Original Research Article

Posterior thigh isometric force measurement with extended knee

ABSTRACT

Aims: The establishment of normal values for the hamstring flexibility and isometric posterior thigh force of healthy adults performing standard motor task consisting of acting against a rubber band in the supine position.
Study design: Observation and ecological.
Place and Duration of Study: During a Sports Medicine three days event (*Congreso DePunta*) in Uruguay, September 2018.
Methodology: Random sample of 21 men and 16 women were asked to have their biomechanics properties measured by DIBABANG which is a novel clinical instrument to guide lower limb rehabilitation. DINABANG measures the force signal as the specific motor task until further effort would lift the patient from the mat. The motor task consists of, in supine position, hip flexion with fully extended knee and ankle attached to a rubber band operated by a Physical Therapist behind the head of the person.
Results: Normal values for body weight specific peak force during isometric effort with extended limb in supine position and ankle bracelet tied to an elastic band are (mean ± SD) 1.7 ± 0.4 / 1.9 ± 0.5 N•Kg-1 for men and 2.1 ± 0.5 / 2.3 ± 0.5 N•Kg-1 for women and weak/strong limb respectively. The volunteer-defined flexibility angles of the healthy young populations (21 men and 16 women) were found to be 67.5° ± 6.5° and 77.5°± 10° merging the distributions of both lower limbs, strong and weak.
Conclusion: These values will be included in subsequent versions of DINABANG to be used in clinical practice helping to avoid muscle strains by quantifying efforts during rehabilitation under Physical Therapist monitoring.

Keywords: Rehabilitation hamstring injury prevention, Physical Therapy, Knee joint, Biomechanics, Normal values

1. INTRODUCTION

Lower limb movement analysis has been addressed in several studies to determine the sequence of contraction of posterior and anterior muscles of the thigh [1]. Moreover, muscle force characterization is increasingly important in rehabilitation and sports medicine [2], especially for elite athletes [3] [4]. Despite its importance, little has been published on such measurements which are seldom used in practice due to the lack of instruments suitable for field work. To foster quantitative evaluation of rehabilitation and to further the efficiency of sports training, we have developed CINARTRO [5] to quantify knee joint movement, CINAR-3D [6] to estimate leg rotation and DINABANG [7] to measure motor task force for hamstring strains avoidance during guided exercise. To this end, DINABANG is able to measure angular velocity, force and torque to help the Physical Therapist during hamstring rehabilitation exercises.

This report establishes the first set of isometric normal values using DINABANG in healthy adults, as a contribution to physiological knowledge but primarily to be included in subsequent versions of DINABANG as reference values to compare measurements to.

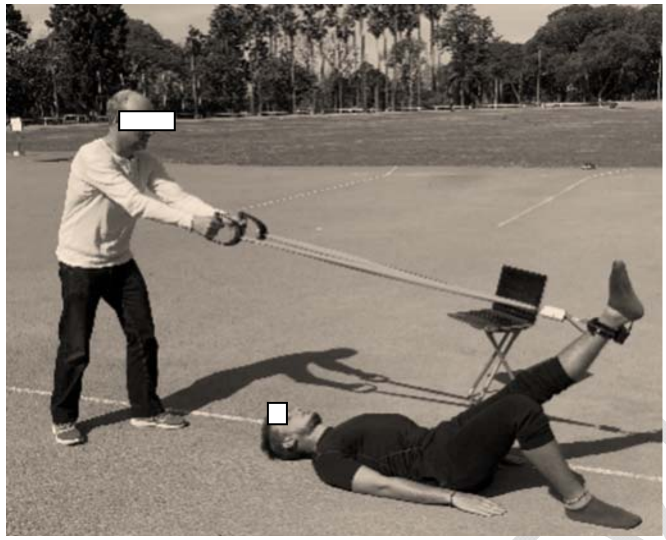

Fig. 1. The Physical Therapist, located past the volunteer's head, holds the ankle attached elastic band

2. MATERIAL AND METHODS

2.1 Participants

A group of young healthy adults with ongoing sports activity was asked to be part of the present research. The study was carried out in accordance with the guidelines contained in the Declaration of Helsinki and all participants signed an informed consent approved by the University Ethics Committee of the Hospital de Clínicas. We studied a population of n= 37 athletes (men n= 21, women n=16), whose ages, standing heights and body masses were (mean ± SD) men: 24.6 ± 3.8 years, 174.3 ± 7.4 cm and 72.4 ± 11.6 Kg, women: 26.0 ± 6.7 years, 166.9 ± 4.0 cm and 61.9 ± 7.5 Kg. The sportspersons were evaluated during a Sports Medicine three days event (*Congreso DePunta*) in Uruguay, September 2018. Participants were excluded if they had had hamstring injuries ever or any knee injury history 12 months prior to the event.

2.2 Measurements

DINABANG is an original device [7] to record the force, angular velocity and elastic band vector direction which, along with lower limb length and weight, allows monitoring torque and effort during guided exercise. Among other information, DINABANG gives the isometric force measurement as the maximum value of the force signal. The specific motor task analysed by DINABANG consists of thigh posterior muscles contraction under Physical Therapist direction (Figure 1). There is a moment when, despite increasing the effort, the force signal does not increase anymore because the patient or the Therapist let go, since the lumbar region would be otherwise lifted.

2.3 Design and procedures

The measurement of thigh posterior muscular force is the result of a special setup by which the person is laying down in supine position on a gymnastic mat. DINABANG strap bracelet is successively attached to the strong and weak ankle. The Physical Therapist is located past the head of the volunteer holding an elastic TheraBand® band attached to the ankle strap (Figure 1) and guides the isometric effort, one limb at a time. The position familiarization phase consists of selecting the most comfortable angle for the active limb, around 60° with respect to horizontal (Figure 2, angle graph). This angle depends on the flexibility of the volunteer and is determined by the angle signal given by DINABANG (Figure 2). The direction of the effort is towards 0° or extending the hip, with fully extended knee. Once in a comfortable position (60° approximately, point **b** in Figure 2), the athlete is asked to increase the strength of his or her effort until the lumbar region is about to be lifted from the mat (point **c** in Figure 2). At this point, there is a drastic decrease in the force applied because the athlete stops his or her effort. The peak force reached is measured by selecting the maximum of the signal (point **c**, Figure 2), which therefore represents the necessary force to barely lift the body. The relaxing phase of the limb goes from point **c** to point **d** in Figure 2 while maintaining roughly the same 60° position as held in place by the elastic band.

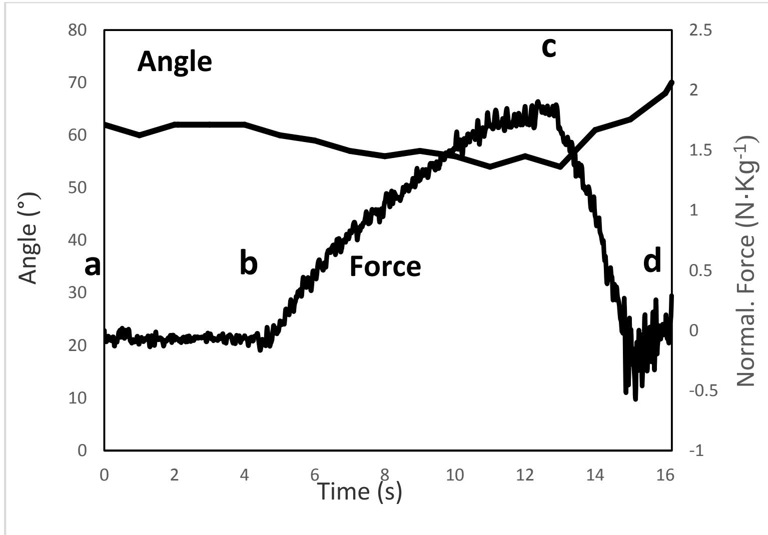

Fig. 2. DINABANG angle and force measurements. *Phase **a**-**b**: familiarization at most comfortable position 60°; phase **b**-**c**: increasing isometric force; point **c**: lumbar region about to be lifted and interruption of effort; phase **c**-**d**: relaxing limb held in place by elastic band. This athlete M, 24y, 77Kg, 182cm, reached a maximum isometric force of 2N·Kg^{-1}.*

The average of the comfortable hip flexion angles (three tries each athlete) was used as a hamstring flexibility score for each limb. We therefore used the “passive straight-leg-raise test” [8] to measure the flexibility angle.

2.4 Statistical Analysis

We performed Kolmogorov-Smirnov and Shapiro-Wilk tests to assess Gaussian distribution within men’s and women’s series, as well as within strong and weak limbs of both genders. We applied non-paired t-test to men versus women strong limb and weak limb hamstring flexibility angle (bilateral) and hamstring isometric force (unilateral) respectively. Type 1 error was set at 5% and all data were analysed with XLSTAT Free®.

3. RESULTS

The maximum isometric standardized force measurements (N·Kg-1) were separated in strong and weak limb series, for men and women as shown in Table 1. For both lower limbs (weak and strong) women body weight-specific force is higher than men’s which represents a statistically different physiologic reality (Table 1).

Table 1. Weak/strong standardized peak force analysis of 74 lower limbs

	Weak Limb (n=37)		**Strong Limb (n=37)**	
	Mean	SD	Mean	SD
Men	1.7	0.4	1.9	0.5
Women	2.1	0.5	2.3	0.5
p values <	0.01		0.03	

Figure 3 shows the four adjusted distribution curves of the posterior thigh isometric force of strong and weak lower limbs of a normal population. The mean force exerted is 1.7 ± 0.4 N·Kg-1 and 1.9 ± 0.5 N·Kg-1 for men and 2.1 ± 0.5 N·Kg-1 and 2.3 ± 0.5 N·Kg-1 for women, exercising the weak and strong limb respectively. The women curves are displaced towards higher values, with respect to men.

Table 2. Weak/strong and men/women flexibility angle analysis

	Men (n=42)	**Women (n=32)**

	Mean	SD	Mean	SD
Angle Strong Limb (°)	67.5	6.6	77.9	10.7
Angle Weak Limb (°)	67.5	6.5	77.1	8.7
p values =	0.96		0.80	

In a similar way, the measurements of the flexibility angle selected by each athlete to perform the isometric effort are given in Table 2. The weak limb flexibility angle distribution coincides with the strong limb flexibility angle distribution, which allow us to show a single distribution (Table 2): 67.5° for men and 77.5° for women. Women flexibility angle is thus larger by about 10 degrees than the selected angle for men (Table 2).

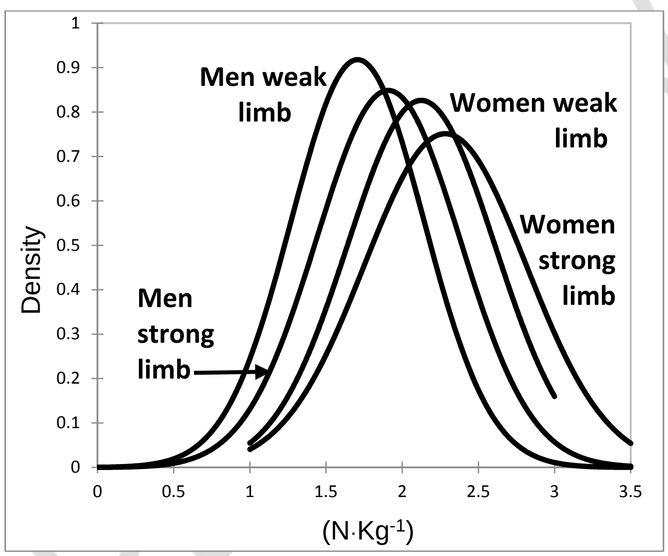

Fig. 3. Body weight adjusted normal distributions of posterior thigh isometric force. *Note that the women Gaussian curve spans higher weight specific figures than men's curve*.

Figure 4 shows the adjusted distribution curves of men and women flexibility angle resulting from 42 and 32 lower limbs respectively. The normal population of men selects an angle of 67.5° ± 6.5° while women select an angle of 77.5°± 10°. The flexibility of women is greater than men's by about 13%.

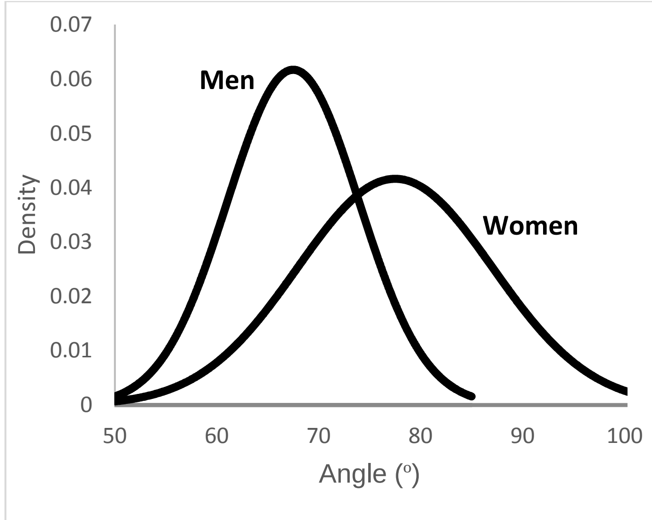

Fig. 4. Adjusted normal distributions of flexibility angles for isometric force of the lower limb. *Note that the women Gaussian curve spans higher angles than men's curve by 13%.*

4. DISCUSSION

We believe that the measurements reported here are the first to be taken by a clinical instrument such as DINABANG. Isometric efforts of the order of 2 N·Kg^{-1} of body weight are similar to other muscle force measurements such as the isometric mid-thigh pull (IMTP) motor task for which a standardized value of 0.92 ± 0.15 N·Kg^{-1} was reported by Dos Santos, et al. (2017). Our figure of 2.0 ± 0.5 N·Kg^{-1} is higher than the IMTP because strength developed by the hamstring opposing the elastic band is by far larger than the strength of the downwards mid-thigh pull.

The rationale to develop DINABANG was in the first place derived from observing Anterior Cruciate Ligament (ACL) reconstructed patients and their resulting post-operative weakness. Common clinical practice was to stress mobility rehabilitation and front (quadriceps) recovery. No special attention was ever given to posterior thigh muscles. This clearly appeared to us as a limitation since no objective measurement was available to support such practices. Good Physical Therapist practice includes, according to our clinical experience, strengthening of both posterior and anterior limb muscles. Posterior thigh strengthening is an important goal to work towards to, contrary to common practice which only stresses mobility and front recovery (quadriceps training). Our experience with ACL rehabilitation suggests [9] that posterior knee structures are affected by surgery of the hamstring tendon autograph because of its reduced activity [10]. Therefore, one of the major problems addressed by the Physical Therapist, in addition to the rehabilitation of the functional quadriceps which is the visible aspect, is to return full functionality to the hamstring. Patients with a hamstring weakness should work towards restoration of its strength and, by doing so, inevitably face rupture risks. Until now there was nothing but clinical judgment by the Physical Therapist to control such efforts and therefore to avoid iatrogenic consequences of excess exercise. DINABANG was conceived [7] to address this very critical point of rehabilitation. It allows setting safety alarms during rehabilitation exercises. Hence, the original measurements given here for the first time are a contribution to include safety standards to limit efforts during clinical rehabilitation. Such limits are also useful on the lower side of the normal interval because they allow the Physical Therapist to detect insufficient patient effort to fulfil the muscular strengthening goals.

Askling and Thorstensson (2008) in Sweden published an empirical test with unfortunately no quantitative angle measurements. We addressed this limitation by developing DINABANG instrument and by publishing the measurements we are reporting in the present paper. The use of DINABANG may in the future be useful to measure athletes' efforts during the Askling's h-test as a very much-needed objective quantification.

The force exerted by the volunteers may appear to be of a low value. Indeed, the forces would be a lot larger in case the body was tied to the medical table or mat. In our case, the peak force is the consequence of interrupting the increasing isometric effort when it is barely capable of lifting the body. The standard evaluation technique described in this paper and tested for the first time at the *Congreso DePunta* in 2018 is a simple and repeatable measurement to be used in clinical settings. The objective and unmistakable situation of the lumbar region lifting from the mat is part of the protocol to measure, in a standardized way, the force exerted during this test. Since the definition of the peak force is given by the lifting of the athlete's body, we have adopted a specific unit such as $N{\cdot}Kg^{-1}$: heavier bodies are usually associated with higher muscle masses, thus justifying our unit selection.

DINABANG is a novel instrument now available for lower limb muscle rehabilitation. Despite the costly instrumentation offered on the market for isokinetic and isometric evaluation, DINABANG only uses simple and common elements such as the TheraBand® elastic band, an ankle strap, microcontroller/Bluetooth® device and a laptop computer. This is readily available in the outpatient unit or in the training field. Normal values of body weight specific effort are available after the 74 measurements published in the present paper which will be included in the DINABANG software. The use of such instrument for bilateral evaluation over time will allow monitoring the rehabilitation exercises intensity progression and may be used to detect any asymmetry. The contribution of this research may in the near future have consequences on the efficiency of elite athletes training and their performance.

5. CONCLUSION

DINABANG is a novel clinical instrument which needed normal values to be included as real time alarms during rehabilitation exercises. The measurements of body mass normalized peak forces and of the flexibility angle reported here fill this need and, at the same time, constitute unpublished normal measurements for young healthy adults.

ETHICAL APPROVAL

The *Programa de Apoyo a la Investigación Estudiantil* PAIE 2018 research was carried out in accordance with the guidelines contained in the declaration of Helsinki and all participants signed an informed consent approved by the University Ethics Committee of the Hospital de Clínicas directed by Prof. Dr. Raúl Ruggia.

COMPETING INTERESTS DISCLAIMER:

Authors have declared that no competing interests exist. The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

REFERENCES

[1] A. Monajati, E. Larumbe-Zabala, M. Goss-Sampson, and F. Naclerio, "Analysis of the Hamstring Muscle Activation During two Injury Prevention Exercises," *J. Hum. Kinet.*, vol. 60, no. 1, pp. 29–37, 2017.
[2] L. N. Erickson and M. A. Sherry, "Rehabilitation and return to sport after hamstring strain injury," *J. Sport Heal. Sci.*, vol. 6, no. 3, pp. 262–270, 2017.
[3] T. Dos Santos, C. Thomas, P. Comfort, Mcmahon, and P. Jones, "Relationships between Isometric Force-Time Characteristics and Dynamic Performance," *Sports*, vol. 5, no. 3, p. 68, 2017.
[4] X. Wan, F. Qu, W. E. Garrett, H. Liu, and B. Yu, "The effect of hamstring flexibility on peak hamstring muscle strain in sprinting," *J. Sport Heal. Sci.*, vol. 6, no. 3, pp. 283–289, 2017.
[5] F. Simini and D. Santos, "Anterior Cruciate Ligament reconstruction follow-up instrumentation based on Centre of Rotation videofluoroscopy determination: Development of an original equipment, CINARTRO, and first clinical use," in *Conference Record - IEEE Instrumentation and Measurement Technology Conference*, 2014, pp. 923–926.
[6] M. R. Ledesma, A. Braidot, D. Santos, and F. Simini, "3D Reconstruction of Knee Motion by Videofluoroscopy & Videography with Orthogonal Cameras," in *XV International Symposium on 3D Analysis of Human (3DAHM-2018)*, 2018, p. In: press.

[7] D. Santos *et al.*, “DINABANG: Explosive Force Hamstring Rehabilitation Biomechanics Instrument,” *6th Int. Conf. Biotechnol. Bioeng. 2017 Offenburg, Ger.*, vol. 23, no. 1, p. 2017, 2017.
[8] J. C. Andersen, “Flexibility in Performance: Foundational Concepts and Practical Issues,” *Athl. Ther. Today*, vol. 11, no. 3, pp. 9–12, 2006.
[9] D. Santos, F. Massa, and F. Simini, “Evaluation of anterior cruciate ligament reconstructed patients should include both self-evaluation and anteroposterior joint movement estimation?,” *Phys. Ther. Rehabil.*, vol. 2, no. 1, p. 3, 2015.
[10] S. Van Grinsven, R. E. H. Van Cingel, C. J. M. Holla, and C. J. M. Van Loon, “Evidence-based rehabilitation following anterior cruciate ligament reconstruction,” *Knee Surg Sport. Traumatol Arthrosc*, vol. 18, pp. 1128–1144, 2010.