PERIODICUM BIOLOGORUM
VOL. 117, No 1, 109–118, 2015

UDC 57:61
CODEN PDBIAD
ISSN 0031-5362

Biomechanical evaluation of articulations and isokinetic rehabilitation of patient with musculosceletal disorders

SLOBODAN KUVALJA

Cybex Center for Isokinetic Diagnostic and Rehabilitation
Voćarska 106, 10000 Zagreb, Croatia
E-mail: slobodan.kuvalja@gmail.com

Received January 15, 2015.

INTRODUCTION

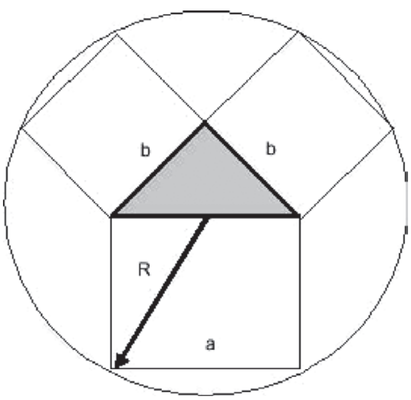
Diseases of musculoskeletal system are becoming an ever greater public health issue. According to some recent statistical data, 20% of European population (100 million people) suffer from musculoskeletal pain which is the cause of 50% of all sick leaves and is the most frequent reason for disability. In the USA, symptoms of sacralgia or radiculopathy are established in 7-14% of working-age population during the course of a year, and cause more than 30 days of absence from work in 15% of affected patients older than 50 years. According to International Disease Classification applied in Report on the Rate of Sick Leaves debited to the Croatian Health Insurance Fund, musculoskeletal system diseases may be singled out as the leading cause of sick leaves (30%) in the Republic of Croatia for the January – August 2015 period. These diseases were in the third place, with 10% percent share, among the total number of diagnosed diseases and conditions in general practitioners' (GP) offices in the Republic of Croatia in 2012, after pulmonary system diseases (17%) and cardiovascular diseases (11.5%). According to these data, 2/3 of painful conditions in GP offices are due to musculoskeletal diseases. In year 2013, 15% of the total amount of sickness allowances were associated with musculoskeletal diseases.

Public health indicators clearly point to morbidity trends associated with musculoskeletal system, yet the activities proposed within the public health system are confined to general recommendations for the need of increased physical activity. Much has been researched and published on ergonomics, particularly in industrial design of work environment, with the aim to reduce physical body load; unfortunately, too few medical professionals are engaged in such projects, and examples of actual application of the gained knowledge in medical practice are even fewer. Behind seemingly important health-directed approach in manufacture of contemporary products for everyday life, the real goal is marketing new products or devices that indeed do free people from hard and time-consuming physical labor; however, the free time gained is not used for real physical recovery and rest but mainly to achieve increased productivity and profitability of the work process in most countries, excluding some conscious exceptions like Scandinavian countries *(1, 2).*

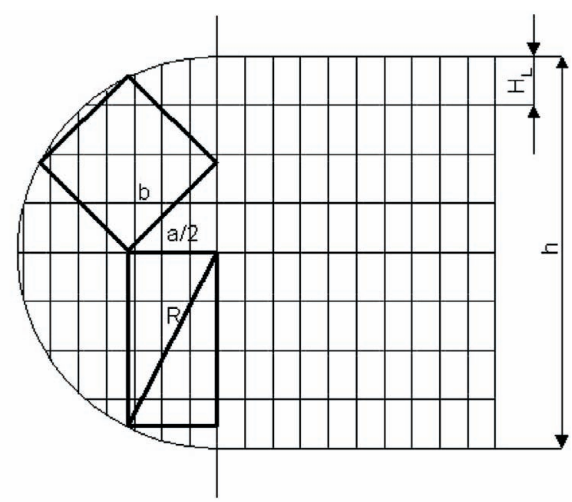
NATURAL LAWS AND BIOMECHANICS

Natural laws that affect the function of the human locomotor system have not basically changed since man stood on his feet into the upright body position. If we observe only some external conditions that affect movement, we should take into account gravitational force, body weight, body height, and our wish to maintain upright body position. If we think about movement and motion of the body or its segments without considering biological and physiological characteristics of a moving body, the laws of biomechanics come into play with relations of forces, mass and lever. From the aspect of mechanical engineering, the process can be called motion of a dynamic construction. The process becomes exceptionally complex when our consideration begins to comprise biological and physiological properties of body segments, dynamically inactive bone and joint structures and dynamically active muscular and tendon structures, and finally governing neurological „communication and regulating" centers. Figuratively, human movement can simply be compared to unbelievably numerous symphonic orchestra that must perfectly play different scores at any time, but also maintain and not disrupt harmony *(2)*.

Education of physicians does not include some important papers in biomechanics any more which I consider



Harmonic circle



Harmonic circle and associated grid of eight head cannon

the basis of all contemporary approaches and developments of sophisticated systems for locomotor system rehabilitation.

Study of human body movement should begin with analysis of hypotheses of Zederbauer harmonic circle and the Principle of eight head canon.

By integrating these ideas, a renowned Croatian expert in mechanics and biomechanics prof Osman Muftić developed a synthetized approach called „Harmonic circle and associated grid of eight head canon" *(2)*.

This shows that it is, by using a mathematical formula of harmonic numbers, possible to calculate anthropometric dimensions of each particular body segment.

$$a = 1; \quad R = \frac{\sqrt{5}}{2}; \quad b = \frac{\sqrt{2}}{2}.$$

$$r = \frac{\sqrt{2}-1}{2} = b - \frac{a}{2},$$
$$d = \frac{\sqrt{5}-1}{2} = R - \frac{a}{2},$$
$$b + r = \frac{2\sqrt{2}-1}{2}.$$

Based on this calculation, prof. O. Muftić elaborated a special table:

TABLE
Harmonic lengths of body segments.

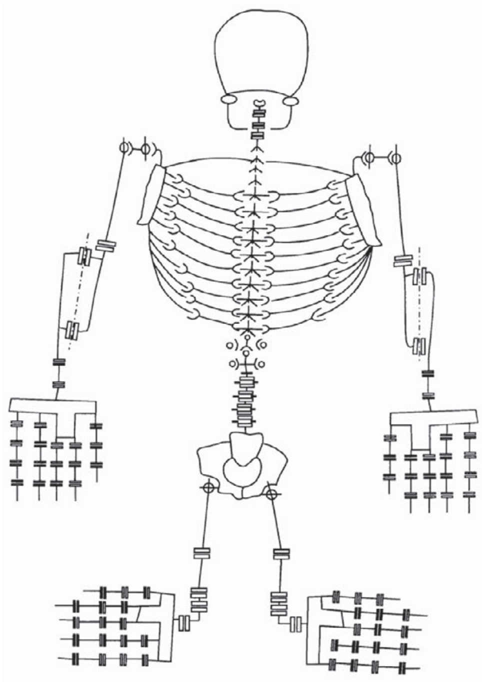
Arm length = $\frac{25}{64}$ standing height	Upper arm length = $\frac{5}{32}$ standing height
Forearm length = $\frac{17}{32}$ standing height	Hand length = $\frac{9}{64}$ standing height
Leg length = $\frac{17}{32}$ standing height	Upper leg length = $\frac{9}{32}$ standing height
Lower leg length = $\frac{7}{32}$ standing height	Foot length = $\frac{1}{8}$ standing height

By associating methods and formulas for determination of segmental masses by Donski and Zacjorski to the above mentioned principles

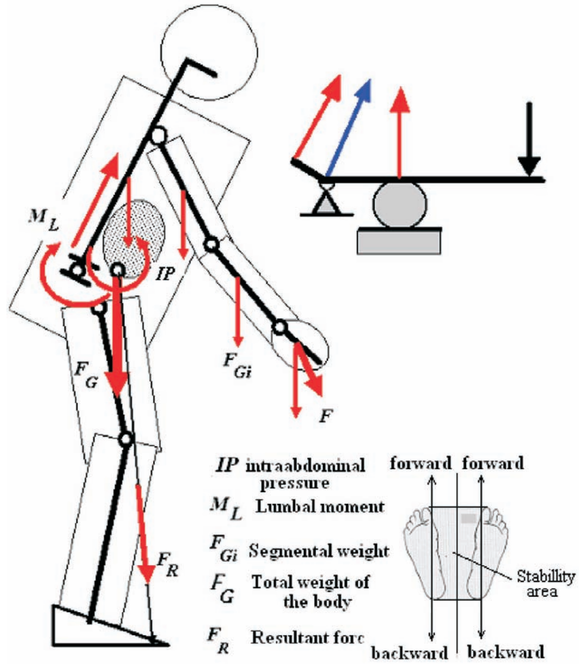
$$m_i = B_0 + B_1 M + B_2 h, \text{kg}$$

we can, from the known height of a subject (either woman or man) and the total mass, calculate each segmental mass according to the so-called external division.

All this shows that movement in the gravitational field of all segments and functional wholes of the locomotor system of each individual has its own personal mathematical and biomechanical algorithm, which has been documented in many articles on kinetics and kinematics of human body movement.



Degrees of freedom in body movement (O.M)



Planar biomechanical model of human motion (O.M)

If we switch from theoretical to clinical approach to the problem of „rehabilitation" (reversion to previous condition) of the locomotor system segments that ensure the posture and motion of entire body and its parts, we should ask ourselves how we can begin to determine the degree of function disturbance in an individual. Which members of the „orchestra" are, and to what degree, deficient in function with regard to age, sex, weight, height and needs in an individual that has now already turned a patient? Another important question is how much the knowledge gained in human kinetics and kinematics is applied in education of physicians and in clinical practice and treatment?

Microtraumatic articular injuries as the major reason for development of lesions of articular structures

It is pivotal in each rehabilitation process to establish the cause and degree of lesion or dysfunction and, based on objective analyses of condition, set up the goal and program of recovery of determined disorders.

A widely accepted attitude today is that microtraumatic injuries are the main unrecognized cause of the lesions of articular structures. The most common cause of microtraumatic articular injuries are disrupted static and dynamic relations that occur due to the loss of muscular strength and to disbalance in muscular strength relations in kinematic chain. Serious external injuries or postoperative conditions in the locomotor system segments have long been a known cause of dysfunction.

Disorders in muscle and joint function without external lesions and possible surgical procedures are due to ever lower physical activity caused by changes in lifestyle, to development of technologies that eliminate the need for physical labor, to increased number and extent of jobs that involve prolonged sitting, and to increased life expectancy *(3, 4, 5)*.

Although this may seem a dark prediction of civilization development, we should be aware that the live body is keen to repair damages that have occurred in any organ, including the locomotor system, if we remove main obstacles that hinder restoration to health.

If – with regard to gravity – the locomotor system is divided into active, dynamic segment, i.e. muscles, and relatively adynamic segment, i.e. joints and articular structures, then muscles occur with their physiological characteristics as the major cause of development of the problem, but also as a potential key solution. In this respect, we should remind ourselves of a few important characteristics of the muscle. Each muscle maintains or increases its strength or ability to gain force in proportion to actual active work, i. e. it loses strength at rest. A sportsman's muscle may lose during immobilization up to 3% of strength daily. At the same time, a muscle has a „memory" and loses strength due to absence of activity, which results in articular system overload and reduced ability for movement and thus leads into a negative vicious circle of ever lesser mobility and damage progression.

Still, existence of the „memory" allows a possibility of regaining the strength of a healthy muscle by precise and optimal program of age-adequate exercises, of eliminating factors of overloading, and of maintaining optimum joint function *(6, 7).*

The ideas above have made room for significantly more effective rehabilitation after objective diagnostics of muscle and joint function and optimized program of muscular exercises performed to establish correct strength relations in each segment of the locomotor system *(4-8).*

Isokinetics as part of the clinical program of rehabilitation

By the end of the 1960's, the ideas above resulted in development of sophisticated isokinetic dynamometers and systems for precise analysis of the labor and rehabilitation of muscles and joints through active movement *(4, 8),* Fig. 1. The basis of isokinetic movement is joint motion at constant rate through a full range of movements, with development of maximum muscle strength and adaptation of resistance in proportion to current muscular potential *(8).*

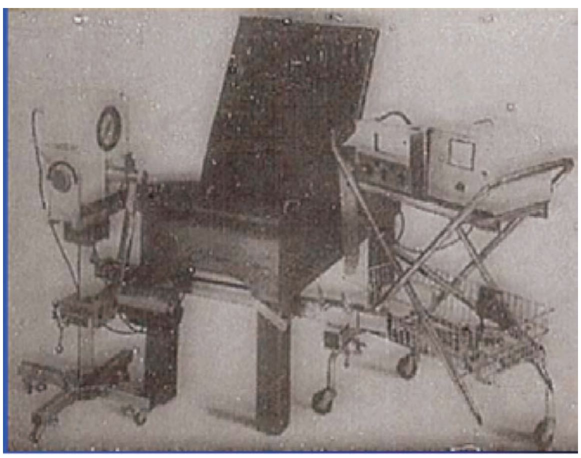


Figure 1. *First isokinetic diagnostic system Cybex 1 from year 1967.*

The major component of modern isokinetic system is a precise dynamometer that allows isokinetic muscular contraction or joint motion at constant, predetermined rate, with rapid adaptation of resistance to thrust force by using the entire range of muscle and joint movements (Figures 2, 3, 4). Movement velocities that may be achieved on modern dynamometers in concentric muscle contraction are approximately 500°/sec depending on the program selected and patient's capability. At the same time, dynamometers measure rotational moment of force and adjust resistance at every 0.04° of the volume of movement *(8).*

Figure 2. *Isotonic movement – invariable resistance.*

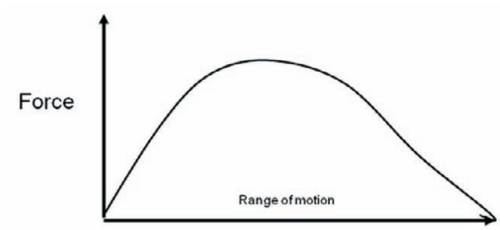


Figure 3. *Isokinetic movement– adjusted resistance.*

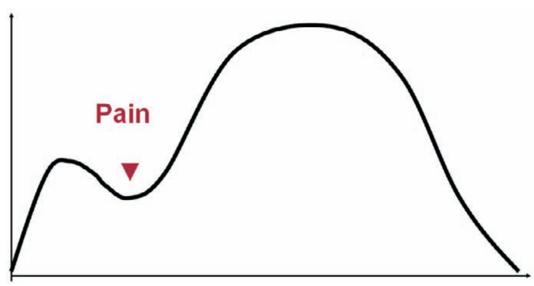


Figure 4. *Illustration of the adaptation of resistance to pain during isokinetic movement in the joint and muscle.*

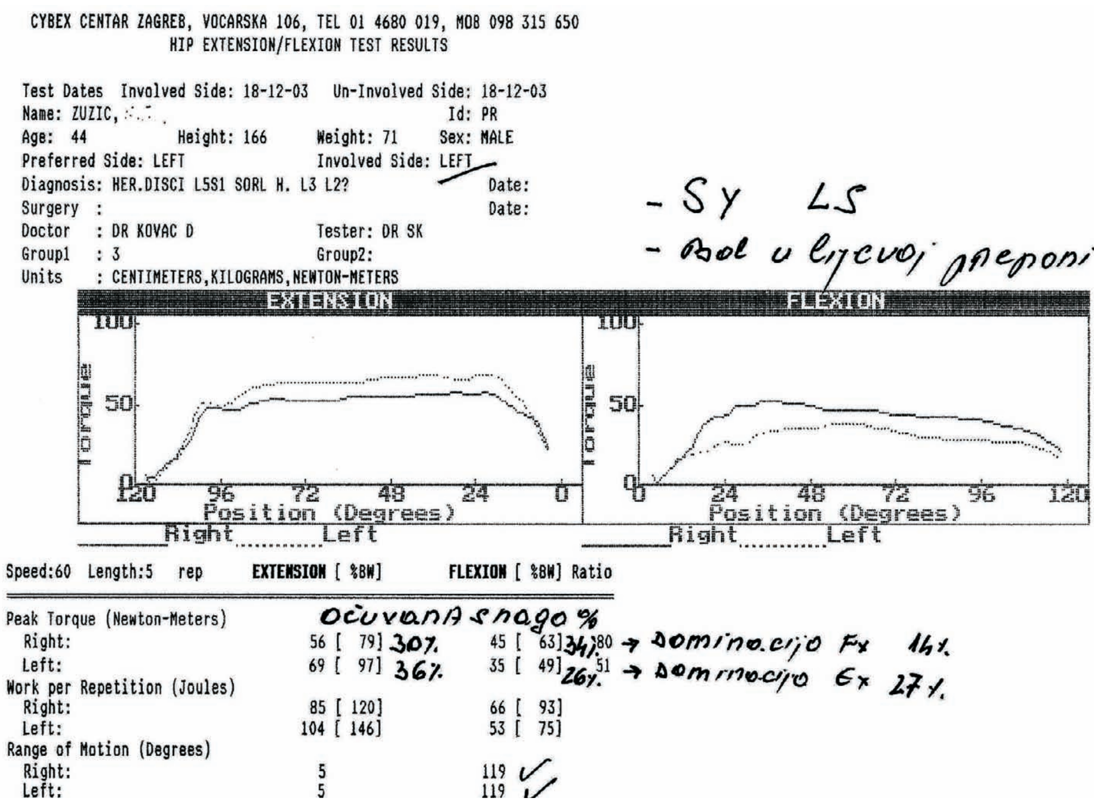
Another important component of the device is computer system with special software for rapid measurement of motion parameters and graphical and mathematical processing and analyses, and a display with measured test parameters.

Figure 5. *The most recent isokinetic system HUMAC NORM-Cybex.*

Figure 6. *Modul Cybex for the spine.*

Analyses of data obtained in tests are an extremely important segment of the entire examination procedure. Results of measured parameters are calculated in analyses according to tables with tje expected values elaborated for each kinematic unit and kinematic chain (knee, hip, ankle joint, shoulder, spine...) and defined for a person under observation according to age, gender, body weight, frequency of exercises and dominant side of the observed individual. Present isokinetic systems allow movement to be realized – according to patient's needs and therapist's wishes – in isokinetic, concentric-concentric, concentric-excentric, excentric-concentric, isotonic, and isometric muscle contraction. In therapy with particularly low muscle strength, it is also possible to use a program of robotized movement support by monitoring actual muscle strength and its change using the CPM program (Continuous Passive Motion), which is a remarkable advantage in rehabilitation of neurological patients. Current isokinetic systems also allow special programs of proprioreception exercises and motion control *(4, 5, 8, 9)*, Figures 5, 6.

Indications, testing programs, analyses of results and the program of isokinetic exercises must be designed by a trained physician and carried out by trained therapists. Such approach to organization has shown to be most successful during our 19 years of daily practice in over


CYBEX CENTAR ZAGREB, VOCARSKA 106, TEL 01 4680 019, MOB 098 315 650
HIP EXTENSION/FLEXION TEST RESULTS

Test Dates Involved Side: 18-12-03 Un-Involved Side: 18-12-03
Name: ZUZIC, Id: PR
Age: 44 Height: 166 Weight: 71 Sex: MALE
Preferred Side: LEFT Involved Side: LEFT
Diagnosis: HER.DISCI L5S1 SORL H. L3 L2? Date:
Surgery : Date:
Doctor : DR KOVAC D Tester: DR SK
Group1 : 3 Group2:
Units : CENTIMETERS,KILOGRAMS,NEWTON-METERS

- Sy LS

Speed:60 Length:5 rep	EXTENSION [%BW]	FLEXION [%BW]	Ratio
Peak Torque (Newton-Meters)			
Right:	56 [79] 30%	45 [63] 34%	80
Left:	69 [97] 36%	35 [49] 26%	51
Work per Repetition (Joules)			
Right:	85 [120]	66 [93]	
Left:	104 [146]	53 [75]	
Range of Motion (Degrees)			
Right:	5	119 ✓	
Left:	5	119 ✓	

Figure 7. *Results of hip tests in patients with normal X-ray findings, hip and lumbosacral spine pain, and pronounced strength loss due to long-term sitting.*

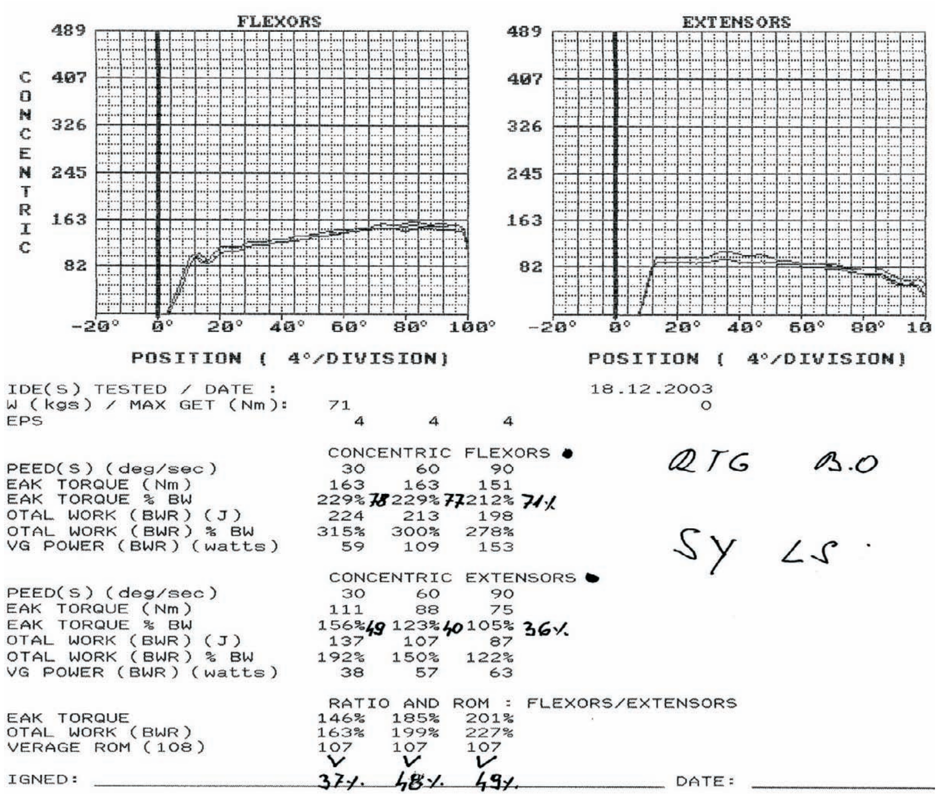


Figure 8. *Test of lumbosacral spine performed in the same patient as above, with symptoms of LS SY (normal MR finding) due to considerable loss in extensor strength.*

110,000 performed isokinetic diagnostic testings of all body segments and approximately 4,000 isokinetic treatments of our patients yearly *(10).*

During rehabilitation, it is necessary to ensure objective monitoring of the effect of recovery and adjustment of parameters according to stated body characteristics, with synchronization of all members of the „orchestra" according to the biomechanical algorithm of an individual. In this regard, it should be taken into consideration that temporary adaptational and compensatory adjustments to the pathological status of the whole kinematic chain occur due to specific dysfunction of a body segment, and that adjoining kinematic chain segments should be examined regardless of the absence of pain in them in order to carry out corrections of established deviations *(11).*

During diagnostic examination, a physician should compare possible results of X-ray, MR, CT or ultrasound testing. It is important to emphasize that these results often do not provide evidence of serious tissue changes, while at the same time very serious deviations and disorders may be confirmed by isokinetic tests. This phenomenon is more common in young patients. Possible explanation for this discrepancy between symptomatology and relatively insignificant changes established by, e. g., MR or CT, is that a period of prolonged function disturbance precedes the occurrence of tissue damage that can be detected by those techniques; such function disturbance reaches the degree of change that is observable by those

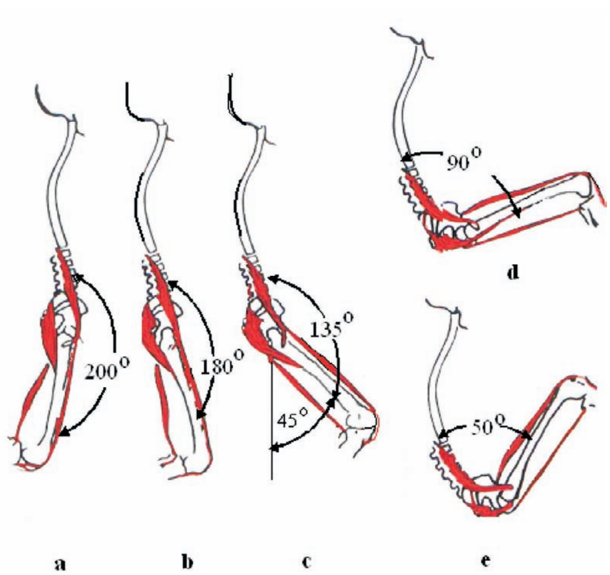


Figure 9. *Relations between hip flexor – extensor strengths*

techniques only after prolonged adverse impact (Figures 7, 8).

In-house studies at Cybex Center (dr. S. Kuvalja and prof. O. Muftić) on patients with LS syndrome included tests involving kinematic column: thoracolumbar spine, hips, knees and lower legs, and revealed the highest deficiencies and disbalance in muscle strength relations between hip flexors and extensors (over 30%), while deficiencies and disbalance in strength relations of extensors and flexors of the thoracolumbar spine amounted to 15% (Figures 9, 10, 11). The loss in hip flexor strength showed to be the major cause of the occurrence of dysfunction of the spinal lumbosacral segment due to their impact on pelvic statics *(12, 13).*

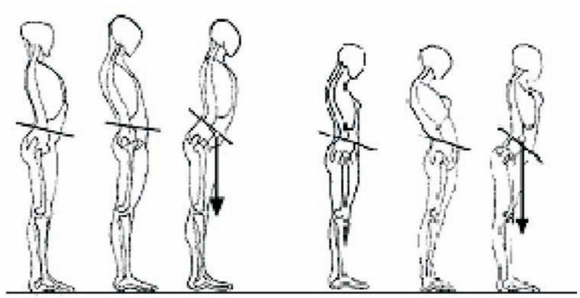


Figure 10. *Impact of relations of hip flexor – extensor strengths on pelvis position.*

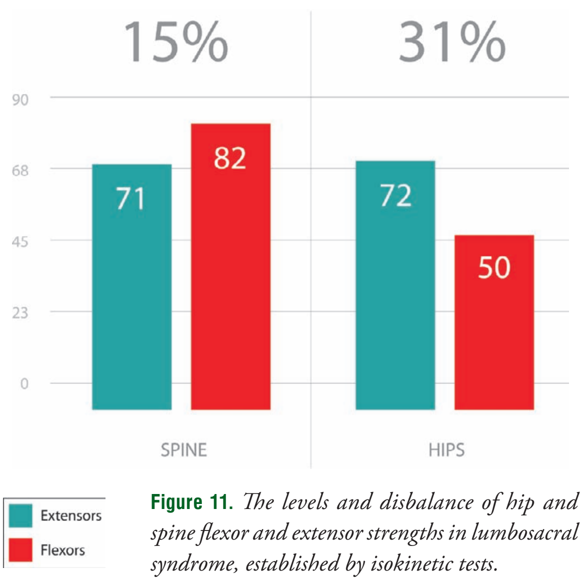


Figure 11. *The levels and disbalance of hip and spine flexor and extensor strengths in lumbosacral syndrome, established by isokinetic tests.*

Based on further analyses of results in this study, we concluded that prominent decline in flexor and extensor strength is present in most cases during development of hip osteoarthritis, with considerably higher loss in flexor strength and consequent 30% predominance of extensors over flexors. Using mathematical simulations of force vector shifts in the hip joint during such disorder in relations of agonist and antagonist forces, we concluded that a shift in the femoral head toward the anterior segment of the acetabulum occurs because of weak flexor force in orthostatic position. This exponentially increases the pressure force to the anterior segment of the acetabulum and leads to osteochondral changes in the acetabulum presenting as osteoarthritis that may subsequently be also verified by X-ray changes in the acetabulum (Figure 12) *(14, 15).*

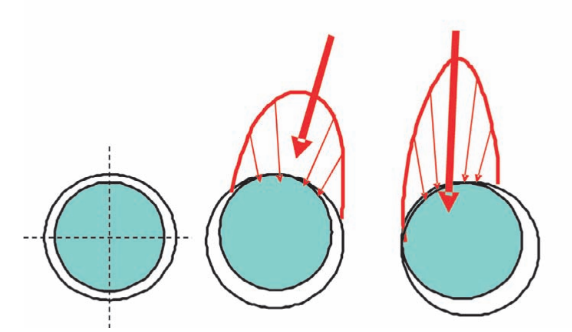
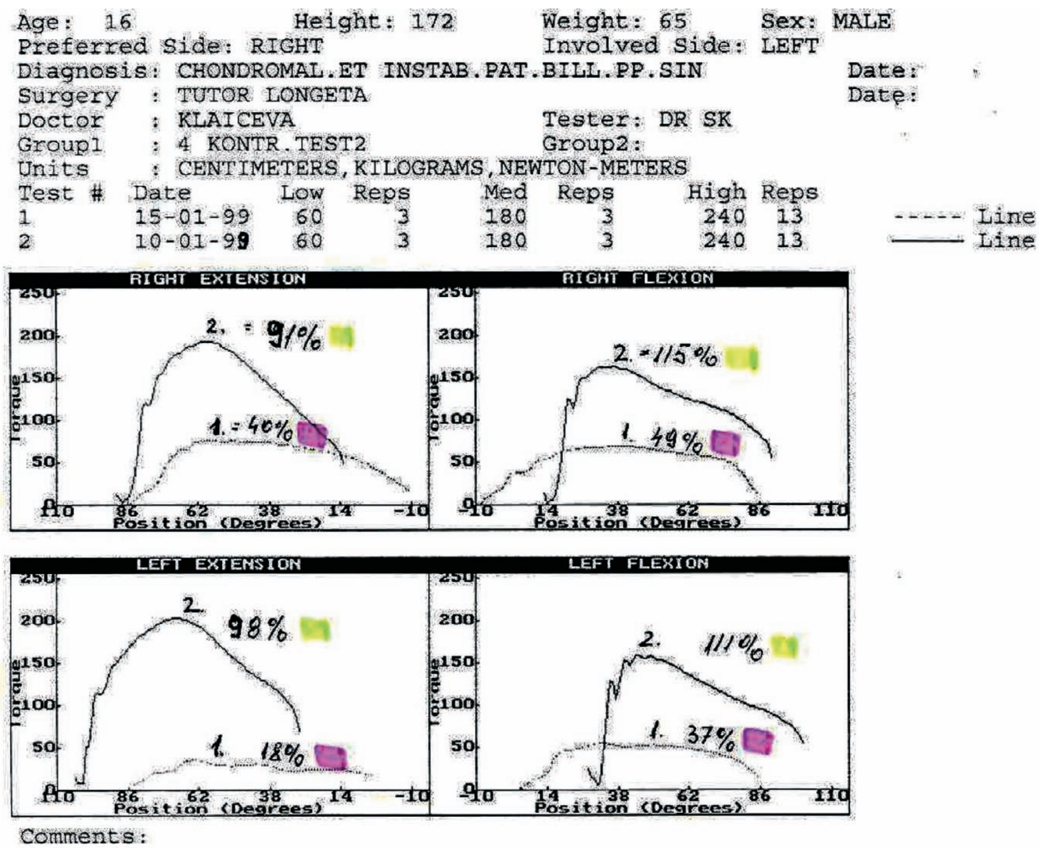


Figure 12. *Illustration of a shift in load force vectors in the acetabulum at predominance of hip flexor force.*

The established increased disbalance between hip extensor and flexor strengths of over 30% in favor of extensor strength and a present, yet two-fold (15%) lesser, disbalance in relations between flexor and extensor strengths of thoracolumbar spine muscles in favor of flexors during painful spine conditions directed us to the logical conclusion that such statico-dynamic relations typically lead to altered pelvis position and lumbosacral junction. These alterations are accompanied by decreased lumbosacral angle and exponential load increase in the area of terminal lumbar articular segments, with consequent degenerative changes in intervertebral joint elements. Based on these assumptions, we introduced in year 2000 a new algorithm of isokinetic therapy procedures for painful conditions related to the lumbosacral spine. Earlier isokinetic practice for such conditions had included tests and exercises only for the spinal segment, and in 2000 we introduced mandatory diagnostics of muscles and joints of the thoracolumbar spine, hips, knees and lower legs. Based on test results, we began with correcting the established deficiencies and disbalance in knees, hips and lower legs, while therapy program for the thoracolumbar spine was also started after stabilization of leg segments. This resulted in surprisingly rapid and long-term patient recovery with remission periods between 2 and 7 years. In currently already a large number of treated patients, our experience showed that it is necessary to repeat control tests and therapy after 1.5 to 2 years and thus ensure longstanding satisfactory functioning of the system.

The possibility of mathematical detection of the risk of articular damage using isokinetic tests undoubtedly warrants preventive application of isokinetic testing with the aim of early detection of initial changes and risks of



Comparison test of recovery of the knee muscle strengths in grade 4 Chondromalacia after 25 isokinetic treatments

serious articular damage like osteoarthritis of hips, knees, development of lumbosacral or cervicobrachial syndrome and other possible degenerative joint lesions *(16, 17).*

Isokinetics in postoperative and posttraumatic rehabilitation

Introduction of isokinetic diagnostics in postoperative or posttraumatic rehabilitation showed the usual rehabilitation procedure for these conditions to be insufficient for achievement of the actually possible degree of muscle and joint recovery and ultimately of normal movement. The main reason for this can be recognized in insufficient knowledge of fundamental biomechanical characteristics of a patient and unjustifiably reduced participation of kinesitherapy in rehabilitation algorithm at the expense of electrotherapy. Obviously, there is a wrong assumption that muscle strength and articular function will recover only through personal activity of a patient after physical therapy. According to our experience, this assumption is the key mistake in predictions of complete recovery. The truth of this could probably not have been established until introduction of isokinetic tests because of lack of possibilities to objectively assess the attained degree of recovery of the muscle and joint function.

In everyday management of such patients, we have observed that, considering only the component of muscle strength, about 30 – 40% of the necessary muscle strength level can be achieved by applying usual procedures. Young patients sometimes manage to acquire up to 60% of the necessary strength by intense months-long exercising in fitness clubs. However, there still remains an open and very important question of the right proportion of agonist and antagonist strengths in each joint and of adjusted strength flow in kinematic chain (e.g. of legs from hips to the ankle joint). Considering the immediate postoperative or posttraumatic period on the short-term basis, any type of rehabilitation will improve the condition of every patient, lessen the pain and allow acceptable functioning. Patients often understand such condition as the only possible one, and this view is also probably shared by their general practititoner. From a long-term view, such patient becomes a potential candidate for chronic lesions due to disrupted statico-dynamical relations, and is heading for early disability, reduced work capacity, and eventually to the loss of mobility and quality of life *(18, 19).*

Objective diagnostics, targeted isokinetic procedure and monitoring of its results ensure several-fold faster and correct treatment result maintanable for years, as well as prevention of subsequent appearance of degenerative changes. It is particularly important to mention significantly shortened time of recovery of the muscle and joint function (Figures 12,13).

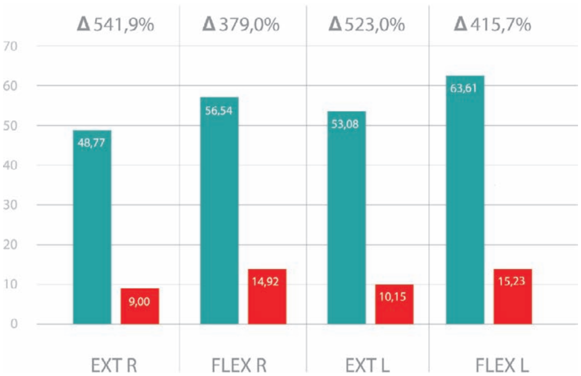


Figure 13. *Comparison of muscle strength increase in knee osteoarthritis: subject group: isokinetic procedure: control group: standard procedure.*

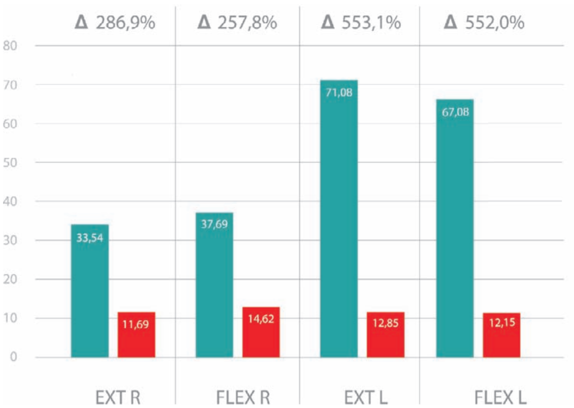


Figure 14. *Comparison of muscle performance increase in knee osteoarthritis: subject group: isokinetic procedure; control group: standard procedure.*

Comparison of results of the standard rehabilitation procedure for knee osteoarthritis and results achieved by applying our protocols of isokinetic procedure for muscle strength recovery and joint unloading revealed 3-5-fold faster progression (a study by dr. Katarina Lohman, SBMR VT) (Figures 14, 15).

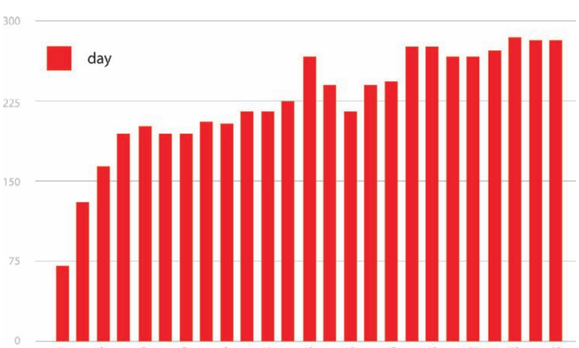


Figure 15. *Daily presentation of the knee muscle strength recovery in the same patient.*

CONCLUSION

Considering the possibility of early detection of disorders in the joint biomechanical parameters that lead to articular degenerative lesions, the possibility of precise and rapid elimination of causes and somewhat holistic covering of the problem, proper and professional application of isokinetic therapy can significantly reduce the need for aggressive surgical procedures, considerably diminish the development of serious degenerative joint and locomotor system lesions, preserve mobility and quality of life, and substantially reduce the cost of treating such diseases.

Isokinetic tests should be components of every diagnostic procedure before and during rehabilitation, just as ergometrics today is a constituent of every major cardiological management of a patient. Based on isokinetic testing, rehabilitation process could be personalized, precisely programmed and guided, treatment procedure could be significantly shortened and remission prolonged to several years with concurrent significant reduction in treatment and sick leave expenses *(20, 21)*.

The greatest advantages and savings in health care will be realized in the future by introducing isokinetic testings as a method of preventing development of bone and muscle illnesses in working population by applying targeted preventive testing programs for workers employed on both physical jobs and jobs that involve everyday sitting.

REFERENCES

1. MUFTIĆ O 2004 Biomehanička ergonomija, podloge za predavanja. FSB, Zagreb.
2. MUFTIĆ O, JURČEVIĆ LULIĆ T, GODAN B 2011 Harmonijska raspodjela mase dijelova ljudskog tijela. *Sigurnost 53(1):* 1 – 10
3. THISTLE H G, HISLOP H G, MOFFROID M *et al.* 1966 Isokinetic contraction: A new concept of resistive exercise. *Arch Phys Med Rehab 48* (June)
4. HISLOP H J, PERRINE J J 1967 The isokinetic concept of exercise. *Phys Ther 47:* 114-117
5. KANNUS P 1994 Isokinetic evaluation of muscular performance: implications for muscle testing and rehabilitation. *Int J Sports Med (15):* S11-S18
6. FRONTERA W R, HUGHES V A, FIELDING R A, FIATARONE M A, EVANS W J, ROUBENOFF R 2000 Aging of skeletal muscle: a 12-yr longitudinal study. *Journal of Applied Physiology 88 (4):* 1321-1326 DO
7. TIIDUS P 2008 Skeletal Muscle Damage and Repair: Mechanisms & Interventions, Jan 31, ISBN-13: 978- 0736058674
8. DAVIES G J 1992 Compendium of Isokinetics in Clinical Usage and Rehabilitation Techniques – June. S & S Pub, 4th edition.
9. MUFTIĆ O, KUVALJA S, HADJINA J, PULJIĆ A 2010 Periodicum biologorum, Vol.112 No.1 Ergonomical comparision between the back function tests.
10. WILDER P A, SYKES J1982 Using an isokinetic exercise machine to improve the gait pattern in a hemiplegic patient. A case report. Phys Ther. 62(9): 1291-5
11. MESSIER S P, GLASSER J L, ETTINGER W H JR, CRAVEN T E, MILLERM M E 2002 Declines in strength and balance in

older adults with chronic knee pain: A 30-month longitudinal, observational study. *Arthritis Care & Research Volume 47, Issue 2* : 141–148

12. TIMM K E 1995 Clinical applications of a normative database for the CYBEX TEF and TORSO spinal isokinetic dynamometers. *Isokinetics Ex Sci 5:* 43-49
13. TAKALA E P, VIIKARI-JUNTURA E 2000 Do functional tests predict low back pain? *Spine (Phila Pa 1976) 25(16):* 2126-32
14. BERTOCCI G E, MUNIN M C, FROST K L, BURDETT R, WVASSINGER C A, FITZGERALD S G 2004 Isokinetic Performance After Total Hip Replacement. *American Journal of Physical Medicine & Rehabilitation 83(1):* 1-9
15. RUBENSTEIN L Z, JOSEPHSON K R, TRUEBLOOD P R, LOY S, HARKER J O, PIETRUSZKA F M, ROBBINS A S 2000 Effects of a group exercise program on strength, mobility, and falls among fall-prone elderly men. *J Gerontol A Biol Sci Med Sci 55(6):* M317-21
16. LEE J H, HOSHINO Y†, NAKAMURA K‡, KARIYA Y†, SAITA K†, ITO K 1999 Trunk Muscle Weakness as a Risk Factor for Low Back Pain: A 5-Year Prospective Study. *Spine 24(1):* 54–57
17. ELLENBECKER T S, DAVIES G J 2000 The Application of Isokinetics in Testing and Rehabilitation of the Shoulder Complex. *J Athletic Training 35:* 338-350
18. UGANET HERNÁNDEZ ROSA, JORGE VELÁSQUEZ, TLAPANCO, CATALINA LARA MAYA,, ENRIQUE VILLARREAL RÍOS, LIDIA MARTÍNEZ GONZÁLEZ, EMMA ROSA VARGAS DAZA, LILIANA GALICIA RODRÍGUEZ 2012 Comparison of the Effectiveness of Isokinetic vs Isometric Therapeutic Exercise in Patients With Osteoarthritis of Knee. *Reumatol Clin 8(1):*10-4; DOI: 10.1016/j.reumae.2011.08.003
19. JAN M H, LIN J J, LIAU J J, LIN Y F, LIN D H 2008 Investigation of clinical effects of high- and low-resistance training for patients with knee osteoarthritis: a randomized controlled trial. *Phys Ther 88(4):* 427-36; doi: 10.2522/ptj.20060300. Epub 2008 Jan 24.
20. DAVIES G J, ZILLMER D A Functional Progression of a Patient Through a Rehabilitation Program Orthopaedic Physical Therapy Clinics of North America, Jan 31, 2008, ISBN-13: 978-0736058674. 9:103-118, 2000.
21. KEITH E 2006 Rosenbluma and Arti Shankarb; A study of the effects of isokinetic pre-employment physical capability screening in the reduction of usculoskeletal disorders in a labor intensive work environment. *Work 26:* 215–228 215; IOS Press