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Anisokinetic Exercise: Isokinetics-Alternative for Developing Countries

David Greenblatt[1]* and Renate van Rensburg[2]

[1]*Faculty of Mechanical Engineering, Technion-Israel Institute of Technology, Technion City, Haifa 3200003, Israel*
[2]*Natalspruit Hospital, Private Bag X01, Alrode 1c451, South Africa*

Abstract

A novel low-cost knee exerciser concept, previously assessed under laboratory and sports-related clinical conditions, was evaluated within the context of a developing world hospital environment. The newly-designed exerciser is of simple and robust design, incorporating a shock absorber/lever mechanism, and patient testing was carried out without resorting to previously used sophisticated measurement techniques. Motion is not purely isokinetic, mainly due to gentle acceleration and deceleration at the limb extremities, and rotational speeds vary depending upon the patient knee-joint strength. We call this anisokinetic exercise, because it has the inherent safety of isokinetics and facilitates near maximum muscle contraction throughout the range of movement. Tests carried out on a cross-section of patients and pathologies produced quantitative knee-joint data, and patient progress was monitored on the basis of average rotational speed. The combination of functionality, design simplicity and robustness, renders anisokinetics ideally suited to developing world environments. Further work on the exerciser should be aimed at establishing normative knee-joint data specifically geared for developing world environments and developing motivational feedback to the patients during exercise.

Keywords: Isokinetics; Anisokinetic exercise; Knee-joint; Isokinetics alternative; Developing Countries; Low-cost; Joint strengthening

Introduction and Objectives

Isokinetic exercise is commonly used for joint strength training, rehabilitation and testing. It ensures that angular rotation of the joint is constant and employs sophisticated dynamometers for measuring joint torque and power. Isokinetic rehabilitation and testing was originally employed in the domain of sport medicine [1-6], but it has steadily found its way into general joint rehabilitation and assessment [7-10]. The importance of this mode of exercise and its many benefits over other modes are well documented and universally appreciated [11]. In particular, isokinetic exercise is inherently safe and muscle contraction is attained throughout the range of joint motion. However, high levels of sophistication increase costs, and consequently isokinetic equipment often cannot be acquired for general rehabilitation or by many developing world healthcare institutions [12]. There is thus clearly a need for isokinetics machines that are affordable, reliable and available to the public at large, particularly in developing countries.

Some years ago, a novel, inexpensive alternative to traditional isokinetic knee-joint exercisers was conceptualized, that relies on the fact that knee torque attains its maximum value, between fully extended and fully flexed positions (the "Blix curve") [13]. A knee-joint exerciser was selected because this joint it is the most frequency injured joint in the body [14, 15]. A shock absorber and lever mechanism adapts its resistance to mimic the Blix curve and thereby attain isokinetic motion. The exerciser was tested in a laboratory environment, with healthy males, and achieved isokinetic type motion in both flexion and extension of the lower limb [13]. In addition, it was demonstrated that this exerciser could be significantly cheaper than comparable equipment as well as being robust, fully calibratable and capable of providing reproducible results over the entire range of knee-joint movement.

Following this study, the exerciser was subjected to a clinical evaluation where 11 healthy male subjects were evaluated at speeds between 100°/s and 300°/s. It was shown that at these speeds, the torque generated by the subjects in both extension and flexion could be estimated without resorting to sophisticated measurement techniques [16]. This work also highlighted the attainment of a "spectrum of velocities", repeatability, patient safety, exerciser reliability, ease of use and patient comfort thus fulfilling the major criteria required from isokinetic equipment. Up until the present time, this novel exercise regimen was not evaluated in a developing world setting.

One limitation of the exerciser is that it does not produce isokinetic motion when the knee-joint is injured, post-operative, or there is some underlying pathology. Nevertheless, the exerciser still maintains the inherent advantages of isokinetic exercise, including control of average speed, accommodation of musculoskeletal leverage, and patient safety. Considering the prevalence of knee-joint injuries [14, 15] and limited rehabilitation budgets in healthcare institutions [12], the objectives of this research were twofold. The first was to construct a low-cost variation of the exerciser that can be produced in the simplest of workshops; and the second was to conduct an evaluation of the exerciser when installed in a typical developing world hospital (The Natalspruit Hospital (Katlehong), Alrode, South Africa). The exerciser was used as part of an integrated approach to rehabilitation, at times involving other modes of exercise and muscle stimulation. We assessed firstly the suitability of the exerciser to this developing world environment, and secondly, the ability of the exerciser to act as a quantitative performance measurement device.

Principle of Operation

An ideal isokinetic exerciser allows a patient's limb to move at a constant speed irrespective of the torque developed. This is achieved, for example, in hydraulics based actuators, by means of pressure

***Corresponding author:** David Greenblatt, Faculty of Mechanical Engineering, Technion-Israel Institute of Technology, Technion City, Haifa 3200003, Israel, E-mail: davidg@me.technion.ac.il

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compensating valves. Another less obvious method for achieving isokinetic motion is to determine, *a priori*, the patient's limb torque versus angle characteristics and then set up a resistance to bring about isokinetic motion [13, 16].

The problem of designing such a system is greatly simplified if it is assumed that the torque versus angle characteristics for all patients can be characterized by a family of similar curves. By considering the results from a large cross section of patients [1], it is evident that for both extensor and flexor muscles of the knee; torque is at a minimum at the fully extended and flexed positions (extremities) and reaches a maximum somewhere in between. This result, which is represented as the so called Blix curve, was used as the basis for designing the exerciser, using a shock absorber and lever mechanism. This resulted in approximate isokinetic motion for both extension and flexion of the joint, where negligible deviations were observed at the extremities of flexion and extension. However, when different pathologies are considered, Blix curves vary greatly resulting in deviations from isokinetic motion, producing *anisokinetic* motion. The original knee exercise was modified with simplicity and robustness as the overriding design criteria (see Figure 1). It was constructed from a welded steel frame, with a padded seat and adjustable backrest. The patient's lower-legs were attached to adjustable rods via shin-pads and Velcro straps (shin-pads not visible). Each rod was joined to a lever arm, with a 90º offset, by means of a 50 mm diameter horizontal shaft and two off-the-shelf standard SKF bearings. An automotive shock absorber was mounted between the lever arm and an upper horizontal bar. The points of attachment of the shock absorber to lever arm and a bar were located by means of pins and locked in place by hand operated lock bolts. Different speeds were attained by the varying attachment locations of the shock absorber to the horizontal bar and lever arm.

It is important to note that this anisokinetic exerciser differs from traditional isokinetic dynamometers. Here, a larger *average* torque delivered by the patient results in a larger *average* speed attained by the limb. Moreover, the limb will always meet resistance, regardless of the torque delivered. For a traditional isokinetic dynamometer, the speed is pre-selected and this *speed cannot be exceeded*, regardless of the torque delivered. Additionally, no resistance is offered if the preset speed is not attained.

It is equally important to emphasize that for anisokinetic exercise the limb speed is *approximately isokinetic* during extension and flexion [13, 16]. Thus, for a patient who has never been tested before, the average speed will not be known *a priori*, but it will be approximately isokinetic. The deviations from isokinetic motion were not considered a major point of concern since ideal isokinetic motion requires infinite accelerations at the extremities. So clearly for *all* exercisers it is impossible to achieve ideal isokinetic motion throughout the range of motion [2].

Patient Testing: The following protocol was adopted for the testing of all patients;

1. The patient's name, sex and pathology were recorded.

2. Joint-related muscles, i.e. quadriceps and hamstrings, were passively and actively warmed up.

3. The patient was allowed to 'get the feel' of the exerciser by performing several sub-maximal and maximal effort extensions and flexions.

4. The time was recorded for 10 maximal effort extensions and flexions. Consistent verbal encouragement was given to all patients during each test.

5. Average angular speed (ω) for the 10 repetitions was computed, considering the arc of motion traversed as well as the recorded time.

6. Average torque was calculated from the simple linear relationship [5, 6]: $T=c\omega L$, where c is the calibrated average shock absorber damping coefficient which also depends on the system geometry [13] and L is the lever-arm length between the shock absorber attachment point and the axis of rotation.

Results and Evaluation

The results presented in this paper were obtained over a period of

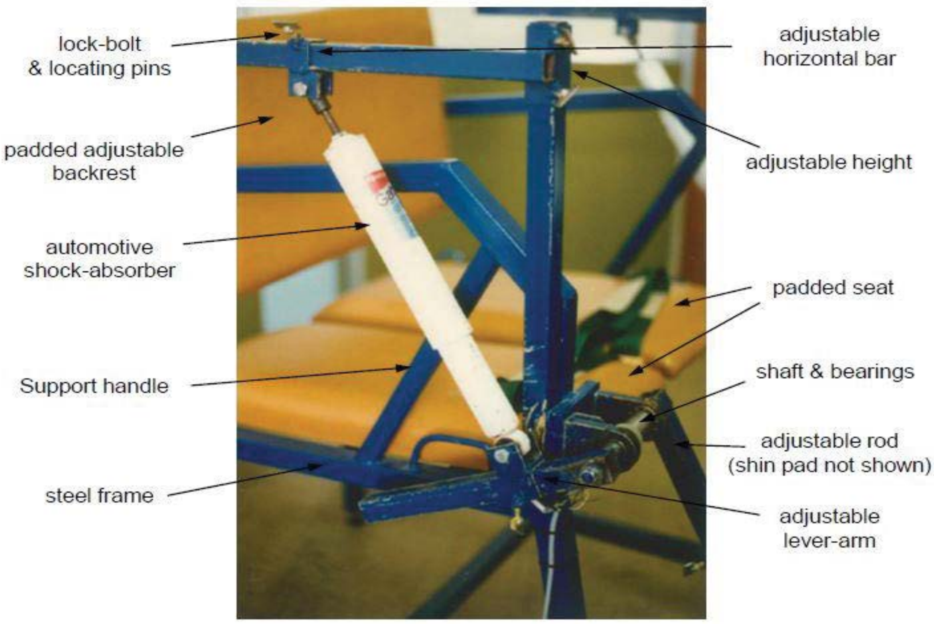

Figure 1: Photograph of the redesigned VariCom anisokinetic exerciser showing the main design elements.

approximately three months. During this period, approximately 10 different conditions were treated, providing a representative cross section of conditions encountered in such an environment. These included: recovering paraplegics and mild hemiplegics; muscles strengthening after prolonged bed rest; strengthening amputee's supporting limb in preparation for crutch walking; post injury or operative rehabilitation such as fractures, gunshot wounds, and soft tissue injuries and surgery. An attempt was made to conduct the protocol, outlined in the previous section, on as many patients as possible. In many cases, however, the patients did not return for more than two tests. This was one typical problem encountered when attempting to conduct basic research in a developing world environment.

The average angular-speed results, as a function of time (starting the treatment commencement date, i.e. day number 1), for six patients are presented in Figure 2, where the pathologies tested are identified in the figure caption. Upper and lower limits for healthy male and female sports-orientated patients (provisional 'normative' data [16]), are also indicated on the figure. Tests at a relatively low speed are presented here, simply because the largest amount of data had been acquired at this exerciser setting. The data presented here is meant to be mainly illustrative and it should be noted that speeds of up to 300°/s were attained by the exerciser in a previous study [16]. The data are both for males and females of varying ages since acquisition of data for a specific pathology where approximate age and gender were the same proved to be virtually impossible given the research time constraints. The figure clearly indicates quantitative speed variations with time as the patients progress through the rehabilitation process. Note that the average torque generated by each patient is linearly related to average angular speed, and so the figure can also be interpreted as the patient knee-joint strength as a function of time. Moreover, average power can also be inferred from the product, $T\omega$. This set of data shows positive overall improvement for all patients, with the exception of one with osteoarthritis who was experiencing pain after arthroscopy. Apart from this patient, none of the patients experienced any form of discomfort during or after the tests. This is a well-documented feature of isokinetic exercise.

Figure 2 also indicates that most of the patients approach the 'normative' data range over a period of time. Two of the patients, one with torn ligaments and another recovering from a femur fracture, could only maintain speeds of approximately 60°/s and did not return for further rehabilitation. Furthermore, it can be seen that the time taken for complete rehabilitation can vary greatly, i.e. anything from 10 to 30 days. Many factors can account for this large variation, such as the nature of the pathology or injury, or the individual patients ability and motivation. It is important to note, however, that no quantitative conclusions can be made regarding a particular pathology due to the small and varied sample considered here.

The 'normative' data presented here was acquired from a sport orientated developed world environment and consequently cannot be used to draw firm conclusions. The challenge is to establish normative data using this exerciser in a developing world environment. The magnitude of this task cannot be underestimated and Davies [1] points out that even in developed world settings, with extremely large data samples, there is still controversy regarding the normative data for the knee-joint. Thus, the development of normative data for developing countries emerges as an important are for future research.

Discussion

In the United States, five million people visit orthopedic surgeons for knee-related injuries every year, including fractures (femur, tibia and patella) [17], muscle and ligament injuries (cruciate and collateral) [7, 18], meniscus and tendon tears [15] and osteoarthritis [19]. Many of these patients are not exposed to isokinetic exercise as part of their rehabilitation regimen because many clinicians cannot justify it on the basis of a cost-benefit analysis [20]. In contrast, the exerciser described here offers a significant reduction in mechanical complexity, and therefore cost, when compared to standard isokinetic dynamometers. This break with tradition is intended primarily to bring the main benefits of isokinetic exercise to a far greater population, for both sport and non-sport related rehabilitation and testing. The significant reduction in complexity and cost certainly brings with it additional challenges, particularly when dealing with various post-operative patients and various knee-joint pathologies. In this section we highlight the novelty and significance of our study and we discuss ways in which the exerciser can be modified and adapted to clinical conditions.

A key benefit that anisokinetics retains when compared to standard isokinetics is that if a patient experiences pain or discomfort during exercise, then by stopping the exercise the load immediately drops. Just like conventional isokinetics, the applied toque is reactive and

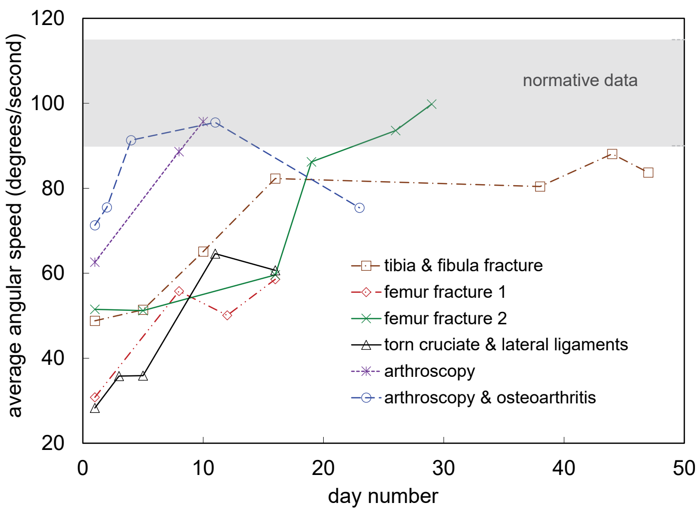

Figure 2: Quantification of patient development via the measurement of average angular velocity as a function of time for a number of representative pathologies.

is therefore only applied to the knee-joint when the patient actively applies a torque. This should be contrasted with isotonic exercise (free weights), weight-based mechanisms and springs. Similarly, anisokinetics also accommodates to fatigue, and thus a fatigued patient can still exercise the joint through the full range of motion. In addition, because we measure the average speed ω and therefore the average torque by $T=c\omega L$ (see Patient testing, item 6), the clinician can also measure average power, total work and endurance. In fact, average values are sometimes considered to be a better estimate of overall function than peak values, because function depends upon repetition of movement under load.

An important difference between isokinetics and anisokinetics is this. For a given exerciser configuration (c) and lever setting (L), the clinician does not know, *a priori*, what average speed the patient will attain. There are two ways to deal with this. If the clinician has an estimate of the average torque produced by the patient, then the equation in item 6 of Patient testing can be inverted to obtain the lever-arm length $L = T/c\omega$, which is then set on the exerciser. Alternatively, the clinician can conduct a pre-test using a reference lever-arm, say L_{ref} and then measure an average (reference) speed ω_{ref}. There after, an arbitrary desired average speed ω can be attained by setting the lever arm according to $L = L_{ref}\,(\omega_{ref}/\omega)$.

A drawback of anisokinetics is that large deviations from isokinetic motion may occur for patients that have severe joint pathologies, or muscle damage/weakness. This obviates a direct comparison with isokinetic dynamometers. Moreover, common metrics, such as time rate to torque development (TRTD) and force decay rate (FDR) cannot be unambiguously determined. Conventional isokinetic dynamometers can also act as a diagnostic tool for identifying specific pathologies, such as patella femoral chondrosis, plica syndrome, patella subluxation, or anterior cruciate deficiency, where significantly deviations are visible in the Blix curves. For the present anisokinetic exerciser, a greater level of sophistication can be attained by simultaneously measuring the instantaneous lever angle and angula speeds [13]. The general relation developed in used [13] can then be used to calculate torque and hence produce an anisokinetic Blix curve. This will not allow direct comparison with standard isokinetic dynamometers, but will allow the clinician to chart development of a particular patient and, ultimately, establish standard testing protocols.

Conclusions and Further Work

1. During evaluation of the exercise, the following specific observations were made:

The exerciser was capable of providing quantitative knee-joint data during the rehabilitation process. As a result of this:

- Patient improvement, as well as deterioration, could be quantitatively monitored.
- A method for assessing patients' development in time, on the basis of normative data, was established.

2. The above conclusions were drawn despite the relatively simple nature of testing performed here. This low level of sophistication as a means of achieving meaningful quantitative data is an ideal combination for a developing world environment.

Further work on this exerciser should be aimed at:

- Establishing normative knee-joint data for developing world environments.
- Establishing normative data for specific pathologies, such as normative recovery rate.
- Determining a minimum average speed/torque level for discharging patients.
- Incorporating more accurate dynamometry into the present exerciser.

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