A preliminary study on quality of knee strength measurements by means of Hand Held Dynamometer and Optoelectronic System

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Introduction

Measurements of maximum voluntary contraction force are popular in the medical practice. A simple method to measure muscle strength is the Hand Held Dynamometer (HHD) that consists in a small dynamometer manually operated by a trained clinician. The dynamometer is applied on defined landmarks while the patient exerts his/her maximum force against it [1]. The use of HHD is common nowadays because it is fast, inexpensive and easy to use. From a literature review, it emerged that the main issue of HHDs is their poor reliability due to low operator strength and experience, that may lead to low repeatability and measurement inaccuracies [2].

Assuming that operator's deficiencies are the inaccurate positioning of the dynamometer and failure in keeping the limb still, the authors implemented a novel methodology to quantify the positioning inaccuracies in measurements of knee strength, by means of an Optoelectronic System, that was proved to be accurate enough and reliable for use in the clinical practice [3].

Figure 2: Dynamometer with the four markers.

Materials and methods

Measures were conducted in the Motion Analysis and Robotics Laboratory at 'Bambino Gesù' Children's Hospital, Rome, IT. Kinematic was recorded by an Optoelectronic System (Vicon MX, Oxford Metrics, UK, 8 IR cameras, s.f.=200 Hz, overall inaccuracy ~1 mm). Force was measured by a MicroFet™ HHD (Hoggan Scientific, Salt Lake City, US, max load 1.3 kN, accuracy 1% FSO). The subject and the HHD were equipped with the set of markers shown in Figures 1 and 2.

Ten healthy adult subjects were enrolled in this study: 6 males, 4 females, mean age 27.3±1.4 years, mean height 169.2±11.2 cm, mean body mass 65.4±11.2 kg. Knee flexion and extension strength was measured by trained clinician who held the HHD proximal to the ankle of the subjects. The participants were instructed to avoid explosive contraction but to increase force gradually to the maximum.

Measured quantities were: Maximum strength force (F_{nom}), maximum knee moment (M_{nom}) knee range of motion (RoM), HHD positioning angles (A1: sagittal plane, A2: transverse plane), angle variation (RoM-A1, RoM-A2), 3D components of maximum moment (M_x, M_y, M_z). The main component of knee moment is on the z-axis and, ideally, lateral component should be ~0 Nm.

Quality analysis was conducted on the moment components, as they take into account overall effects due to the positioning and orientation of HHD. To quantify the difference between the nominal moment and the M_z , RMSE was computed. RMSEs for lateral components M_x, M_y were also computed and merged as quadratic mean. Coefficient of variation (CV) was also computed to quantify repeatability within the same subject.

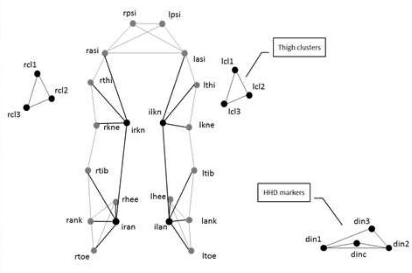

Figure 1: Full marker protocol used for this study; grey lines and dots: PIG protocol, black dots: markers added to the PIG protocol.

Results and Discussion

The overall uncertainties were estimated as 13 N for the nominal force and 4 Nm for the nominal moment. Tables 1 and 2 show results for knee extension and flexion respectively. The mean value and SD between subjects are reported for each parameter.

In our analysis, the measured angular RoM was never close to 0° (that is the ideal value) but we observed a value of 32±12° (Table 1); hence, the operator was not able to hold the limb still because he was not able to exert a correct opposing force to the subject. The RoM had more variability in knee extension than knee flexion. This was related to the lower force exerted in flexion trial.

The average CV% of F_{nom} and M_{nom} was < 10% for both knee extension and knee flexion trials (Tables 1 and 2), meaning high repeatability of measurements. Positioning angles A1 and A2 were close to 90° with a low CV % (<10%) , meaning a good positioning of the HHD. Worst results were obtained for the knee flexion trials.

RMSEz characterized the error between the M_{nom} and the M_z (moment on the flex/ext axis), while RMSExy represented the magnitude of lateral moment. The knee extension had a RMSEz <5% indicating a low inaccuracy, while RMSEz for flexion was >10%. Moreover, RMSExy was higher for knee flexion than knee extension. Absolute RMSEs on the main axis were comparable with the respective uncertainty level. RMSEs of lateral components were slightly higher but lower than the moment on the main axis. These findings were connected to the angular displacement observed in A1 and A2 values and confirmed that angular misplacement induced an inaccuracy in the estimation of flex/extension moment.

	Mean (SD)	CV% (SD)
Knee RoM [°]	32 (12)	20.9 (12.1)
A1 [°]	93 (7)	3.4 (2.0)
RoM-A1 [°]	14 (6)	27.3 (8.6)
A2 [°]	90 (8)	5.7 (2.1)
RoM-A2 [°]	21 (7)	27.1 (9.5)
F_nom [N]	240 (29)	7.6 (2.9)
M_nom [Nm]	83 (13)	7.6 (3.0)
RMSEz [%]	4.8 (1.7)	
RMSExy [%]	15.3 (7.6)	
RMSEz [Nm]	4 (2)	
RMSExy [Nm]	12 (5)	

Table 1: Knee Extension.

	Mean (SD)	CV% (SD)
Knee RoM [°]	27 (5)	16.7 (7.2)
A1 [°]	87 (8)	9.1 (11.4)
RoM-A1 [°]	20 (14)	36.3 (14.9)
A2 [°]	101 (8)	4.1 (1.9)
RoM-A2 [°]	16 (6)	34.1 (17.1)
F_nom [N]	-138 (22)	6.9 (1.5)
M_nom [Nm]	-46 (6)	6.8 (1.6)
RMSEz [%]	11.6 (5.7)	
RMSExy [%]	20.4 (11.5)	
RMSEz [Nm]	5 (3)	
RMSExy [Nm]	9 (6)	

Table 2: Knee Flexion.

Figure 3: Trial acquisition.

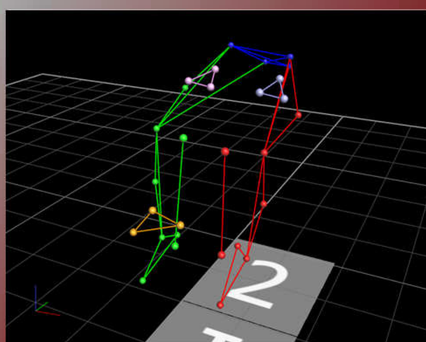

Figure 4: Trial reconstruction.

Conclusion

This work confirmed that HHD positioning and stability is crucial, therefore training of the operator is extremely important. Moreover, the operator should be strong enough to exert enough force to avoid motion of the limb.

Based on the RMSEs values observed, strength assessment of knee extension and flexion could be considered reliable. Our results showed that the inaccuracy was higher in the case of knee flexion. Moreover, the RMSEs values on the lateral components indicated the presence of knee solicitation in the undesired directions.

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Presented at:
MeMeA 2015
Turin, IT, 6 – 9 May 2015