself and the consequences on the functional level.

The object of this thesis is the testing of muscle strength of the knee extensors in healthy subjects and in patients.

In chapter 1 some main types of muscle testing are discussed. Definitions are given and the (dis-)advantages are explained.

In a short review of the available literature the factors that influence the reliability of the strength tests are discussed. Studies about the relationship between impaired muscle strength and the resulting disabilities are described.

Finally the purpose and the structure of the thesis are presented.

In chapter 2 the dynamometers and the methods used to measure muscle strength are described. The design of the Quadriceps Dynamometer (Q.D.) and the way it is applied are explained.

Consequently the results of a study on healthy volunteers are presented. Isokinetic torque angle curves of the knee extensors were measured with the Q.D. and the Cybex II.

It appeared that the differences between the respective torque angle curves are considerable, especially in the first part of the curve. The design of the dynamometer was assumed to be responsible for these differences. The parameter most frequently used, maximal torque, was 10% lower on the Q.D. maximally.

It was concluded that, with some reservations, the results of the tests on the Q.D. are comparable with the data found in the literature about the Cybex II.

The second part of chapter 2 describes the influence of the starting positions and the angular velocities on maximal isokinetic torque. Most other dynamometers dispose of a starting position which cannot be preselected accurately. On the

Q.D., however, the starting position can be determined exactly before the test. The study was executed with healthy volunteers and the Q.D. A reverse relationship between maximal torque and angular velocity was found. This result is in accordance with the results of studies with the Cybex II and in vitro studies on isolated muscles and muscle fibers. The starting position had a distinct influence. Changing the starting position from 90 to 60 degr. resulted in lower maximal torque and a shift of maximal torque towards extension. This may be explained by the starting mechanism of the dynamometer. Before the dynamic phase of the contraction an isometric phase of 0.2 sec. is present. At a starting position of 60 degr. the force the knee extensors can produce in this short period is less than at a starting position of 90 degr. In the dynamic phase the muscles are not capable, after a start at 60 degr., to make up for the difference. It is not clear which consequences these results have for other dynamometers than the Q.D., because they are not always provided with a variable starting position. However, when tests are performed on the Q.D. the starting position has to be kept constant in order to be capable of comparing the results.

Chapter 3 presents a study on the variability of isometric and isokinetic measurements of the knee extensors of healthy volunteers. At the same time this study explores the relationship between isometric and isokinetic torque measurements. Each subject was tested three times with one week intervals. The interindividual variability, as could be expected, was considerable (13-20%). The intraindividual variability was 11% at most. The subjects showed substantial differences from week to week and at the respective angular velocities. The correlation coefficients of the isometric and the isokinetic tests were low and it was concluded that the results of an isometric test cannot be used to predict the result of an isokinetic test. Both methods measure other aspects of muscle strength.

Chapter 4 describes a prospective study of patients after a meniscectomy. During a training period of 8 weeks strength tests of the knee extensors of both legs were performed and the results were compared with a vertical jump test. Healthy volunteers served as a control group. At the end of the training period strength of the knee extensors was not equal. A difference of 12% at the isometric test and 21% at the isokinetic test was found. This result suggests that strength differences are better detected with an isokinetic test. The relationship between the results of the strength test and the jump performance were low, especially during the initial part of the training period. Pain and swelling of the operated knee probably caused inhibition of a maximal voluntary contraction of the knee muscles.

The relationship between the isokinetic test and jump performance seemed to be somewhat better than the isometric test.

These results indicate that isokinetic tests may be preferable to isometric tests in the follow-up of a therapy programme or in testing small strength differences.

In chapter 5 the results of a follow-up study of the subjects of chapter 4 are presented. The strength differences of the operated and the non-operated leg as well as possible complaints were investigated.

It appeared that the strength differences did not exist anymore two years after the training period despite the fact that only a few patients were treated after their discharge.

The results of resumption of professional and sporting activities indicated no negative effects of the strength deficit present at the end of the training period. In this study the potential risks of a strength difference of the knee extensors and the necessity to continue the treatment could not be demonstrated.

In chapter 6 the question of the relationship between impairment and disability is approached in another way than by using correlation coefficients.

Instead, strength was determined after complete recovery and these values were used as an individual standard during the phase of recovery.

Five patients with a Guillain-Barré syndrome were tested from an early phase of their disease until the time of complete recovery. After every strength test of the knee extensors 10 functional tests were performed to assess disabilities. The functional tests ranged from easy (standing) to heavy activities (squatting and jumping). It appeared that the patients executed all functional tests when they had reached a level of 60-70% of their normal strength. Thus, when strength is diminished 30-40% no relationship can be demonstrated between the impairment (muscle weakness) and disability, as defined by the functional tests.

When strength is reduced by more than 80% no functional activities could be performed. Between 20% and 60-70% of the normal strength the relationship between muscle strength and the functional ability differs considerably for each individual.

In summary it is concluded that:

- the isokinetic angle torque curves of the Q.D. are different from the curves of the Cybex II, but the results of the strength test on the Q.D. may be compared with the Cybex II when maximal torque is used as a parameter.
- the design of an isokinetic dynamometer has a strong influence on the shape of the angle torque curve. When the curve is interpreted one should discern between artefacts, caused by the apparatus, and the real characteristics of the muscle group studied.

- isometric and isokinetic tests of the knee extensors each measure a different aspect of strength of this muscle group.  
Isokinetic tests seem to be more sensitive and seem to have a stronger relationship with practical activities.
- when a strength difference of the knee extensors exists at the end of a training period after meniscectomy and when the training is not continued, complaints do not necessarily follow and a spontaneous recovery is possible.
- the approach of the relationship between impairment and disability by correlation coefficients is often insufficient. A deeper understanding may be provided when the performance is not expressed in absolute values and when each individual provides its own reference value.

## SAMENVATTING.

De revalidatie-geneeskunde richt zich op de gevolgen van ziekten, aangeboren afwijkingen en traumata.

Deze gevolgen bestaan uit functiestoornissen zoals krachtverlies, gevoelstoornissen, coördinatioestoornissen, etc.

De functiestoornissen kunnen op hun beurt leiden tot (vaardigheids)beperkingen zoals bijv. een verminderde ambulantie, het niet zelfstandig zijn in de zelfverzorging, etc.

In de revalidatie-geneeskunde bestaat de behoefte de functiestoornissen op een betrouwbare wijze te meten, omdat men het effect van bepaalde therapievormen wil vastleggen of omdat men een objectieve maat wil hebben van voor- of achteruitgang van een aandoening.

De meetmethode van de functiestoornis dient betrouwbaar te zijn, hetgeen zich ondermeer uit in de reproduceerbaarheid en de variabiliteit van de meting.

Tevens zal een meetmethode valide moeten zijn, d.w.z. dat men inderdaad die eigenschap meet, die men beoogt te meten. De validiteit van een meetmethode kan men onder meer aannemelijk maken wanneer er een relatie is aan te tonen tussen de gemeten functiestoornis en de daaruit af te leiden (vaardigheids)beperking. Dit proefschrift richt zich op de functiestoornis krachtsverlies c.q. op de functiekracht van de kniestickekkers.

In hoofdstuk 1 worden enige vormen van krachtmeting besproken. Enkele gangbare meetmethoden worden gedefinieerd en de voor- en nadelen uitgelegd.

Een literatuur-overzicht wordt gegeven van de factoren die de betrouwbaarheid van de meting negatief beïnvloeden.

Tevens wordt ingegaan op de relatie tussen kracht en praktische vaardigheden voor zover beschreven in de literatuur.

Tenslotte worden het doel en de opzet van het onderzoek besproken.

Hoofdstuk 2 beschrijft de apparatuur en de methoden die gebruikt werden om kracht te meten. Het ontwerp van de quadriceps dynamometer (de Q.D.) en de wijze waarop de Q.D. wordt gebruikt, worden uitgelegd.

Vervolgens worden de resultaten van een onderzoek weergegeven, waarin de isokinetische moment hoek curven van de kniestickekkers van gezonde proefpersonen werden bepaald met zowel de Q.D. als de Cybex II, een andere veel gebruikte dynamometer.

Het bleek dat de moment hoek curven aanzienlijke verschillen vertoonden. De vorm van de curve verschilde vooral in de eerste fase van de spiercontractie. Het ontwerp van de dynamometers bleek voor de verschillen verantwoordelijk. De meest gebruikte parameter, het maximale moment, was, afhankelijk van de gekozen hoeksnelheid, maximaal 10% lager op de Q.D.

Geconcludeerd werd dat met enig voorbehoud de resultaten van de krachtmeting met de Q.D. goed te vergelijken zijn met de gegevens uit de literatuur, waarbij meestal de Cybex II wordt gebruikt.

Het tweede deel van hoofdstuk 2 beschrijft de invloed van de starthoek en de hoeksnelheid op het maximale isokinetische moment. Bij sommige apparatuur is de starthoek variabel en niet goed instelbaar. De Q.D. daarentegen beschikt over de mogelijkheid de starthoek precies in te stellen.

Het onderzoek werd uitgevoerd bij gezonde vrijwilligers. Een omgekeerde relatie kon worden aangetoond tussen maximaal moment en de hoeksnelheid. Dit komt overeen met de resultaten van onderzoek met de Cybex II en in vitro onderzoek bij geïsoleerde spieren en spiervezels.

De invloed van de starthoek was duidelijk. Het verplaatsen van de starthoek van 90 naar 60 graden flexie resulteerde in een lager maximaal moment en een verschuiving van het maximale moment naar extensie.

De verklaring wordt gezocht in het startmechanisme van de dynamometer. Vóór de dynamische fase van de contractie vindt een isometrische contractie plaats gedurende 0.2 seconde. De kracht die de spieren kunnen ontwikkelen in deze korte tijd is bij 60 graden starthoek kleiner dan bij 90 graden. In de daaropvolgende dynamische fase is de spier niet meer in staat om, na een start bij 60 graden, het verschil goed te maken. De consequenties van deze bevindingen voor de commercieel verkrijgbare dynamometers zijn niet geheel duidelijk, omdat deze niet altijd met een instelbare starthoek zijn uitgerust. Voor de metingen met de Q.D. betekent het dat testen die men onderling wil vergelijken bij een zelfde starthoek uitgevoerd dienen te worden.

Hoofdstuk 3 beschrijft een onderzoek bij gezonde vrijwilligers naar de variabiliteit van isometrische en isokinetische metingen van de kniestrekkers. Tevens wil dit onderzoek een beter inzicht geven in de relatie tussen isometrische en isokinetische metingen.

Drie meetsessies werden per proefpersoon gehouden met een week tussentijd. De interindividuele variabiliteit was, zoals verwacht, aanzienlijk (13-20%). De intraïndividuele variabiliteit overschreed de 11% niet. De proefpersonen verschilden sterk in hun prestaties van week tot week en bij de verschillende hoeksnelheden.

De correlatie-coëfficiënten tussen de isometrische en de isokinetische krachtmetingen waren zo laag, dat geconcludeerd werd dat het resultaat van een isometrische test niet gebruikt kan worden om het resultaat van een isokinetische test accuraat te voorspellen. Beide methoden meten elk een ander aspect van spierkracht.

Hoofdstuk 4 behandelt een prospectief onderzoek bij patiënten na een meniscectomie. Tijdens de behandelperiode van 8 weken werden geregeld krachtmetingen van de kniestrekkers van beide benen verricht en de resultaten hiervan werden vergeleken met de verticale sprongprestatie. Een groep gezonde vrijwilligers diende als controlegroep.

Aan het einde van de behandelperiode was er nog geen sprake van een gelijke kracht van de kniestrekkers van beide benen. Het verschil was gemiddeld 12% bij de isometrische test en 21% bij de isokinetische test. Dit suggereert dat de isokinetische test gevoeliger is voor krachtsverschillen.

De relatie tussen de krachtmeting en de sprongprestatie was matig, vooral in het begin van de behandelperiode. Waarschijnlijk was dit deels te wijten aan pijn en zwelling van de knie, waardoor een maximale inspanning werd geïnhibeed.

De resultaten van de isokinetische meting bleken een wat grotere correlatie te hebben met de sprongprestatie dan de isometrische meting. Op grond van deze resultaten zou men voor het vervolgen van een therapie of voor het meten van een geringe krachtverlies de voorkeur kunnen geven aan isokinetische testen boven isometrische testen.

In hoofdstuk 5 worden de resultaten weergegeven van een na-onderzoek van de patiënten uit hoofdstuk 4. Onderzocht werd of de krachtsverschillen tussen geopereerde en niet-geopereerde been nog bestonden en of deze verschillen hadden geleid tot klachten.

Het bleek dat de verschillen twee jaar na de behandelperiode niet meer bestonden, ondanks het feit dat slechts een enkeling na ontslag nog specifieke training had ondergaan. Gegevens over werk- en sporthervatting wezen niet op een nadelig effect van het krachtsverschil waarmee de behandelperiode was afgesloten.

Het risico van dysbalans in kracht van de kniestrekkers en de noodzaak van voortzetting van de behandeling kon in dit onderzoek niet worden aangetoond.

In hoofdstuk 6 wordt het probleem van de relatie tussen functiestoornis en (vaardigheids)beperking op een andere wijze benaderd, dan door het gebruik van correlatiecoëfficiënten. Er werd gekozen voor een benadering, waarbij per patient de kracht gemeten bij volledig herstel diende als norm voor de krachtmetingen tijdens de herstelfase.

Vijf patiënten met een Guillain-Barré-syndroom werden gemeten van een vroege fase van hun ziekte tot het tijdstip van volledig herstel. Na elke krachtmeting van de kniestrekkers werden 10 vaardigheidsproeven verricht om de beperking vast te leggen. De vaardigheidsproeven varieerden van licht (staan) tot zwaar (hurken en springen).

Het bleek dat de patiënten alle vaardigheidsproeven konden uitvoeren wanneer zij nog slechts 60 à 70% van hun normale kracht hadden bereikt. Bij een krachtverlies van 30 à 40% is er met deze benadering geen relatie te leggen tussen de func-

tiestoornis krachtverlies en de beperking in de vorm van verminderde vaardigheid.

Bij een krachtverlies van meer dan 80% kunnen de patienten geen van de vaardigheidsproeven uitvoeren. Bij een kracht tussen 20 en 60 à 70% is de relatie tussen kracht en vaardigheid individueel sterk verschillend.

Samenvattend lijken de volgende conclusies getrokken te kunnen worden:

- de isokinetische moment hoek curven van de Q.D. verschillen van de curven van de Cybex II, maar de resultaten van krachtmeting met de Q.D. kunnen daarmee goed vergeleken worden, wanneer het maximale moment als parameter wordt gebruikt.
- het ontwerp van een isokinetische dynamometer heeft grote invloed op de vorm van de moment hoek curve, zodat men bij de interpretatie van de curve moet trachten te onderscheiden tussen artefacten, veroorzaakt door de apparatuur, en de werkelijke eigenschappen van de te onderzoeken spiergroep.
- isometrische en isokinetische tests van de kniestrekkers meten elk een ander aspect van de kracht van deze spiergroep.  
Isokinetische metingen lijken gevoeliger te zijn en een betere relatie te hebben met de praktische vaardigheid.
- wanneer een verschil in kracht van de kniestrekkers bestaat aan het einde van een behandelperiode na meniscectomie en deze niet gevolgd wordt door een nieuwe oefenperiode, hoeft dit niet te leiden tot klachten en kan spontaan herstel van de kracht optreden.
- de benadering van de relatie tussen kracht en vaardigheid d.m.v. correlatieberekeningen biedt vaak onvoldoende inzicht. Methoden waarbij de prestatie niet in absolute waarden wordt uitgedrukt en elk individu zijn eigen referentie vormt, lijken meer inzicht te geven in de relatie tussen functiestoornis en beperking.

## APPENDIX I.

Med. & Biol. Eng. & Comput., 1983, 21, 764-767

### Technical note

## Apparatus for measuring the functional capacity of the knee extensors and flexors

**Keywords**—Force measurement, Knee extension

### 1 Introduction

THE results of strengthening therapy in rehabilitation can be established by measuring the muscle force with a dynamometer. Isometric measuring systems are most commonly used for this purpose. Most activities of man are, however, combinations of isometric, isokinetic and isotonic contractions. In the last ten years a number of systems for measuring muscle force under dynamic conditions have been developed. Isokinetic devices, such as the Cybex II, have become well known and are nowadays commercially available (HERMAN *et al.*, 1967; MOFFROID *et al.*, 1969; LÖFSTED, 1978).

Efforts have also been made to measure the functional capacity of muscles under isotonic conditions. In these measuring systems electronic torque servosystems were used (THOMAS *et al.*, 1976), as well as weights via a reduction system (DANOFF, 1978). This could be of particular interest owing to the fact that in many activities of daily living muscle force is exerted under isotonic conditions; e.g. load lifting, pushing and pulling. Contractions under these conditions

compared with isokinetic conditions may, however, give different results in power measurements because of the different way in which the neuromuscular system is involved (KEARNY, 1978). It is therefore useful to investigate the differences in muscular performance under these different conditions.

In most studies, force measurements were made during concentric contractions. In our opinion the measurement of force during eccentric contractions is equally important. This demands, however, a particular device performance, because the torque exerted by the device must be greater than the maximum torque exerted by the test subject. A system is described which can generate the three conditions previously mentioned (isometric, isotonic and isokinetic). It should be emphasised that these external conditions are theoretical concepts concerning the actual muscle contraction.

Previous considerations and biomechanical and anatomical reasons (KROEMER, 1970) have provided the following starting points for the design of a new device for muscle force measurements:

- (a) Measuring the force of the thigh muscles, in particular the quadriceps muscle, is the most practical.

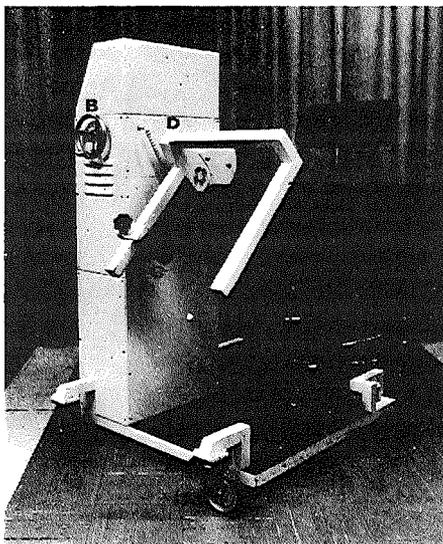


Fig. 1 Photograph of the dynamometer, test subject side (see text)

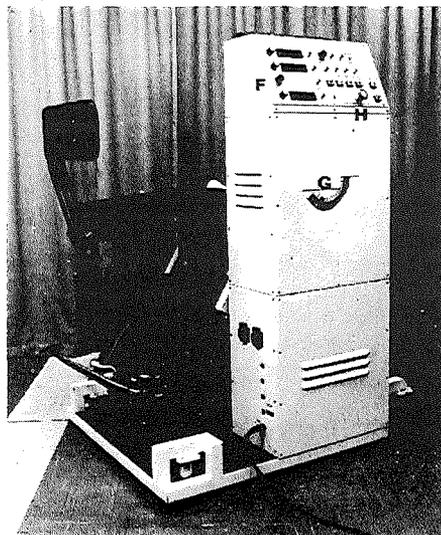


Fig. 2 Photograph of the dynamometer, control panel side (see text)

First received 6th October 1982 and in final form 5th April 1983

© IFMBE: 1983

- (b) Measuring conditions should be comparable with those of other isometric and isokinetic devices. For instance, the speed should be comparable with functional knee-angle speeds used in rehabilitation practice.
- (c) Measurements under isotonic conditions should be possible.
- (d) Measurements during eccentric as well as concentric conditions are necessary.
- (e) The device should record angle, torque, speed and power.
- (f) It should be of use for clinical application.

## 2 Functional description

The newly designed dynamic quadriceps dynamometer (q.d.) is shown in Fig. 1 and Fig. 2 and is schematically presented in Fig. 3. The test subject is seated on a dental chair (A) adjustable in height from 0.45 to 0.65 m. The subject is secured in the chair by a seatbelt across the upper legs near the pelvis. The chair can be rotated through 180°. The distance and angle of the back of the chair are adjustable in relation to the underframe. The chair can be hydraulically adjusted to such a position that the knee axis of the subject is at the same level as the axis of the q.d. The axis of the q.d. can be moved in a horizontal direction over  $\pm 10$  cm (B), thus allowing a good alignment with the knee axis. In this position it is possible to measure the knee moment of muscle force for

both the right and the left leg by replacing a block (C) fixed on the transducer arms (D).

The moment of force of the quadriceps muscle is measured by a torque transducer (E). The driving system can be operated by a control panel (F). The range of movement of the transducer arm can be adjusted with electrical switches (G).

Mechanical stops and two 'panic buttons' (H) are available for both operator and test subject in order to safeguard the latter from mechanical hazards.

The q.d. has been assembled on a steel baseplate ( $1 \times 0.85$  m) on four wheels (I).

## 3 Driving system

The preference for an electric driving system for this combination of different control tasks is obvious. It should, however, be of limited dimensions and powerful enough to allow measurement of force during eccentric contraction. A high instantaneous torque a.c. motor of power 0.6 kW has therefore been used (AREG, type RC 602 EB). The torque available is 2.6 Nm at 2400 r.p.m.

For measurements of the functional capacity equivalent to functional activities of daily living, it should be sufficient to measure torque at a maximum speed of  $90^\circ \text{ s}^{-1}$  ( $1.5 \text{ rad s}^{-1}$ ). For this purpose a squared transmission (worm gear) is assembled with a gear ratio of 156:1 (Fig. 3). The efficiency of this reduction gear is 0.7, so that during eccentric contraction a torque of up to 280 Nm ( $2.6 \times 156.0 \times 0.7$ ) can be measured.

## 4 Control system

The control system for the different conditions will be described from a block diagram (Fig. 4)

### 4.1 Isometric condition

It is not necessary to control the driving system under isometric conditions because the system cannot be rotated against the squared transmission.

The transducer arm can be placed in a position determined by the operator (manual control). Torque exerted by knee extensors or flexors is measured by the torque transducer.

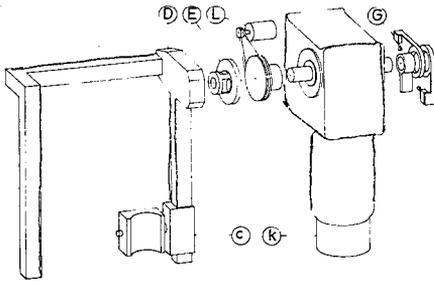


Fig. 3 Schematic diagram of the driving system

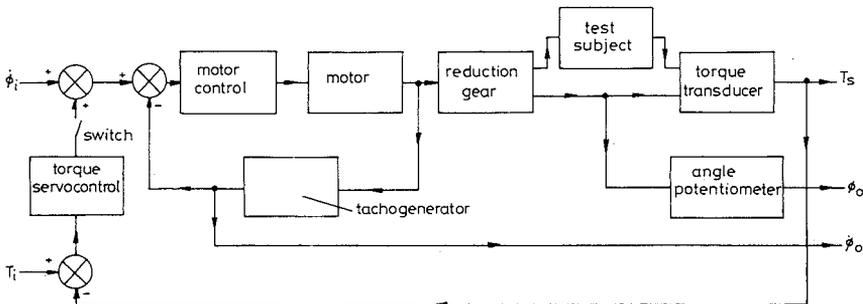


Fig. 4 Block diagram of the control system. Input signals:  $\dot{\phi}_i$ , the angle speed adjusted with a potentiometer;  $T_i$ , the adjustable torque under isotonic condition. Output signals:  $T_s$ , the torque exerted by the test subject and measured by the transducer;  $\phi_o$ , the angle position of the transducer arm;  $\dot{\phi}_o$ , the actual angle speed of the transducer arm, measured by the tachogenerator

#### 4.2 Isokinetic condition

A speed control has been implemented by means of tachogenerator feedback (Fig. 3, K). The angular speed can be adjusted with a ten-turn potentiometer as well as by a remote electric signal ( $\phi_0$ ). Switch S in Fig. 4 is open. The driving system can be triggered either by the operator (hand control switches) or by the test subject, who has, therefore, to exceed a threshold torque. This threshold torque can be adjusted up to 250 Nm. In the endstop position (determined by angle range, Fig. 3, G) the direction of movement is determined by operator control only. In the endstop position the driving system is or will be switched off. Torque measurements remain, however, possible in these positions (isometric condition).

#### 4.3 Isotonic condition

For isotonic contractions switch S must be closed. The initial angular speed is set at zero. In this way a torque servosystem has been created. The task of the subject is to exert a maximum speed of contraction. There will be an optimum in speed for a certain load, depending on the force/speed relationship of the muscle and the joint angle (muscle length).

A high gain factor in the control loop would cause a small difference between the applied torque ( $T_i$ ) and the measured torque ( $T_j$ ). This, however, causes instability in the closed loop system owing to the characteristics of the transfer function of the test subject and torque transducer. We overcame this instability by adjusting the gain factor. This factor has been established by experiments. It is adjusted at  $3^\circ \text{s}^{-1} \text{Nm}^{-1}$ , i.e. full speed ( $90^\circ \text{s}^{-1}$ ) is obtained by 30 Nm difference between  $T_i$  and  $T_j$ .

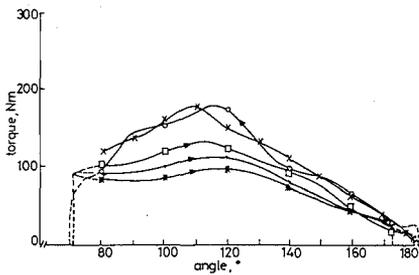


Fig. 5 Torque/angle curves during isokinetic and static contractions of a healthy female test subject. The starting angle for dynamic contractions is  $70^\circ$  and for the eccentric contraction  $170^\circ$ . The speed is  $\approx 30^\circ \text{s}^{-1}$  (eccentric contraction) and 30, 60 and  $90^\circ \text{s}^{-1}$  (concentric contractions). Torque is measured during isometric contractions at the angles  $80^\circ, 90^\circ, 100^\circ, \dots, 180^\circ$

Contraction, $^\circ \text{s}^{-1}$	
○	-30 (eccentric)
×	0 (static)
□	30 (concentric)
+	60 (concentric)
★	90 (concentric)

#### 5 Measuring equipment and recording

The most important measured data (Fig. 4) can be recorded: angle ( $\phi_0$ ), speed ( $\dot{\phi}_0$ ), torque ( $T_j$ ) and power. It is possible to check a number of signals in the control loop, e.g. the motor input, gain factors, threshold torque etc.

The angle is measured with a potentiometer (Fig. 3, L). The sensitivity is  $180^\circ \text{V}^{-1}$ , the range  $45$  to  $180^\circ$ , where full extension of the knee is equal to  $180^\circ$ .

The speed is available as a feedback signal from the tachogenerator. This is the actual speed of the system. The sensitivity of the output is  $100^\circ \text{s}^{-1} \text{V}^{-1}$ , the range  $-90$  to  $+90^\circ \text{s}^{-1}$ .

The adjusted level of speed is reached after a starting period formed by a start delay (0.15 s) brought about by electronic switches and the limited acceleration of the speed control. The acceleration is  $300^\circ \text{s}^{-2}$ . This acceleration will also bring about an error, caused by inertia, in the torque measured under nonisokinetic conditions. For the moving machine parts it is 5 Nm and for the subject leg  $\pm 3$  Nm at the maximum acceleration ( $5.2 \text{ rad s}^{-2}$ ).

The specially constructed torque transducer, exclusively sensitive to torque (GOMMERS, 1976), contains a full-bridge strain-gauge system. The range is  $-500$  to  $+500$  Nm. The sensitivity of the output is  $1000 \text{ Nm V}^{-1}$ . The maximum error in the output is less than 1% full scale. The maximum frequency is limited by a resonant frequency of about 20 Hz.

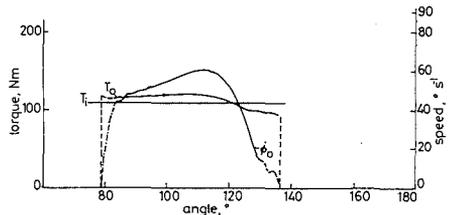


Fig. 6 Torque/angle and speed/angle curves during a concentric isotonic contraction of a healthy female subject. Torque was adjusted at 108 Nm. The range of motion was from  $80^\circ$  to  $135^\circ$ . The broken line must be conceived as starting and stopping phenomena

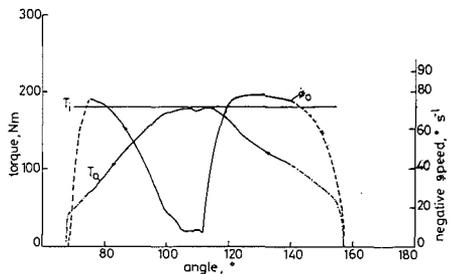


Fig. 7 Torque/angle and negative speed/angle curves during an eccentric isotonic contraction of a healthy female subject (see also Fig. 6). Torque was adjusted at 180 Nm. The range of motion was from  $160^\circ$  to  $70^\circ$ . The broken line must be conceived as starting and stopping phenomena

The torque transducer is calibrated by weights under isometric conditions.

The power is calculated by an electronic four-quadrant multiplier. (The product of torque and speed = the momentary or instantaneous power.) The sensitivity is  $2000 \text{ Nm s}^{-1} \text{ V}^{-1}$ .

The signals representing angle, speed, torque and power are fed into a four-channel pen recorder (W + W. 314). It is possible to record the *yz* mode as well as the *xy* mode. In the *yx* mode a torque/angle curve is made directly with simultaneous recording of speed and power. Other combinations are, of course, possible. In Fig. 5 curves are shown of a healthy female test subject during an isokinetic maximum voluntary contraction (m.v.c.) of the knee extensors (torque against angle).

Figs. 6 and 7 show curves of an isotonic m.v.c. of the knee extensors during eccentric and concentric contraction (torque and speed against angle).

With these graphs torque/speed curves can be constructed.

## 6 Conclusion

The device described is a very useful apparatus for research on the functional capacity of the knee extensors and flexors. Many specific conditions can be set up to investigate the behaviour of the thigh muscles under different loads, speeds and angles.

For clinical purposes it is possible to measure well known standardised torque curves under isometric and isokinetic conditions.

*Acknowledgment*—The authors want to thank Mr. J. F. van Nieuwenhuizen for his help during the period of design and operation and Mr. J. Storm for his contribution to the construction of the electronic system. The apparatus was built by the Central Research Workshops. Research activities

are taking place in collaboration with the Department of Rehabilitation, Academic Hospital Rotterdam-Dijkzigt.

C. N. A. PRONK

\* *Department of Rehabilitation*  
*Faculty of Medicine*  
*Erasmus University Rotterdam*  
*PO Box 1738*  
*3000 DR Rotterdam*  
*The Netherlands*

R. NIESING

*Central Research Workshops*  
*Faculty of Medicine*  
*Erasmus University Rotterdam*  
*PO Box 1738*  
*3000 DR Rotterdam*  
*The Netherlands*

## References

- DANOFF, J. V. (1978) Power produced by maximal velocity elbow flexion. *J. Biomech.*, **11**, 481–486.
- GOMMERS, C. M. J. (1976) Enige nieuwe vormen voor rekstrookelementen. *Mikrotechniek*, **6**, 109–122.
- HERMAN, R., SCHARMBURG, H. and REINER, S. (1967) A rotational apparatus: a device for study of tension-length relation of human muscle. *Med. Res. Engin.*, **6**, 18–20.
- KEARNY, R. E. (1978) Simulation of the human neuromuscular response to angle rotation with a segmental reflex model. *Comp. Biol. Med.*, **8**, 329–341.
- KROEMER, K. H. E. (1970) Human strength; terminology, measurements and interpretation of data. *Human Factors*, **12**, 297–313.
- LÖFSTED, L. (1978) An apparatus for generating controlled ramp movements during studies of muscle spindle afferent activity and muscle tone in man. *IEEE Trans.*, **BME-25**, 374–477.
- MOFFROID, M., WHIPPLE, R., HOFKOSH, J., LOWMAN, E. and THISTLE, H. (1969) A study of isokinetic exercise. *J. Am. Phys. Ther. Ass.*, **49**, 735–746.
- THOMAS, J. S., CROFT, D. A. and BROOKS, V. B. (1976) A manipulandum for human motor studies. *IEEE Trans.*, **BME-23**, 83–84.

\* *accommodation address*

## APPENDIX II.

### TRAINING PROGRAMME (Chapter 4).

#### Week 1:

- Mobilisation of the knee joint in case of restricted flexion or extension.
- Cycling on a ergometer (Monark): 6 min.; 5 N; 20-25 km/h.
- Isometric exercises of the knee extensors without external load and with extended knee: 10 x 20 sec.; restintervals of 5-10 sec.
- Isometric exercises of the knee flexors with an external load of 20 N, with flexed knee (90 degr.): 10 x 20 sec.; 5-10 sec. restintervals.

The exercises with external loads are performed on an exercise bench. Every two days the duration of the isometric exercise is extended with 5 sec. till a total of 45 sec. is reached. Then the duration returns to 30 sec. and 5 N is added to the external load of the knee extensors and 10 N to the knee flexors. This scheme is maintained during the next weeks.

#### Week 2:

As in week 1, except:

- The duration of the cycling exercise is 10 min.
- The exercises of the knee extensors remain without external load, but the duration increases to 45 sec.
- Stabilisation exercises of the hip and knee muscles in a closed chain situation are prescribed.

#### Week 3:

As in week 2, except:

- Cycling: 10 min.; 10-15 N; 25-30 km/h.
- The closed chain exercises of the knee and hip muscles are intensified.

#### Week 4:

As in week 3, except:

- Cycling: 10 min.; 15-20 N; 30-35 km/h.
- Closed chain exercises for the calf muscles are added.
- Step-up (10x) and side-step (15x) exercises are started.

#### Week 5:

As in week 4, except:

- Cycling: 10 min.; 20-25 N; 30-35 km/h.
- Step-ups 15x; side-steps 20x.
- Jumping on both legs: 30 sec.

Week 6:

As in week 5, except:

- Cycling: 10 min.; 20-25 N; 30-35 km/h with tempo intervals of 40- 45 km/h for 30 sec.
- Jumping exercises on both legs: 60 sec. and on the operated leg: 30 sec.

Week 7:

As in week 6, but sporting activities, supervised by a sport- instructor are started.

Week 8:

The exercise programme is stopped and only sporting activities are continued.

## CURRICULUM VITAE.

De auteur van dit proefschrift werd geboren op 20 juni 1953 te Rotterdam.

Na het behalen van het diploma Gymnasium-B in 1971, studeerde hij Geneeskunde aan de Erasmus Universiteit in Rotterdam.

Het artsexamen werd in 1978 afgelegd, waarna de militaire dienstplicht werd vervuld in het Militair Revalidatiecentrum te Doorn.

Vanaf 1980 t/m 1983 was hij in opleiding tot revalidatie-arts op de afdeling Revalidatie van het Academisch Ziekenhuis te Rotterdam (opleider Prof. B.D. Bangma) en het revalidatiecentrum 'De Hoogstraat' te Leersum (opleider Prof. H. Bakker).

Vervolgens was hij tot medio 1987 als chef de clinique verbonden aan de afdeling Revalidatie van het Academisch Ziekenhuis te Rotterdam (hoofd Prof. B.D. Bangma).

Vanaf 1987 is hij werkzaam als revalidatie-arts in de regio Zeeuws-Vlaanderen.

