# AN OBJECTIVE METHOD TO EVALUATE FORCE AND KNEE JOINT MOMENTS DURING ISOMETRIC EXTENSION

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Abstract: A simple method to evaluate force and moments of knee joint during isometric extension has been developed and provides to the physicians a fast and objective tool for the evaluation of patients before and after a surgery or rehabilitative program. The experiment was made on normal young patients. Graphs of angle-moment were obtained. The patients started from 90° of knee flexion and extended step-by-step the knee joint until the maximum knee extension was achieved. Force, angle and moment were measured at each step. In comparison with literature, even if significant differences of technical instrumentation, age and activity of the patients are present, the maximum moment-angle behaviour during extension is the same but different magnitude. Future development of this device is to make it easy to use directly in clinical applications.

## 1 INTRODUCTION

When a patient with a neuromuscular disease is subject to an intervention or physical rehabilitation, it is always necessary to make a physical evaluation to check the functional state of the muscles and joints. In the specific case of spastic patients, several methods exist to see the deficit of active extension angle (DAE) and the maximum extension force (MEF) (Rabaiotti, 2004). Also, most mathematical models describe the forces in the knee under isometric quadriceps contractions (Huss et al.,2000). The most common methods of measure used are: A manual force test, manual dynamometers and isokinetic dynamometers. It is usually assumed that the moment measured by the dynamometer is equivalent to the resultant joint moment (Adamantios et al.,2004). Some of those methods, as the manual force test, are subjective and not precise because it depends on the magnitude of the manual force the evaluator can exert on the patient. Other methods require a big instrumentation or are relatively expensive because of the technology of the machine, such as the Isokinetic Dynamometer.

The aim of the present work is to create a simple, portable and economic device for the measure of forces and moments of knee joint during extension, and to provide to physicians a fast and objective tool for the evaluation of their patients before and after a surgery or rehabilitative programs.

## 2 MATERIALS

A mechanical device that is attached to the base of the bed where the patients are lying supine (See Fig. 1).This device includes a force cell connected with a string to the leg of the patient in order to calculate the tension force made by the leg of the patient during the knee extension.

An electrogoniometer made by a precision linear potentiometer in order to measure the flexion angle of the knee. A conventional video camera synchronized with the electrogoniometer and the force cell in order to acquire the different positions of the knee during the extension. A Software (*MB Ruler*) for bidimensional analysis of images (distance and angles) in order to calculate the angle of the force cell with respect to the ground and the angle of the string with respect to the leg of the patient during the knee extension. A Software environment in *MATLAB* to acquire and synchronize the data of the angles of the electrogoniometer and the forces of the cell.



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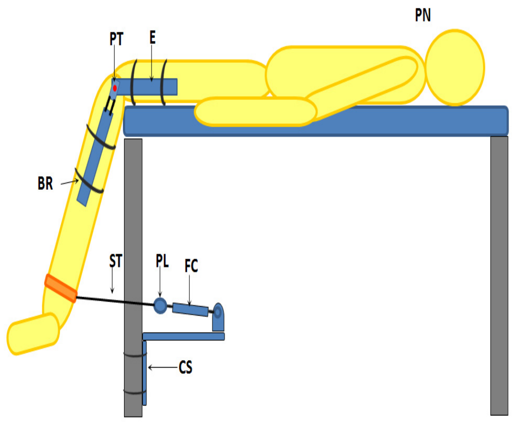


Figure 1: Instrumentation of the patient.

*PN:* Patient
*PT:* Precision Linear Potenciometer
*E* : Elettrogoniometer
*ST:* String
*PL*: Pulley
*CS:* Cell Support and system for attach to bed
*BR:* Braces for fix the electrogoniometer and the Cell Support
*FC:* Force cell

# 3 METHODS

The mechanical device is attached to the bed and supports the force cell that is connected by a string to the ankle of the patient. 26 normal patients participated in the experiment. (9 boys age $10^{+/-}2.24$ years and 17 girls age $10.12^{+/-}$ 1.87years). The patient is in supine position with both legs outside the bed and flexed to 90° (See fig. 1). Considering that there is a decline of $48^{+/-}11\%$ in the mean dynamic flexion torque by fatigue (Beltman et al., 2003) and that some differences are caused by the time-of-day of the exam (Onambele-Pearson et al.,2007) we recorded only the maximum moment on the first trial for each angle and made the exam to each patient at morning. The patient is instrumented with the electrogoniometer aligned with the axis of rotation of the knee joint, which is defined as the midpoint of the segment connecting the lateral and medial condyles. The knee is flexed initially at 90° and the patient is ordered to extend his knee and as a consequence pulling the string, the force is then recorded by the cell. In a next step the length of the string is manually increased by an operator which controls the pulley and consequently the angle of knee flexion is changed while the force measurement continues until it arrives to the maximum extension of the knee which is at 0°. The conventional video system, synchronized with the electrogoniometer and the force cell is made in order to acquire the different positions of the knee during the extension and be analyzed by the software for bidimensional images in order to calculate the angle of the force cell relative to the ground and the angle of the string with respect to the leg of the patient during the knee extension.

Anthropometric measurements of the patients allowed us to calculate mass properties of the leg and to compensate for gravitational force. A *MATLAB* algorithm takes all the data (electrogoniometer, force cell, inertia properties, anthropometrical data, force cell-ground angles and string-leg angles) to calculate the perpendicular force to the leg during each measure and consequently the resultant knee torque with planar analysis. (See Fig. 2).

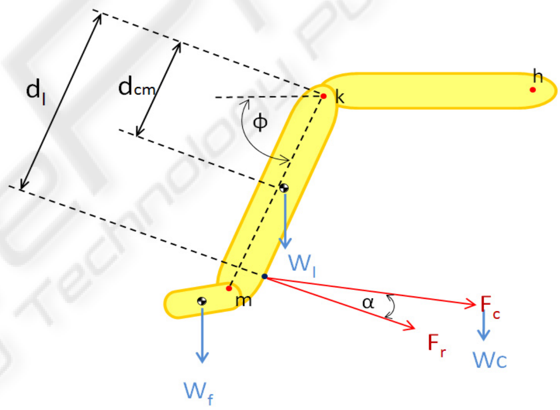


Figure 2: Free body diagram of the patient shank and force cell.

dl : Lever arm of force Fr to the knee joint
dcm: Lever arm of Wl to the knee joint
φ: Angle of knee flexion
α: Angle of resultant force Fr
m: Malleolus joint
k : Knee joint
h: Hip joint
$W_f$: Weight of foot
$W_l$: Weight of Leg
$W_c$: Weight of force cell
$F_c$: Force in extension and measured by the cell
$F_r$: Reaction Force of the cell, perpendicular to *mk* segment.

The reaction force Fr was to be assumed perpendicular to the patient shank *mk*.

# 4 RESULTS

## 4.1 Construction of the Device

A simple method to evaluate force and moments of knee joint during isometric extension has been developed. It provides to the physicians a fast and objective tool for the evaluation of their patients before and after an orthopaedic surgery or rehabilitative program.

## 4.2 Extensor Torque in Normal Patients

The obtained information is useful to understand the isometric extensor torque on normal and pathological patients. Normalized moment [N*m/kg] vs. angle [deg] of the normal patients of this study are reported in figure 3. Graphs are separated in male (thin line) and female (thick line) subjects.

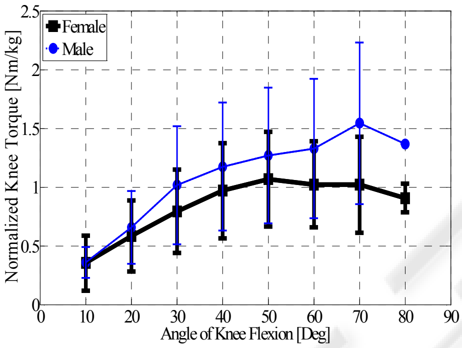


Figure 3: Normalized Moment torque vs. flexion angle.

The results demonstrated significant differences between gender according to Pincivero et al. (2004). The highest torque was generated at 70° for men and 50° for women. Both curves have a continuous growing behavior until his maximum value to decrease until maximum knee flexion as reported in literature (Beltman et al., 2003; Pincivero et al., 2004; Welsch et al., 1998; West et al., 2005).

# 5 DISCUSSION

## 5.1 Construction of the Device

Future development of this device is to make it usable in clinical applications. To make the process faster and more precise, it's specifically necessary to eliminate the measures made by the video system and instead install potentiometers to measure the shank-string angle and force cell-ground angle.

## 5.2 Extensor Torque in Normal Patients

If we make a comparison with literature, even if significant differences of technical instrumentation, age and activity of the patients are present, the results have the same behavior but are different in magnitude: We made the experiment with a self constructed device on 9 occasionally active boys age 10 $^{+/-}$2.24 years and 17 occasionally active girls age 10.12 $^{+/-}$1.87 years, while Pincivero et al. (2004) experimented with a Biodex Isokinetic Dynamometer on 14 men age 25$^{+/-}$4years and 14 women 23$^{+/-}$4 years all physically active, as they reported performing various types of routine exercises. Beltman et al. (2003) doesn't report the data normalized, (only the torque in Nm) but the behaviour of the curve is similar and he used an Isokinetic dynamometer (Lido Active, Loredon Biomedical, Davis) on 7 recreationally active male subjects age 27$^{+/-}$8 years. Welsh et al. (1998) experimented with 39 active men age 29.7 $^{+/-}$12.6 years and 38 active women age 27.2 $^{+/-}$ 11.3 years with an isometric knee flexion extension strength testing device; so we can conclude that differences in age, activity and instrumentation explains the higher values of torque of those experiments with respect to our study.

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