Isokinetics and Exercise Science 10 (2002) 211–219
IOS Press

ACL rehabilitation program using a combined isokinetic and isotonic strengthening protocol

P. Tsaklis[a,b,*] and G. Abatzides[a]
[a]*Sports Injuries Lab, Faculty of Physical Education and Sports Sciences, Aristotle University of Thessaloniki, Greece*
[b]*Physical Therapy Department, Technological Educational Institute of Thessaloniki, Greece*

Abstract. The purpose of this paper is to present a rehabilitation program following ACL reconstruction. This program consists of isotonic as well as isokinetic muscle strengthening components. Forty-five post-ACL surgery patients took part in this study. They were all male athletes participating in different events. Patients were divided randomly into 3 groups of 15 corresponding to 3 distinct rehabilitation programs which continued for 3 months after surgery. During the first month the groups followed the same paradigm. For the next two months, group A continued the practice by using only isotonic strengthening exercises, group B used exclusively isokinetic strengthening exercises and group C performed a combined program of isokinetic and isotonic exercises. The three groups appear to have improved until the 3rd post operative month, with highly significant pre-post differences in the various measured parameters. However, group C patients achieved the highest outcome scores and therefore our recommendation calls for a mixed isokinetic-isotonic program.

1. Introduction

The opinions and choices which follow rehabilitation of the knee after plastic surgery of the ACL vary in the scientific community and reflect the multiplicity of factors associated with optimal return of the patient to normal activity pattern. In particular, when the patient is also an athlete one of the most frequent questions concerns the time of the abstention after the operation. The answer depends on factors such as the nature of the injury, the grade of the lesion, the specific demands of the sport, the level of the athlete and the time where the injury occured in the year practicing cycle. The fastest way for an athlete to come back requires: acute diagnosis of the problem, proper operational procedure and 'aggressive' physiotherapy before and after the surgery [17]. Applying conservative programs return to full practice takes about 9–12 months post-operatively [4]. On the other hand, the return to the practice using an aggressive program varies from 4 to 6 months after surgery, but may also be fulfilled in 3 months [1,2,9].

Fast regaining of full range of motion (ROM), especially in full extension, is one of the most characteristic points of the aggressive rehabilitation programs [1,2,9, 12], in contrast with some conservative programs that demand immobilization of the joint initially [3,6,10,11, 17]. Another element of the aggressive program is the extensive use of close kinetic chain (CKC) exercises. It has been noticed that CKC exercises were associated with an increase of the intrarticular forces and at the same time a decrease in the giving way forces [12]. In this way the stretching of the graft is avoided especially in the first stages; furthermore the stability of the joint is increased as well as the patient's confidence in his performance level [12]. Moreover, application of the aggressive rehabilitation programs, results in a higher rate of quadriceps conditioning compared to the conservative programs [12].

Literature search has failed to indicate which of the muscle conditioning method was superior in terms of reaching the rehabilitation goal in the most optimal way. Therefore main purpose of this study was to compare

*Address for correspondence: Dr. P. Tsaklis, Anthokipon 19, Nea Efkarpia, 564 29 Thessaloniki, Greece. Tel.: +30 2310 689289; E-mail: tsaklis@hotmail.com.

ISSN 0959-3020/02/$8.00

Table 1
Common rehabilitation program (first month)

Time	First week	Second week	Third week	Fourth week
BRACE	postsurgical $-30°$	functional full ROM	functional full ROM	
ROM	$0° - 120°$	$0° - 135$ full		
WB	25% two crutches	50% one crutch	75% to 100 %	100 %
PHYSIOTHERAPY	1. EMS med/lat vastus 2. SLR to 3Kgr at 4- directions 3. tendon massage 4. Biofeedback $0°$ rectus fem.& med/lat vastus 5. ultrasound $5'$-75% - 1,2 W 6. Laser $4'$ - 3500 A scan 7. TENS const.12' 90 Hz-140 width. 8. ice 10'	1. EMS med/lat vastus 2. SLR to 5 Kgr at 4- directions 3. massage 4. Hydromassage 10' 5. Biofeedback $0°$ and $60°$ 6. friction massage 7. 4K free energetic $130° - 40°$ 8. ultrasound $5'$-75% - 1,2 W 9. Laser $4'$ - 3500 A scan. 10. TENS const and dur. $12'$ 90 Hz- 140 width. 11. ice $10'$	1. EMS med/lat vastus 2. SLR to 5 Kgr at 4- directions 3. Hydromassage $10'$ 4. Biofeedback $0°$ and $60°$ 5. friction massage 6. 4K free energetic $135° - 0°$ 7. ultrasound $5'$-75% - 1,2 W 8. Laser $4'$ - 3500 A scan. 9. TENS const and dur. $12'$ 90 Hz- 140 width. 10. ice $10'$	1. EMS med/lat vastus 2. SLR to 5 Kgr at 4- directions 3. Hydromassage $10'$ 4. Biofeedback $0°$ and $60°$ 5. ultrasound $5'$-75% - 1,2 W 6. Laser $4'$ - 3500 A scan. 7. TENS const and dur. $12'$ 90 Hz- 140 width. 8. ice $10'$
ERGO-CYCLE	–	–	8 min	12 min
ISOMETRICS 10 sec $\times$ 10 REPS	1. QUAD $0°$ 2. HAMS every $30°$	1. QUAD every $30°$ $3 \times 10 \times 10''$ 2. HAMS every $30°$ $3 \times 10 \times 10''$ 3. cocontractions QUAD/HAMS every $30°$ $4 \times 10 \times 10''$	1. QUAD every $30°$ $3 \times 10 \times 10''$ 2. HAMS every $30°$ $3 \times 10 \times 10''$ 3. cocontractions QUAD/HAMS every $30°$ $4 \times 10 \times 10''$ 4. PNF rhythm stab	1. cocontractions QUAD/HAMS every $30°$ $6 \times 10 \times 10''$ 2. PNF rhythm stab
ISOTONICS (super sets)	HAMS $0° - 90°$ easy 5 set $\times$ 10 Rep	1. HAMS $0° - 120°$ submax 5×10 Rep 2. slides on the wall semisquat $0° - 90°$ 5×10 3. leg press $30° - 120°$ 5×10 submax 4. CKC with rubber	1. QUAD $90° - 40°$ submax 5×10 Rep 2. HAMS $0° - 135°$ max 5×10 Rep 3. slides on the wall semisquat $0° - 90°$ 5×10 4. leg press $0° - 135°$ 5×10 submax 5. CKC with rubber	1. QUAD full ROM progressive max 5×10 Rep 2. HAMS full ROM max 5×10 Rep 3. up heels 6×15 two legs 4. slides on the wall $0° - 90°$ 5×10 5. leg press $0° - 135°$ 5×10 max 6. CKC with rubber
ISOKINETICS			1. QUAD/HAMS $0° - 135°$ linear- leg press supine $4 \times 10 \times 180°$sec submax 2. HAMS $0° - 90°$ prone $60° - 180°$/sec submax 3. ANKLE EXT/FLEX 4×10 $120°$/sec straight knee 4×10 $120°$/sec knee $90°$ supine	1. QUAD/HAMS $0° - 135°$ linear- leg press supine $3 \times 10 \times 180°$/sec max 2. QUAD/HAMS $0° - 135°$ rotate siting position $4 \times 10 \times 180°$/sec submax 3. HAMS $0° - 135°$ prone $60° - 180°$/sec max 4. ANKLE EXT/FLEX $60° - 90° - 120° - 180°$/sec
BALANCE PROPRIOCEPTION				Tilt board Two legs $4 \times 1'.30''$

Table 2
Rehabilitation program 2nd month for group C (bolds are a common protocol in all three groups)

TIME	5 PW	6 PW	7 PW	8 PW
PHYSIOTHERAPY	1. **TENS** 2. **massage/hydro** 3. **ice 10′**	1. **TENS** 2. **massage/hydro** 3. **ice 10′**	1. **TENS** 2. **massage/hydro** 3. **ice 10′**	1. **TENS** 2. **massage/hydro** 3. **ice 10′**
ERGO-CYCLE **ISOMETRICS**	**10′** **4 × 10 × 10′′ − 0°**	**10′** **2 × 10 × 10′′ − 0°** **2 × 10 × 10′′ − 30°** **2 × 10 × 8′′ − 65°**	**10′** **3 × 10 × 10′′ − 0°** **3 × 10 × 10′′ − 65°**	**10′** **3 × 10 × 10′′ − 0°** **3 × 10 × 10′′ − 65°**
Close Kinetic Chain exercises (CKC) (3rd day of the weekly program)	1. **semisquat** **5 × 10 × 65% BW** 2. **Step : 10′–15′ varied resistance** 3. **up-heels** **6 × 15 one leg**	1. **semisquat** **5 × 10 × 80% BW** 2. **Step : 10′–15′ varied resistance** 3. **up-heels** **6 × 15 one leg**	1. **semisquat** **5 × 8 × 100% BW** 2. **Step : 10′–15′ varied resistance** 3. **up-heels** **6 × 15 one leg**	1. **semisquat** **5 × 10 × 100% BW** 2. **Step : 10′–15′ varied resistance** 3. **up-heels** **6 × 15 one leg**
COMBINED PROGRAM α) *Isokinetic speed* °/sec β) *Isotonic* %RM perform super sets Q/H (OKC) Rest between sets 90′′ 5 days of exercising (1.2.3.4.5) - the third day exercising only on prone position for the Hamstrings	1α. $3 \times 8 \times 120$ 1β. $3 \times 8 \times 70\%$ 2α. 10×180 8×150 6×120 4×90 2×60 2β. $10 \times 50\%$ $8 \times 60\%$ $6 \times 70\%$ $4 \times 80\%$ $2 \times 90\%$ 3α. $3 \times 8 \times 150$ HAMS 3β. $3 \times 8 \times 60\%$ 4α. $3 \times 14 \times 180$ 4β. $3 \times 14 \times 50\%$ 5α. $2 \times 5 \times 90$ $2 \times 12 \times 150$ 5β. $2 \times 5 \times 80\%$ $2 \times 12 \times 60\%$	1α. $3 \times 8 \times 120$ 1β. $3 \times 8 \times 70\%$ 2α. 10×180 8×150 6×120 4×90 2×60 2β. $10 \times 50\%$ $8 \times 60\%$ $6 \times 70\%$ $4 \times 80\%$ $2 \times 90\%$ 3α. $3 \times 8 \times 120$ HAMS 3β. $3 \times 8 \times 70\%$ 4α. $3 \times 14 \times 180$ 4β. $3 \times 14 \times 50\%$ 5α. $2 \times 5 \times 90$ $2 \times 12 \times 150$ 5β. $2 \times 5 \times 80\%$ $2 \times 12 \times 60\%$	1α. $3 \times 10 \times 120$ 1α. $3 \times 10 \times 70\%$ 2α. 8×150 6×120 4×90 2×60 2β. $8 \times 60\%$ $6 \times 70\%$ $4 \times 80\%$ $2 \times 90\%$ 3α. $3 \times 5 \times 90$ HAMS 3β. $3 \times 5 \times 80\%$ 4α. $3 \times 14 \times 150$ 4β. $3 \times 14 \times 60\%$ 5α. $2 \times 8 \times 90$ $2 \times 12 \times 150$ 5β. $2 \times 8 \times 80\%$ $2 \times 12 \times 60\%$	1α. $3 \times 10 \times 90$ 1β. $3 \times 10 \times 80\%$ 2α. 8×150 6×120 4×90 2×60 2×60 2β. $8 \times 60\%$ $6 \times 70\%$ $4 \times 80\%$ $2 \times 90\%$ $2 \times 90\%$ 3α. $3 \times 6 \times 90$ HAMS 3β. $3 \times 6 \times 80\%$ 4α. $3 \times 16 \times 150$ 4β. $3 \times 16 \times 60\%$ 5α. $2 \times 4 \times 60$ $2 \times 10 \times 90$ 5β. $2 \times 4 \times 90\%$ $2 \times 10 \times 80\%$
BALANCE **PROPRIOCEPTION** **ENDURANCE**	**Tilt board** **Two legs 5 × 1′.30′′** **Swimming 6th day free style to 500 m**	**Tilt board** **One leg 3 × 1′** **Swimming 6th day free style to 40′**	**Tilt board** **One leg 4 × 1′.30′′** **Swimming 6th day free style to 45′**	**Tilt board** **One leg 4 × 1′.30′′** **Swimming 6th day free style to 60′**

isokinetic with isotonic conditioning methods as the main tool in rehabilitation after surgery of the ACL.

2. Methodology

Forty five male athletes (age 24.8 ± 5.6 yrs; height 185 ± 11.9 cm; mass 81 ± 14 Kg) participating in different events underwent patellar tendon bone graft (PTBG) operation due to lesion of ACL. The distribution per event was as follows: football 18 (40%), basketball 12(27%), track and field 5(11%), volleyball 3(7%), Tae Kwon Do 1(2%), cycling 1(2%) and amateur athletes 5–11.1%

The participants were divided randomly into three groups (A, B, C) of 15. Each of these groups was trained according to a distinct rehabilitation protocol after the first post-operative month in which all groups underwent the same protocol.

The common protocol that had been followed during the first post surgery month and which is outlined in Table 1 consisted of common physiotherapeutic modalities, functional exercises, isometric exercises and strengthening exercises in a close and open kinetic chain way. During the next two months the groups followed a basic therapeutic protocol of physiotherapy, functional exercises, isometrics, strengthening exercises in a close kinetic chain way and only did they differentiate between the practice of the knee extensors

Table 3
Rehabilitation program 3nd month for group C (bolds are a common protocol in all three groups)

TIME	9 PW	10 PW	11 PW	12 PW
PHYSIOTHERAPY	1. **TENS** 2. **massage/hydro** 3. **ice 10′**	1. **TENS** 2. **massage/hydro** 3. **ice 10′**	1. **TENS** 2. **massage/hydro** 3. **ice 10′**	1. **TENS** 2. **massage/hydro** 3. **ice 10′**
ERGO-CYCLE	**12′**	**12′**	**12′**	**12′**
ISOMETRICS	**3 × 10 × 10′′ − 0°** **3 × 10 × 10′′ − 65°**	**3 × 10 × 10′′ − 0°** **3 × 10 × 10′′ − 65°**	**3 × 10 × 10′′ − 0°** **3 × 10 × 10′′ − 65°**	**3 × 10 × 10′′ − 0°** **3 × 10 × 10′′ − 65°**
Close Kinetic Chain exercises (CKC) (3rd day of the weekly program)	1. **semisquat** **5 × 5 × 80% 1RM** 2. **Step : 10′–15′** **varied resistance** 3. **up-heels** **6 × 15 one leg**	1. **semisquat** **5 × 5 × 80% 1RM** 2. **Step : 10′–15′** **varied resistance** 3. **up-heels** **6 × 15 one leg**	1. **semisquat** **5 × 3 × 90% 1RM** 2. **Step : 10′–15′** **varied resistance** 3. **up-heels** **6 × 15 one leg**	1. **semisquat** **5 × 1 × 100% 1RM** 2. **Step : 10′–15′** **varied resistance** 3. **up-heels** **6 × 15 one leg**
COMBINED PROGRAM α) *Isokinetic speed °/sec* β) Isotonic %RM perform super sets Q/H (OKC) Rest between sets 90′′ 5 days of exercising (1.2.3.4.5) - the third day exercising only on prone position for the Hamstrings	1α. $3 \times 10 \times 90$ 1β. $3 \times 10 \times 80\%$ 2α. 8×150 6×120 4×90 2×60 1×30 2β. $8 \times 60\%$ $6 \times 70\%$ $4 \times 80\%$ $2 \times 90\%$ $1 \times 100\%$ 3α. $3 \times 8 \times 90$ HAMS 3β. $3 \times 8 \times 80\%$ 4α. $3 \times 14 \times 120$ 4β. $3 \times 14 \times 70\%$ 5α. $2 \times 1 \times 30$ $2 \times 4 \times 60$ $2 \times 8 \times 90$ 5α. $2 \times 1 \times 100\%$ $2 \times 4 \times 90\%$ $2 \times 8 \times 80\%$	1α. $3 \times 10 \times 90$ 1β. $3 \times 10 \times 80\%$ 2α. 8×150 6×120 4×90 2×60 1×30 2β. $8 \times 60\%$ $6 \times 70\%$ $4 \times 80\%$ $2 \times 90\%$ $1 \times 100\%$ 3α. $2 \times 4 \times 60$ HAMS 3β. $2 \times 4 \times 90\%$ 4α. $3 \times 14 \times 120$ 4β. $3 \times 14 \times 70\%$ 5α. $2 \times 1 \times 30$ $2 \times 4 \times 60$ $2 \times 8 \times 90$ 5α. $2 \times 1 \times 100\%$ $2 \times 4 \times 90\%$ $2 \times 8 \times 80\%$	1α. $3 \times 10 \times 90$ 1β. $3 \times 10 \times 80\%$ 2α. 6×120 4×90 2×60 1×30 2α. $6 \times 70\%$ $4 \times 80\%$ $2 \times 90\%$ $1 \times 100\%$ 3α. $3 \times 4 \times 60$ HAMS 3β. $3 \times 4 \times 90\%$ 4α. $3 \times 14 \times 120$ 4β. $3 \times 14 \times 70\%$ 5α. $3 \times 1 \times 30$ $3 \times 5 \times 90$ 5α. $3 \times 1 \times 100\%$ $3 \times 5 \times 80\%$	1α. $3 \times 10 \times 90$ 1β. $3 \times 10 \times 80\%$ 2α. 6×120 4×90 3×60 1×30 2α. $6 \times 70\%$ $4 \times 80\%$ $3 \times 90\%$ $1 \times 100\%$ 3α. $3 \times 5 \times 60$ HAMS 3β. $3 \times 5 \times 90\%$ 4α. $3 \times 14 \times 120$ 4β. $3 \times 14 \times 70\%$ 5α. $3 \times 1 \times 30$ $3 \times 4 \times 60$ 5α. $3 \times 1 \times 100\%$ $3 \times 4 \times 90\%$
BALANCE PROPRIOCEPTION	1. **swimming 6th day** 2. **fast walking 20′** 3. **Tilt board** **One leg 4 × 1′.30′′**	1. **swimming 6th day** 2. **fast walking 25′** 3. **Tilt board** **One leg 4 × 1′.30′′**	1. **swimming 6th day** 2. **Tilt board** **One leg 4 × 1′.30′′**	1. **swimming 6th day** **free program** 2. **Tilt board** **One leg 4 × 1′.30′′**
ENDURANCE FUNCTIONAL EXERCISES	**Mimetic exercises of the sport**	**2 × 10′ track const** **Mimetic exercises of the sport**	**20′ track const** **Mimetic exercises of the sport**	**3 × 10′ track interval** **Mimetic exercises of the sport**

and flexors in an open kinetic chain (isolated extension/flexion) way.

Group A continued practicing by using isotonic strengthening exercises only (Table 4), group B used isokinetic strengthening exercises only (Table 5) while the group C performed a combined program of isokinetic and isotonic exercises (Tables 2 and 3). Our main concern was the planning of the programs to be in such way that the relevant protocols for strengthening that would be applied, would have strictly quantitative criteria and would achieve an isomeric distribution of the exercise's parameters in each group maintaining objectivity and fair rehabilitation for all the patients.

Thus, quantitative correspondence between isotonic and isokinetic practice was made so that 1RM (repetition maximal) in maximum isotonic effort, would equates the angular speed of 30°/sec of maximum isokinetic effort. According to that, the correspondence was planned so that in every 10% of decline in isotonic effort to equal in 30°/sec of increase in the angular speed

Table 4
Strengthening program Q/H Group A (isotonic) 2nd & 3rd PM

TIME	5 PWeek	6 PW	7 PW	8 PW
ISOTONICS Q/H (OCC) Slow execut. rythm Q/H super sets Rest between sets 90′′ 5 Days (1.2.3.4.5) 3rd Day prone position only Hams	1. $6 \times 8 \times 70\%$ 2. Pyramid $10 \times 50\%$ $8 \times 60\%$ $6 \times 70\%$ $4 \times 80\% \uparrow$ $2 \times 90\%$ $2 \times 90\%$ 3. $6 \times 8 \times 60\%$ Hams 4. $6 \times 14 \times 50\%$ 5. $4 \times 5 \times 80\%$ $4 \times 12 \times 60\%$	1. $6 \times 8 \times 70\%$ 2. Pyramid $10 \times 50\%$ $8 \times 60\%$ $6 \times 70\%$ $4 \times 80\% \uparrow$ $2 \times 90\%$ $2 \times 90\%$ 3. $6 \times 8 \times 70\%$ Hams 4. $6 \times 14 \times 50\%$ 5. $4 \times 5 \times 80\%$ $4 \times 12 \times 60\%$	1. $6 \times 10 \times 70\%$ 2. Pyramid $8 \times 60\%$ $6 \times 70\%$ $4 \times 80\% \uparrow$ $2 \times 90\%$ $2 \times 90\%$ 3. $6 \times 5\%$ Hams 4. $6 \times 14 \times 60\%$ 5. $4 \times 8 \times 80\%$ $4 \times 12 \times 60\%$	1. $6 \times 8 \times 80\%$ 2. Pyramid $8 \times 60\%$ $6 \times 70\%$ $4 \times 80\% \uparrow$ $2 \times 90\%$ $2 \times 90\%$ $2 \times 90\%$ $2 \times 90\%$ 3. $6 \times 6 \times 80\%$ Hams 4. $6 \times 16 \times 60\%$ 5. $4 \times 4 \times 90\%$ $4 \times 10 \times 80\%$

TIME	9 PW	10 PW	11 PW	12 PW
ISOTONICS Q/H (OCC) Slow execut. rythm Q/H super sets Rest between sets 90′′ 5 Days (1.2.3.4.5) 3rd Day prone position only Hams	1. $6 \times 8 \times 80\%$ 2. Pyramid $\times 2$ $8 \times 0\%$ $6 \times 70\%$ $4 \times 80\%$ $2 \times 90\% \uparrow$ $1 \times 100\%$ $1 \times 100\%$ 3. $6 \times 8 \times 80\%$ Hams 4. $6 \times 14 \times 70\%$ 5. $4 \times 1 \times 100\%$ $4 \times 4 \times 90\%$ $4 \times 8 \times 80\%$	1. $6 \times 8\times$ 80% 2. Pyramid $\times 2$ $8 \times 60\%$ $6 \times 70\%$ $4 \times 80\%$ $2 \times 90\% \uparrow$ $1 \times 100\%$ $1 \times 100\%$ 3. $4 \times 4 \times 90\%$ Hams 4. $6 \times 14 \times 70\%$ 5. $4 \times 1 \times 100\%$ $4 \times 4 \times 90\%$ $4 \times 8 \times 80\%$	1. $6 \times 8 \times 80\%$ 2. Pyramid $\times 2$ $6 \times 70\%$ $4 \times 80\%$ $2 \times 90\% \uparrow$ $1 \times 100\%$ $1 \times 100\%$ 3. $6 \times 4 \times 90\%$ Hams 4. $6 \times 14 \times 70\%$ 5. $6 \times 1 \times 100\%$ $6 \times 5 \times 80\%$	1. $6 \times 8 \times 80\%$ 2. pyramid $\times 2$ $6 \times 70\%$ $4 \times 80\%$ $3 \times 90\% \uparrow$ $1 \times 100\%$ $1 \times 100\%$ 3. $6 \times 5 \times 90\%$ Hams 4. $6 \times 14 \times 70\%$ 5. $6 \times 1 \times 100\%$ $6 \times 4 \times 90\%$

Table 5
Strengthening program Q/H Group B (isokinetic) 2nd & 3rd PM

TIME	5 PWeek	6 PW	7 PW	8 PW
ISOKINETICS Speed °/SEC Q/H (OCC) Rest between sets 90′′ 5 Days (1.2.3.4.5) 3rd Day prone position only Hams	1. $6 \times 8 \times 120$ 2. Pyramid 10×180 8×150 6×120 $4 \times 90 \uparrow$ 2×60 2×60 3. $6 \times 8 \times 150$ Hams 4. $6 \times 14 \times 180$ 5. $4 \times 5 \times 90$ $4 \times 12 \times 150$	1. $6 \times 8 \times 120$ 2. Pyramid 10×180 8×150 6×120 $4 \times 90 \uparrow$ 2×60 2×60 3. $6 \times 8 \times 120$ Hams 4. $6 \times 14 \times 180$ 5. $4 \times 5 \times 90$ $4 \times 12 \times 150$	1. $6 \times 10 \times 120$ 2. Pyramid 8×150 6×120 $4 \times 90 \uparrow$ 2×60 2×60 3. $6 \times 5 \times 90$ Hams 4. $6 \times 14 \times 150$ 5. $4 \times 8 \times 90$ $4 \times 12 \times 150$	1. $6 \times 8 \times 90$ 2. Pyramid 8×150 6×120 $4 \times 90 \uparrow$ 2×60 2×60 2×60 2×60 3. $6 \times 6 \times 90$ Hams 4. $6 \times 16 \times 150$ 5. $4 \times 4 \times 60$ $4 \times 10 \times 90$

TIME	9 PW	10 PW	11 PW	12 PW
ISOKINETICS Speed °/SEC Q/H (OCC) Rest between sets 90′′ 5 Days (1.2.3.4.5) 3rd Day prone position only Hams	1. $6 \times 8 \times 90$ 2. Pyramid $\times 2$ 8×150 6×120 4×90 $2 \times 60 \uparrow$ 1×30 1×30 3. $6 \times 8 \times 90$ Hams 4. $6 \times 14 \times 120$ 5. $4 \times 1 \times 30$ $4 \times 4 \times 60$ $4 \times 8 \times 90$	1. $6 \times 8 \times 90$ 2. Pyramid $\times 2$ 8×150 6×120 4×90 $2 \times 60 \uparrow$ 1×30 1×30 3. $6 \times 8 \times 90$ Hams 4. $6 \times 14 \times 120$ 5. $4 \times 1 \times 30$ $4 \times 4 \times 60$ $4 \times 8 \times 90$	1. $6 \times 8 \times 90$ 2. Pyramid $\times 2$ 6×120 4×90 $2 \times 60 \uparrow$ 1×30 1×30 3. $6 \times 4 \times 60$ Hams 4. $6 \times 14 \times 120$ 5. $6 \times 1 \times 30$ $6 \times 5 \times 90$	1. $6 \times 8 \times 90$ 2. Pyramid $\times 2$ 6×120 4×90 $3 \times 60 \uparrow$ 1×30 1×30 3. $6 \times 5 \times 60$ Hams 4. $6 \times 14 \times 120$ 5. $6 \times 1 \times 30$ $6 \times 4 \times 60$

during isokinetic effort i.e. 100% (RM) $\rightarrow$ 30°/sec; 90% (RM) $\rightarrow$ 60°/sec; 80% (RM) $\rightarrow$ 90°/sec; 70% (RM) $\rightarrow$ 120°/sec; 60% (RM) $\rightarrow$ 150°/sec; 50% (RM) $\rightarrow$ 180°/sec. During and immediately after application of the program, various clinical and laboratory tests took place in order to define the differences between

Table 6
The differences between the three programs (groups)

TEST	1ST post month	2nd post month	3rd post month
Measure thigh	$A - B - C\ p = 0.90$	$B - A\ p = 0.15$ $C > B - A\ p < 0.0001$	$B - A\ p = 0.80$ $C > B - A\ p < 0.0001$
Max isotonic 1RM	$A - B - C\ p = 0.70$	$A > B\ p < 0.01$ $C > A > B\ p < 0.0001$	$A > B\ p < 0.01$ $C > A > B\ p < 0.0001$
Max isometric torque	No test	$C > B > A\ p < 0.0001$	$C > A > B\ p < 0.0001$
EMG vastus medialis	$A - B - C\ p = 1.000$	$B > A\ p < 0.03$ $C > B > A\ p < 0.0001$	$B - A\ p < 0.07$ $C > B > A\ p < 0.0001$
Isokinetic Quad torque 60°/sec	No test	$C > B > A\ p < 0.0001$	$C > B > A\ p < 0.0001$
Isokinetic Hams torque 60°/sec	No test	$B - A\ p = 0.9$ $C > B - A\ p < 0.0001$	$B - A\ p = 0.9$ $C > B - A\ p < 0.0001$
Isokinetic ratio Q/H 60°/sec	No test	$C - B\ p = 0.06$ $C - A\ p = 0.7$ $B - A\ p = 0.6$	$B - A\ p = 0.5$ $C > B - A\ p < 0.0001$
Isokinetic Quad torque 120°/sec	No test	$C > B > A\ p < 0.0001$	$C > B > Ap < 0.0001$
Isokinetic Hams torque 120°/sec	No test	$B - A\ p = 0.6$ $C > B - A\ p < 0.0001$	$B - A\ p = 0.3$ $C > B - A\ p < 0.0001$
Isokinetic ratio Q/H 120°/sec	No test	$C - B\ p = 0.5$ $C - A\ p = 0.1$ $B - A\ p < 0.001$	$C > B > A\ p < 0.0001$
Isokinetic total work QUAD 180°/sec	No test	$C > B > A\ p < 0.0001$	$C > B > A\ p < 0.0001$
Isokinetic total work HAMS 180°/sec	No test	$C > B > A\ p < 0.0001$	$C > B > A\ p < 0.0001$
DAVIES SCALE FUNCTIONAL EVALUATION	$B - A\ p = 0.1$ (3rd month) $C > B - A\ p < 0.0001$ $C > A\ p < 0.001$ (15th M) $C > B\ p < 0.005$ $B - A\ p = 0.6$ Follow up	$C > A\ p < 0.0005$ (12th M) $C > B\ p < 0.0001$ $B - A\ p = 0.1$ Follow up $C > A\ p < 0.001$ (18th M) $C > B\ p < 0.004$ $B - A\ p = 0.4$ Follow up	

A: Group used isotonic method of strengthening.
B: Group used isokinetic method of strengthening.
C: Group used combined isotonic/isokinetic of method strengthening.

the progress of the thigh power and strength, as well as the function of the joint and their former condition. The ultimate purpose for performing these tests was to substantiate the most effective of the three rehabilitation programs. Six different control methods were accomplished by repeated measures so as to define the differences between the involved and uninvolved side (Table 6). These methods consisted of measuring variations in the following parameters at the end of the 1st, 2nd and 3rd post surgery month:

1. thigh's circumference 10 cm from the joint line
2. maximum isotonic effort (1RM) of quadriceps (leg extension machine – free weights)
3. isometric torque of quadriceps (CYBEX NORM, Lumex Inc.)
4. EMG output of vastus medialis (Bortec EMG, Bortec Electronics Inc.)
5. isokinetic torque of knee flexors and extensors at 60, and 120°/s and the calculation of their ratio in these speeds well as the total work of these muscle at 180°/s (CYBEX NORM, Lumex Inc.)
6. Clinical assessment using the Davies scale [3] at the end of the 3rd month, as well as a long term follow up during the 12th–15th and 18th. The SPSS version10 has been used for the statistical analysis. Parameters 1, 2 and 4 were analyzed using MANOVA with repeated measures. ANCOVA was used for parameters 3 and 5 whereas the 6th parameters was analyzed via ANOVA. The homogeneity between groups for the follow up measures was controlled by Colmogorov-Smirnov Z-index.

3. Results

The results indicate that the three groups improved significantly through the 3rd month after surgery with highly statistical differences between the measurements ($p < 0.0001$). No difference was shown among the three groups during the measuring of muscular atrophy at the end of the first post surgery month ($p = 0.90$). The muscular deficit decreased during the 2nd month in all three groups but most prominent in group C ($p < 0.0001$ relative to A and B). Group B showed better improvement compared to group A but the dif-

Table 7
7a, Measures results statistical analysis

	Type III sum sqr	df	Mean square	F	Sig.
MANOVA (1)					
ISOT-1RM	1315.786	2	657.893	1835.472	0.000
ISOT * GROUP	137.522	4	34.381	95.919	0.000
Error(ISOT)	30.108	84	0.358		
MANOVA (2)					
MEASURE THIGH	146.269	2	73.135	932.879	0.000
MEAS * GROUP	3.892	4	0.973	12.411	0.000
Error(MEASURE)	6.585	84	7.840E-0		
ANCOVA (3)					
Intercept	1.703	1	1.703	2.113	0.154
ISOM-TQ	80.023	1	80.023	99.290	0.000
GROUP	60.556	2	30.278	37.568	0.000
Error	33.044	41	0.806		
a R Squared = 0.942 (Adj. R Squar = 0.938)					
MANOVA (4)					
EMG-VM	5274.059	2	2637.030	1014.449	0.000
EMG * GROUP	287.585	4	71.896	27.658	0.000
Error(EMG)	218.356	84	2.599		
MANOVA (5) Q/H					
RATIO60°/sec	2190.400	1	2190.400	606.306	0.000
RAT60 * GROUP	352.867	2	176.433	48.837	0.000
Error(RAT60)	151.733	42	3.613		
MANOVA (6) Q/H					
RATIO120°/sec	2901.344	1	2901.344	1001.560	0.000
RAT120 * GROUP	271.489	2	135.744	46.860	0.000
Error(RAT120)	121.667	42	2.897		
ANCOVA (7)					
Intercept	31.999	1	31.999	28.102	0.000
HAM60°/sec	1.714	1	1.714	1.505	0.227
GROUP	287.252	2	143.626	126.134	0.000
Error	46.686	41	1.139		
a R Squared = 0.934 (Adjusted R Squared = 0.929)					
ANCOVA (8)					
Intercept		1	0.693	0.357	0.554
QUAD60°/sec	75.335	1	75.335	38.739	0.000
GROUP	93.086	2	46.543	23.934	0.000
Error	79.731	41	1.945		
a R Squared = 0.932 (Adjusted R Squared = 0.927)					
ANCOVA (9)					
Intercept	0.152	1	0.152	0.164	0.687
HAM120°/sec	24.909	1	24.909	26.953	0.000
GROUP	65.109	2	32.554	35.226	0.000
Error	37.891	41	.924		
a R Squared = 0.935 (Adjusted R Squared = 0.930					
ANCOVA (10)					
Intercept	1.795	1	1.795	1.406	0.243
QUAD120°/sec	41.116	1	41.116	32.201	0.000
GROUP	107.656	2	53.828	42.157	0.000
Error	52.351	41	1.277		
a R Squared =0.955 (Adjusted R Squared = 0.952)					
ANCOVA(11)					
Intercept	0.945	1	0.945	0.896	0.349
HAM180°/sec	35.835	1	35.835	33.985	0.000
GROUP	29.135	2	14.568	13.816	0.000
Error	43.232	41	1.054		
a R Squared =0.929 (Adjusted R Squared = 0.924)					

Table 7a, continued

	Type III sum sqr	df	Mean square	F	Sig.
ANCOVA (12)					
Intercept	0.708	1	0.708	0.210	0.649
QUAD180°/sec	61.707	1	61.707	18.312	0.000
GROUP	104.128	2	52.064	15.450	0.000
Error	138.160	41	3.370		
a R Squared = 0.926 (Adjusted R Squared = 0.920)					

1: Quad Isotonic 1RM, 2: Measure sirc.Thigh, 3: Isometric Torque Quad, 4: EMG Vastus Med. 5: Isok RATIO60°/sec, 6: Isok RATIO120°/sec, 7: PT Hams 60°/sec 8: PT Quad 60°/sec. 9: PT Hams 120°/sec, 10: PT Quad 120°/sec, 11: TW Hams 180°/sec, 12: TW Quad 180°/sec.

Table 7b, Measures results statistical analysis

	df	Mean Square	F	Sig.
(13)ANOVA DAV3rd PM				
GROUP	42	264.6000	77.38997	0.000
(14)ANOVA DAV12th PM				
GROUP	16	47.9651	12.3432	0.0005
(15)ANOVA DAV15th PM				
GROUP	12	273.3500	13.1105	0.0009
(16)ANOVA DAV18thPM				
GROUP	8	20.5000	18.2222	0.0010

13, 14, 15, 16: Davies scale clinic Evaluation 3rd-12th-15th-18th Post Op.Month, respectively.

ference was not significant ($p = 0.15$). The same trend was noticed at the final measurement session (3rd month) when group C differed significantly from the other two ($p < 0.0001$) whicj in turn had similar results ($p = 0.80$).

The maximum isotonic strength (1RM) of quadriceps did not differ among the groups during the 1st post surgery month ($p = 0.70$). Group A improved to a greater extent compared to group B ($p < 0.01$) at the 2nd month; while group C had significant differences ($p < 0.0001$) relative to A and B. This trend proceeded to characterize the final scores ($A > B$, $p < 0.01$) and ($C > A > B$, $p < 0.0001$).

Similar developments took place with respect to the isometric torque of quadriceps: ($C > A > B$, $p < 0.0001$) but ($B > A$, $p < 0.01$).

No inter-group differences in the of EMG of vastus medialis were apparent during the first month ($p = 0.1$). In both the second and the third month group B appeared to be better than A ($p < 0.03$) and ($p < 0.07$) respectively. Correspondingly group C differed significantly from A ($p < 0.0001$) and B ($p < 0.0001$).

The isokinetic tests that took place during the 2nd and 3rd post surgery month showed improvement in all three groups with the abovementioned general order $C > B > A$. Group B appeared to improved better than group A ($p < 0.0001$) regarding peak moment of the quadriceps at 60°/s and 120°/s, ratio Q/H at 120°/s and total work of the quadriceps and hamstring at 180°/s.

The Davie's Scale scores at the end of the 3rd post surgery month, showed that group C differed significantly from either A or B ($p < 0.0001$). Group B was relatively more improved than A without having significant statistical difference ($p = 0.1$). The same trend was apparent during the follow up evaluation at the 12th, 15th and 18th post surgery month in all three groups.

Table 6 outlines the level of statistical difference among the three groups for every measurement. The symbol (>)indicates a significant difference whereas (−) signifies no no significant difference among the groups.

4. Discussion

The analysis indicates that isokinetic strengthening exercises result in higher functional performance compared to the use of the isotonic strengthening exercises only. The clinical evaluation and the functional controls are probably the most basic elements that help clarify the utility of the programs [5,7]. It is evident that program C which provided a combination of isokinetic and isotonic exercises resulted in satisfactory functional rehabilitation of the knee. It is also obvious that the iso-

lated programs of group A and B did not eliminate the deficits judged bilaterally [3,6,8,15].

The measurements of thigh circumference at the end of the 3rd post surgery month, indicated that group C increased significantly compared to the two other groups. Furthermore, in all measurements that referred to quadriceps (1RM, EMG, max. isometric torque, isokinetic torques and total work) C group showed significant differences compared to the other groups. With respect to groups A and B, the previous appeared to be better than B in measurements of 1RM ($p < 0.01$) and isometric torque ($p < 0.001$) while the latter was better in EMG measurements ($p < 0.07$), isokinetic torque and work ($p < 0.0001$). In measurements that referred to the hamstrings at the end of the 3rd post surgery month group C subjects evidenced a highly significant difference ($p < 0.0001$). There were no differences between group A and B except for total work (group B $>$ group A).

In conclusion, the combined program of group C (Tables 2 and 3) appears to have resulted in the best scores among the three programs while indicating that the exclusive use of isokinetic exercises (group B) for strengthening post-ACL knee muscles is not warranted.

References

[1] G. Ackland, *ACL reconstruction rehabilitation*, New England Baptists Hospital, updated 1/30/2000.

[2] C.E. Brewster and J.L. Seto, *Summary of the rehabilitation program following anterior cruciate ligament reconstruction*, from the Kerlan-Jobe Orthopaedic Clinic, Department of Physical Therapy, 2000.

[3] G.J. Davies, A compendium of isokinetics in clinical usage, 4th edition, S&S publishers, 1992.

[4] M.S. De Carlo, K.D. Shelbourne, J.R. McCarroll and A.C. Retting, Traditional versus accelerated rehabilitation following ACL reconstruction: A one year follow up, *J Orthop. Sports Physical Therapy* **15** (1992), 309–316.

[5] A. Delitto, J.J. Irrgang, C.D. Harner and F.H. Fu, Relationship of isokinetic quadriceps peak torque and work to one legged hop and vertical jump in ACL reconstructed knees, *Phys Ther* **73**(6) (1993), S85.

[6] Z. Dvir, Isokinetic muscle testing, interpretation and clinical applications, NY, Churchill Livingstone, 1995.

[7] P.A. Frndak and C.C. Berasi, Rehabilitation concerns following anterior cruciate ligament reconstruction, *Sports Medicine* **12**(5) (1991), 338–346.

[8] E.A. Froese and M.E. Houston, Torque velocity characteristics and musle fiber type in human vastus lateralis, *J Appl Physiol* **59**(2) (1985), 309–314.

[9] P. Kannus, M. Jarvinen, R. Johnson and P. Renstrom, Function of the quadriceps and hamstrings muscles in knees with chronic partial deficiency of the ACL, *Am J Sports Med.* **20**(2) (1992), 162–167.

[10] W. King and A. Ting, *Accelerated rehabilitation of patients following anterior cruciate ligament reconstruction*, Oregon University/Sports med. Dept, 2000.

[11] L.E. Paulos, D.C. Wnorowski and C.L. Beck, Rehabilitation following knee surgery, *Sports Medicine* **11**(4) (1991), 257–275.

[12] J.M. Ray, A proposed natural history of symptomatic anterior cruciate ligament injuries of the knee, *Clinics in Sports Medicine* **7**(4) (1988).

[13] D.K. Shelbourne and P. Nitz, Accelerated rehabilitation after ACL reconstruction, *Am J Sports Med* **18** (1990), 292–299.

[14] D.K. Shelbourne, T.E. Klootwyk and M.S. DeCarlo, Update on accelerated rehabilitation after ACL reconstruction, *J Orthop. Sports Physical Therapy* **15** (1992), 303–308.

[15] M. Solomonow, R. Baratta, R. D'Ambrosia, The role of the hamstrings in the rehabilitation of the ACL deficient knee in athletes, *Sports Medicine* **7** (1989), 42–48.

[16] K.E. Timm , Suggestion from the field- Isokinetic exercise to 50% fatigue, *J. Orthop Sports Phys Ther* **8** (1987), 505–506.

[17] K.E. Timm, Investigation of the physiologic overflow effect from speed specific isokinetic activity, *Journal Orthopaedic Sport Physical Therapy* **9** (1987), 106–110.

[18] S.A. Wasilewski and J. Koth, Effect of surgical timing on return to sports activity after significant knee injuries, *Sports Med.* **18**(3) (1994), 156–161.