



**HAL**  
open science

## Does hip joint positioning affect maximal voluntary contraction in the gluteus maximus, gluteus medius, tensor fasciae latae and sartorius muscles?

J. Bernard, J. Beldame, S. van Driessche, H. Brunel, T. Poirier, P. Guiffault, J. Matsoukis, F. Billuart

### ► To cite this version:

J. Bernard, J. Beldame, S. van Driessche, H. Brunel, T. Poirier, et al.. Does hip joint positioning affect maximal voluntary contraction in the gluteus maximus, gluteus medius, tensor fasciae latae and sartorius muscles?. *Orthopaedics & Traumatology: Surgery & Research*, 2017, 103 (7), pp.999-1004. 10.1016/j.otsr.2017.07.009 . hal-04383413

**HAL Id: hal-04383413**

**<https://hal.science/hal-04383413>**

Submitted on 12 Jan 2024

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Available online at  
**ScienceDirect**  
[www.sciencedirect.com](http://www.sciencedirect.com)

Elsevier Masson France  
**EM|consulte**  
[www.em-consulte.com/en](http://www.em-consulte.com/en)



Original article

## Does hip joint positioning affect maximal voluntary contraction in the gluteus maximus, gluteus medius, tensor fasciae latae and sartorius muscles?



J. Bernard<sup>a</sup>, J. Beldame<sup>b</sup>, S. Van Driessche<sup>c</sup>, H. Brunel<sup>a</sup>, T. Poirier<sup>a</sup>, P. Guiffault<sup>d</sup>,  
 J. Matsoukis<sup>d</sup>, F. Billuart<sup>a,\*</sup>

<sup>a</sup> Laboratoire d'analyse du mouvement, Institut de formation en masso-kinésithérapie « Saint-Michel », 68, rue du Commerce, 75015 Paris, France

<sup>b</sup> Clinique Mégival, 1328, avenue de la Maison-Blanche, 76550 Saint-Aubin-sur-Scie, France

<sup>c</sup> Clinique de Montargis, 46, rue de la Quintaine, 45200 Montargis, France

<sup>d</sup> Département de chirurgie orthopédique, groupe hospitalier du Havre, BP 24, 76083 Le Havre cedex, France

### ARTICLE INFO

#### Article history:

Received 22 April 2017

Accepted 10 July 2017

#### Keywords:

Muscle testing

Hip

Minimally invasive hip approaches

Electromyography

### ABSTRACT

**Background:** Minimally invasive total hip arthroplasty (THA) is presumed to provide functional and clinical benefits, whereas in fact the literature reveals that gait and posturographic parameters following THA do not recover values found in the general population. There is a significant disturbance of postural sway in THA patients, regardless of the surgical approach, although with some differences between approaches compared to controls: the anterior and anterolateral minimally invasive approaches seem to be more disruptive of postural parameters than the posterior approach. Electromyographic (EMG) study of the hip muscles involved in surgery [gluteus maximus (GMax), gluteus medius (GMed), tensor fasciae latae (TFL), and sartorius (S)] could shed light, the relevant literature involves discordant methodologies. We developed a methodology to assess EMG activity during maximal voluntary contraction (MVC) of the GMax, GMed, TFL and sartorius muscles as a reference for normalization. A prospective study aimed to assess whether hip joint positioning and the learning curve on an MVC test affect the EMG signal during a maximal voluntary contraction.

**Hypothesis:** Hip positioning and the learning curve on an MVC test affect EMG signal during MVC of GMax, GMed, TFL and S.

**Methods:** Thirty young asymptomatic subjects participated in the study. Each performed 8 hip muscle MVCs in various joint positions recorded with surface EMG sensors. Each MVC was performed 3 times in 1 week, with the same schedule every day, controlling for activity levels in the preceding 24 h. EMG activity during MVC was expressed as a ratio of EMG activity during unipedal stance. Non-parametric tests were applied.

**Results:** Statistical analysis showed no difference according to hip position for abductors or flexors in assessing EMG signal during MVC over the 3 sessions. Hip abductors showed no difference between abduction in lateral decubitus with hip straight versus hip flexed: GMax ( $19.8 \pm 13.7$  vs.  $14.5 \pm 7.8$ ,  $P=0.78$ ), GMed ( $13.4 \pm 9.0$  vs.  $9.9 \pm 6.6$ ,  $P=0.21$ ) and TFL ( $69.5 \pm 61.7$  vs.  $65.9 \pm 51.3$ ,  $P=0.50$ ). Flexors showed no difference between hip flexion/abduction/lateral rotation performed in supine or sitting position: TFL ( $70.6 \pm 45.9$  vs.  $61.6 \pm 45.8$ ,  $P=0.22$ ) and S ( $101.1 \pm 67.9$  vs.  $72.6 \pm 44.6$ ,  $P=0.21$ ). The most effective tests to assess EMG signal during MVC were for the hip abductors: hip abduction performed in lateral decubitus (36.7% for GMax, 76.7% for GMed), and for hip flexors: hip flexion/abduction/lateral rotation performed in supine decubitus (50% for TFL, 76.7% for S).

**Discussion:** The study hypothesis was not confirmed, since hip joint positioning and the learning curve on an MVC test did not affect EMG signal during MVC of GMax, GMed, TFL and S muscles. Therefore, a single session and one specific test is enough to assess MVC in hip abductors (abduction in lateral decubitus) and flexors (hip flexion/abduction/lateral rotation in supine position). This method could be applied to assess muscle function after THA, and particularly to compare different approaches.

**Level of evidence:** III, case-matched study.

© 2017 Elsevier Masson SAS. All rights reserved.

\* Corresponding author.

E-mail address: [fbilluart@gmail.com](mailto:fbilluart@gmail.com) (F. Billuart).

## 1. Introduction

Total hip arthroplasty (THA) is the second most commonly performed surgical procedure, with an estimated number of more than one million operations each year worldwide [1]. The anterior minimally invasive approaches for THA are presumed to provide functional and clinical benefit, but remain the subject of debate [2–4]. However, Van Driessche et al. [5] showed there is a significant disturbance in postural sway following THA, regardless of the surgical approach, although with some differences between approaches compared to controls: the anterior and anterolateral minimally invasive approaches seemed to be more disruptive of postural parameters than the posterior approach. These results imply that a lesion of the sartorius and tensor fasciae latae muscles during the surgical approach could have a significant impact on posture. Thus, it seems important to study the activity of the muscles crossing the hip joint. Electromyographic study of the hip muscles involved in the surgery [gluteus maximus (GMax), gluteus medius (GMed), tensor fasciae latae (TFL) and sartorius (S)] could shed light on hip joint performance after THA during bipedal and unipedal stance, but there is no consensus on the method for studying hip muscles.

The literature on EMG muscle assessment reports various methodologies [6–17]. Raw EMG data depend on several factors, such as skin impedance and sensor location over the muscle belly. Normalizing the EMG signal allows inter- and intra-group comparison [12]. Nevertheless, sensor location is very often not specified [18], and the raw data normalization reference varies greatly from one study to another; these issues hinder comparison [7,11,13]. The most common references for the study of hip muscles are based on normalization with either submaximal voluntary muscle contraction [13], muscle activity during quiet bipedal stance [7], or maximal voluntary contraction [8,17].

Burden et al. [9] and Lin et al. [14] compared different methods of EMG signal normalization, showing that only isometric and isokinetic contractions are reliable for MVC testing, without any difference in mean signal amplitude between the two. In terms of cost and time, manual isometric MVC testing appears to be reliable and highly valuable for both asymptomatic subjects and patients with hip osteoarthritis or THA [9,11,14].

In this context, as most authors do not specify which test they used for MVC testing [8,10,11,17], we investigated the impact of hip joint positioning and the test learning curve effect on GMax, GMed, TFL and S muscle MVC. The study aimed to answer the following question: do hip joint positioning and the MVC test learning curve affect the EMG signal during GMax, GMed, TFL and S MVC? The hypothesis was that hip positioning and the MVC test learning curve do affect the EMG signal.

## 2. Methods

### 2.1. Participants

Sixteen male and 14 female subjects, aged 18–30 years, volunteered to participate (mean age:  $21.2 \pm 2.4$  years; height:  $1.71 \pm 0.1$  m; weight:  $62.9 \pm 9.5$  kg; BMI:  $21.4 \pm 2$ ). All were free of neurological, vestibular, musculoskeletal, cardiovascular, respiratory, cognitive and psychiatric disease or impairment.

### 2.2. Maximal voluntary contraction testing

For each muscle, MVCs were obtained on manual testing [19] and the most common tests used in EMG studies [12]. Participants were asked to perform 8 MVC tests (2 for each muscle), with manual resistance distal to the femur (Fig. 1):

- gluteus maximustest 1 (TGMax1): hip extension in prone position (Fig. 1A);
- gluteus maximustest 2 (TGMax2): hip extension in lateral decubitus (Fig. 1B);
- gluteus mediustest 1 (TGMed1): hip abduction in lateral decubitus (with hip straight) (Fig. 1C);
- gluteus mediustest 2 (TGMed2): hip abduction in bipedal stance (Fig. 1D);
- TFL test 1 (TTFL1): hip abduction in lateral decubitus (with hip flexed) (Fig. 1E);
- TFL test 2 (TTFL2): hip flexion in lateral decubitus (Fig. 1F);
- sartorius test 1 (TS1): hip flexion/abduction/lateral rotation in supine position (Fig. 1G);
- sartoriustest2 (TS2): hip flexion/abduction/lateral rotation in sitting position (Fig. 1H).

Each MVC was performed 3 times in 1 week, with the same schedule every day, controlling for activity levels in the preceding 24 h.

### 2.3. Data processing

Four bipolar surface electrodes (SX-230, Biometrics Ltd, UK), placed according to SENIAM project (Surface Electromyography for the Non-Invasive Assessment of Muscles) recommendations [18] over the GMax, GMed, TFL and S muscle bellies were used to record the EMG signal. Signals were band-pass filtered (cut-offs: 20 Hz–450 Hz) and digitally sampled at 1000 Hz. The signal was offset by the resting EMG signal, smoothed with a sliding window at 50 Hz and rectified.

The EMG signal at rest was calculated from a dedicated record, using the minimum signal at 1 s after 50 Hz sliding window smoothing. The maximum mean signal over a 0.3-second interval was used as MVC, expressed as a ratio of the EMG activity observed during unipedal stance.

For EMG in unipedal stance, data processing was the same (offset, 50 Hz sliding windowing, rectification), but activity was expressed as the mean rectified signal for a 10 second trial.

$$\text{Value} = \frac{0.3 \text{ s max of the offset and rectified MVC test}}{10 \text{ s mean of offset and rectified unipedal test}}$$

### 2.4. Statistical analysis

Non-parametric statistics were used for comparisons. Mann–Whitney *U*-tests were used for comparisons between dominant and non-dominant legs and for pairwise comparisons between tests. Comparisons between the 3 sessions used a Kruskal–Wallis *H*-test. The significant threshold was set at  $\alpha = 0.05$ . All statistical analyses were carried out with R software, version 2.14 (Bell Laboratories, Murray Hill, NJ, USA).

## 3. Results

### 3.1. Dominant versus non-dominant leg

Table 1 shows the maximum values of MVC EMG activity, expressed as a ratio of the EMG activity observed during unipedal stance, in the 8 tests at the 3rd session. There were no significant differences ( $P > 0.05$ ) between dominant and non-dominant leg for MVC.

### 3.2. Differences between tests

Fig. 2 shows the percentage maximum value for each muscle according to MVC test for the dominant leg. TGMed1 was the most

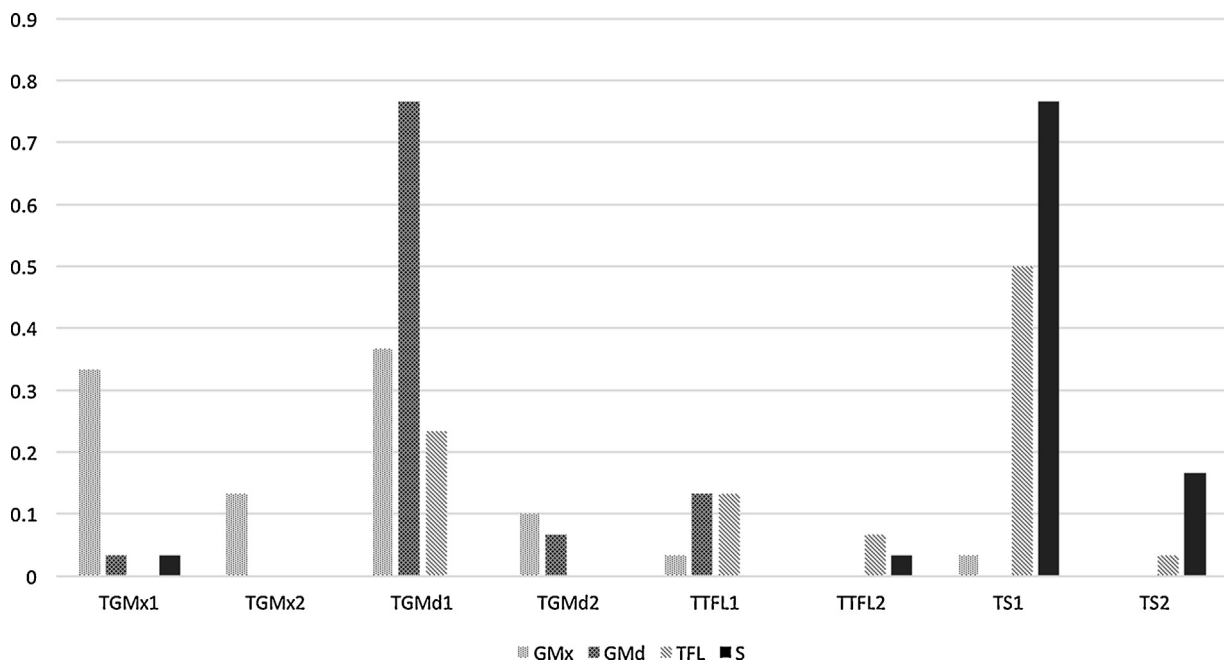


**Fig. 1.** Maximal voluntary contraction tests. A. TGMax1: hip extension in prone position. B. TGMax2: hip extension in lateral decubitus. C. TGMed1: hip abduction in lateral decubitus (with hip straight). D. TGMed2: hip abduction in bipedal stance. E. TTFL1: hip abduction in lateral decubitus (with hip flexed). F. TTFL2: hip flexion in lateral decubitus. G. TS1: hip flexion/abduction/lateral rotation in supine position. H. TS2: hip flexion/abduction/lateral rotation in sitting position.

**Table 1**  
Maximum EMG activity in the 8 tests (3rd MVC session).

	Mean ± SD (range) (DL)	Mean ± SD (range) (NDL)	P-value
GMax	24.9 ± 18.1 (2.6–82.5)	33.2 ± 27.9 (7.4–112.5)	0.42
GMed	13.8 ± 9.4 (2.3–34.9)	13.6 ± 10.1 (3.3–47.9)	0.87
TFL	86.3 ± 61.7 (20.4–335.5)	90.9 ± 59.3 (11.9–243.6)	0.79
S	107.4 ± 66.7 (19.7–225.0)	92.6 ± 72.2 (5.1–379.4)	0.29

GMax: Gluteus Maximus; GMed: Gluteus Medius; TFL: Tensor Fasciae Latae; S: Sartorius; DL: dominant leg; NDL: non-dominant leg; SD: standard deviation.



**Fig. 2.** Percentage of maximum EMG activity according to maximal voluntary contraction tests. GMax: Gluteus Maximus; GMed: Gluteus Medius; TFL: Tensor Fasciae Latae; S: Sartorius; TGMax1: hip extension in prone decubitus; TGMax2: hip extension in lateral position; TGMed1: hip abduction in lateral decubitus (with hip straight); TGMed2: hip abduction in bipedal stance; TTFL1: hip abduction in lateral decubitus (with hip flexed); TTFL2: hip flexion in lateral decubitus; TS1: hip flexion/abduction/lateral rotation in supine position; TS2: hip flexion/abduction/lateral rotation in sitting position.

efficient test to determine MVC in hip abductors (GMax and GMed) and TS1 the most efficient to determine MVC in hip flexors (TFL and S).

Table 2 describes the EMG activity (mean ± SD [range]) for the dominant leg in the 3rd session, and the statistical differences for each muscle between each of the 8 MVC tests and the most efficient test (TGMed1 for GMax and GMed, TS1 for TFL and S). There were no significant differences between tests in abduction for determining hip abductor MVC, or in flexion for determining hip flexor MVC, regardless of hip positioning.

### 3.3. MVC progression between the 3 sessions

Fig. 3 shows the boxplot for the progression of MVC for each muscle over the 3 MVC sessions for the dominant leg. There were no significant differences according to session over the 1-week period ( $P > 0.05$ ).

## 4. Discussion

Few studies investigated the EMG activity of the hip muscles involved in THA [20–23], and did not explore the same muscles or the same questions. Because a reference for raw EMG data normalization is needed to enable inter- and intra-group comparison [9,11,12], and as most authors do not specify which test they used for MVC testing [8,10–12,17], we first wanted to develop a reliable methodology for assessing EMG activity in the GMax, GMed, TFL and S muscles of young asymptomatic subjects. This prospective

study was the first step toward EMG analysis of the hip muscles involved in THA surgery: GMax in the posterior approach, GMed and TFL in the anterolateral approach, and TFL and S in the anterior approach. Eight MVC tests, based on the most common tests used in EMG studies [12], were performed in 3 successive sessions. Hip positioning and training on MVC tests were expected to be determining factors improving the EMG signal of MVC.

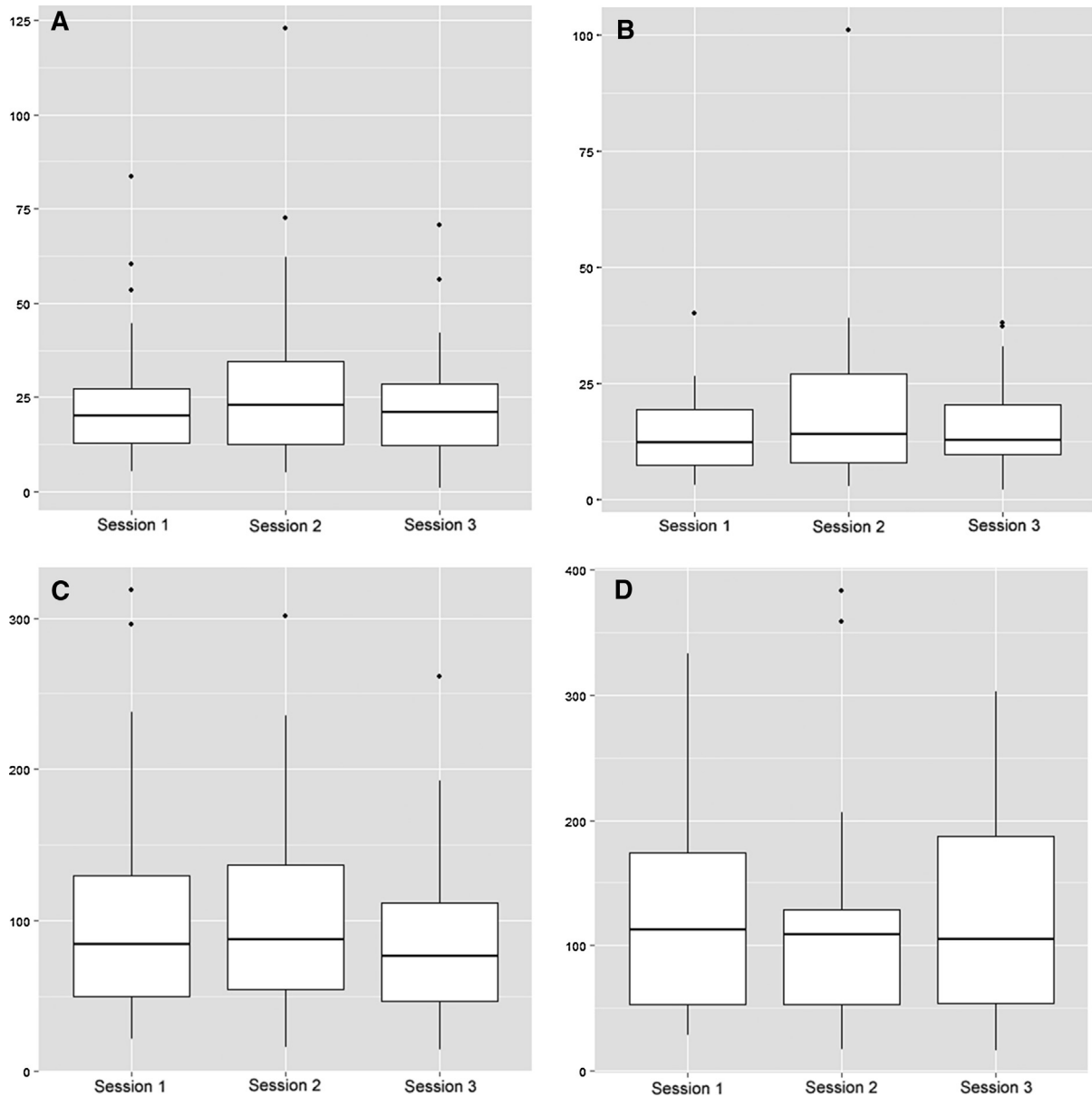
The present study had certain limitations. The reference used for normalization: the purpose of this study was to determine the best way to assess MVC in the GMax, GMed, TFL and S muscles on EMG, in order to use these results as a standard for EMG signal normalization in future studies. EMG activity during unipedal stance was used as reference. Because our population was homogenous in age, height and weight, this selected reference can be assumed to be reliable. However, as previously shown by Burden et al. [9] and Lin et al. [14], this reference tends to show less statistical difference than MVC, which could explain why our results were not concordant with those of Worrel et al. [23], who reported an influence of hip positioning on EMG signal during MVC. The tests conducted, however, were different. There was no test of interobserver reproducibility. Our opinion is that MVC testing must be performed by a trained experimenter, as variability can be considerable. However, there were no significant differences between the 3 trials, so that intraobserver reproducibility can be assumed to have been good. This study involved only young participants, from 18 to 30 years old. This age range is different from that of the THA population, and reproducibility can be expected to be poorer with older patients, as sarcopenia will affect the results. For this reason, we would

**Table 2**  
EMG activity of each muscle on the 8 tests: mean ± SD (range) (3rd session of MVC).

	GMax	GMed	TFL	S
TGMax1	19.9 ± 17.1 (2.7–82.5)	7.3 ± 7.2 (1.2–31.2)*	7.1 ± 8.6 (1.3–48.3)*	15.8 ± 28.6 (1.7–164.2)*
TGMax2	14.6 ± 10.8 (1.4–46.2)	6.5 ± 5.7 (0.8–22.1)*	7.5 ± 5.6 (1.2–27.9)*	15.4 ± 28.3 (2.0–160.6)*
TGMed1	<b>19.8 ± 13.7 (0.9–61.1)</b>	<b>13.4 ± 9.0 (1.8–34.9)</b>	69.5 ± 61.7 (13.3–335.5)	50.1 ± 32.7 (5.4–142.7)*
TGMed2	12.8 ± 14.3 (1.6–73.3)*	9.6 ± 8.8 (1.9–33.1)*	41.6 ± 39.4 (7.7–179.6)*	21.9 ± 17.0 (3.5–58.8)*
TTFL1	14.5 ± 7.8 (1.6–38.3)	9.9 ± 6.6 (1.6–28.6)	65.9 ± 51.3 (11.9–263.9)	43.0 ± 27.1 (4.7–107.7)*
TTFL2	2.7 ± 3.3 (0.3–16.4)*	5.4 ± 4.2 (1.0–20.5)*	61.2 ± 47.8 (15.3–270.8)	43.0 ± 24.7 (5.6–95.6)*
TS1	3.9 ± 6.7 (0.3–31.2)*	2.9 ± 2.9 (0.3–12.9)*	<b>70.6 ± 45.9 (13.0–226.3)</b>	<b>101.1 ± 67.9 (15.1–225.0)</b>
TS2	1.5 ± 1.7 (0.2–7.2)*	2.2 ± 2.5 (0.3–11.9)*	61.6 ± 45.8 (10.8–262.8)	72.6 ± 44.6 (6.5–156.0)

GMax: Gluteus Maximus; GMed: Gluteus Medius; TFL: Tensor Fasciae Latae; S: Sartorius; TGMax1: hip extension in prone position; TGMax2: hip extension in lateral decubitus; TGMed1: hip abduction in lateral decubitus (with hip straight); TGMed2: hip abduction in bipedal stance; TTFL1: hip abduction in lateral decubitus (with hip flexed); TTFL2: hip flexion in lateral decubitus; TS1: hip flexion/abduction/lateral rotation in supine position; TS2: hip flexion/abduction/lateral rotation in sitting position; SD: standard deviation. The most effective tests to assess EMG signal during MVC were for the hip abductors: hip abduction performed in lateral decubitus (36.7% for GMax, 76.7% for GMed), and for hip flexors: hip flexion/abduction/lateral rotation performed in supine decubitus (50% for TFL, 76.7% for S).

\* Significant difference ( $P < 0.05$ ). Significant difference with the most effective test of MVC (in bold font).



**Fig. 3.** Progression of EMG activity during maximal voluntary contraction over the 3 sessions. A. Gluteus Maximus (TGMed1: hip abduction performed from lateral decubitus [with hip straight]). B. Gluteus Medius (TGMed1). C. Tensor Fasciae Latae (TS1: hip flexion/abduction/lateral rotation in supine decubitus). D. Sartorius (TS1).

recommend reducing the present protocol and performing only 2 MVC trials in future studies.

We were not able to confirm our study hypothesis: do hip joint positioning and the MVC test learning curve affect EMG signal during GMax, GMed, TFL and S muscle MVC? Thus, it cannot be affirmed that hip joint positioning and the MVC test learning curve affect the EMG signal. The present results showed no significant difference between MVC tests in obtaining maximum EMG activity for hip flexors or hip abductors. This means that MVC tests are reliable, regardless of hip positioning.

There were also no statistical differences between the 3 sessions over the 1-week interval for each MVC test: i.e., there was no learning effect induced by training over the 3 sessions. This result also shows that the tests are reliable for assessing the maximum EMG activity in the GMax, GMed, TFL and S muscles. We would therefore suggest using only 2 MVC tests, in a single session, to assess MVC in the 4 muscles studied here in young asymptomatic subjects:

- TGMed1 (hip abduction in lateral decubitus) for hip abductors (GMax and GMed);
- TS1 (hip flexion/abduction/lateral rotation in supine decubitus) for the hip flexors tested here (TFL and S).

These tests are those described by Daniels and Worthingham [18] for muscle testing, respectively for GMed (TGMed1) and S (TS1). It can also be concluded from these findings that, although EMG sensor placement and the normalization reference (MVC) is important for EMG data analysis [9,11,14,18], how MVC testing is executed may not be a determining factor. This enables results from different studies to be compared, as long as they used the sensor placement described in the SENIAM recommendations [18].

## 5. Conclusion

We obtained a negative answer to the study question: do hip joint positioning and the MVC test learning curve affect the EMG signal during GMax, GMed, TFL and S muscle MVC? However, the study showed that only 1 test, in a single session, is needed to assess MVC in hip abductors (GMax, GMed) and hip flexors (TFL and S). This is an interesting result regarding cost and time. Hip positioning does not appear to be a determining factor for MVC assessment. This was a preliminary study that will allow GMax, GMed, TFL and S muscle activity to be analyzed for postural assessment in various conditions, with quick, simple, reliable and economic MVC normalization of the EMG signal, in young asymptomatic subjects. Also, new data will complete this study in the future, with patients who underwent THA on a minimally invasive anterior, anterolateral or posterior approach. This would enable hip muscle EMG signal to be studied for THA patients with different surgical approaches.

## Funding

Fabien Billuart perceives grants from Free Motion, outside of this study.

## Disclosure of interest

The authors declare that they have no competing interest.

## Acknowledgment

This study was supported by IFMK Saint-Michel, Paris, France. The authors wish to thank all the participants in the study.

## References

- [1] Quagliarella L, Sasanelli N, Monaco V, Belgiovine G, Spinarelli A, Notarnicola A, et al. Relevance of orthostatic posturography for clinical evaluation of hip and knee joint arthroplasty patients. *Gait Posture* 2011;34:49–54.
- [2] Malagelada F, Del Carmen VA, Barke SJ, Guirao Cano L, Pleguezuelos Cobo E. The anterior mini-open approach for femoroacetabular impingement: gait and functional assessment at one year post-surgery. *Ann Phys Rehabil Med* 2015;58:60–5.
- [3] Mirza AJ, Lombardi Jr AV, Morris MJ, Berend KR. A mini-anterior approach to the hip for total joint replacement: optimising results: improving hip joint replacement outcomes. *Bone Joint J* 2014;96(11 Suppl. A):32–5.
- [4] Poehling-Monaghan KL, Kamath AF, Taunton MJ, Pagnano MW. Direct anterior versus minimally-invasive THA with the same advanced perioperative protocols: surprising early clinical results. *Clin Orthop Relat Res* 2015;473:623–31.
- [5] Van Driessche S, Billuart F, Martinez L, Brunel H, Guiffault P, Beldame J, et al. Short-term comparison of postural effects of three minimally invasive hip approaches in primary total hip arthroplasty: direct anterior, posterolateral and Röttinger. *Orthop Traumatol Surg Res* 2016;102:729–34.
- [6] Agostini V, Ganio D, Facchin K, Cane L, Moreira Carneiro S, Knaflitz M. Gait parameters and muscle activation patterns at 3, 6 and 12 months after total hip arthroplasty. *J Arthroplasty* 2014;29:1265–72.
- [7] Amiridis IG, Hatzitaki V, Arabatzi F. Age-induced modifications of static postural control in humans. *Neurosci Lett* 2003;350:137–40.
- [8] Billot M, Simoneau EM, Van Hoecke J, Martin A. Age-related relative increases in electromyography activity and torque according to the maximal capacity during upright standing. *Eur J Appl Physiol* 2010;109:669–80.
- [9] Burden A, Bartlett R. Normalisation of EMG amplitude: an evaluation and comparison of old and new methods. *Med Eng Phys* 1999;21:247–57.
- [10] Claudino R, dos Santos EC, Santos MJ. Compensatory but not anticipatory adjustments are altered in older adults during lateral postural perturbations. *Clin Neurophysiol* 2013;124:1628–37.
- [11] French HP, Huang X, Cummiskey A, Meldrum D, Malone A. Normalisation method can affect gluteus medius electromyography results during weight bearing exercises in people with hip osteoarthritis (OA): a case control study. *Gait Posture* 2015;41:470–5.
- [12] Halaki M, Ginn K. Normalization of EMG Signals: To normalize or not to normalize and what to normalize to? INTECH; 2012 <https://www.intechopen.com/books/computational-intelligence>. Last access 1/6/2017.
- [13] Horstmann T, Listringhaus R, Haase G-B, Grau S, Mündermann A. Changes in gait patterns and muscle activity following total hip arthroplasty: a six-month follow-up. *Clin Biomech* 2013;28(7):762–9.
- [14] Lin HT, Hsu AT, Chang JH, Chien CS, Chang GL. Comparison of EMG activity between maximal manual muscle testing and cybex maximal isometric testing of the quadriceps femoris. *J Formos Med Assoc* 2008;107:175–80.
- [15] Mohamed O, Perry J, Hislop H. Relationship between wire EMG activity, muscle length, and torque of the hamstrings. *Clin Biomech* 2002;17:569–79.
- [16] Santos MJ, Kanekar N, Aruin AS. The role of anticipatory postural adjustments in compensatory control of posture: 1. Electromyographic analysis. *J Electromyogr Kinesiol* 2010;20:388–97.
- [17] Tsai YC, Hsieh LF, Yang S. Age-related changes in posture response under a continuous and unexpected perturbation. *J Biomech* 2014;47:482–90.
- [18] Hermens HJ, Freriks B, Disselhorst-Klug C, Rau G. Development of recommendations for SEMG sensors and sensor placement procedures. *J Electromyogr Kinesiol* 2000;10:361–74.
- [19] Hislop HJ, Montgomery J. Daniels and Worthingham's Muscle Testing: Techniques of Manual Examination. 8th ed. St Louis, MO: Saunders/Elsevier; 2007.
- [20] Lawrenson P, Grimaldi A, Crossley K, Hodges P, Vicenzino B, Semciw AI, et al. Technical application of fine-wire electromyography, and direction specific action during maximum voluntary isometric contractions. *Gait Posture* 2017;54:300–3.
- [21] Semciw AI, Green RA, Murley GS, Pizzari T. Gluteus minimus: an intramuscular EMG investigation of anterior and posterior segments during gait. *Gait Posture* 2014;39:822–6.
- [22] Semciw AI, Neate R, Pizzari T. A comparison of surface and fine wire EMG recordings of gluteus medius during selected maximum isometric voluntary contractions of the hip. *J Electromyogr Kinesiol* 2014;24:835–40.
- [23] Worrell TW, Karst G, Adamczyk D, Moore R, Stanley C, Steimel B, et al. Influence of joint position on electromyographic and torque generation during maximal voluntary isometric contractions of the hamstrings and gluteus maximus muscles. *J Orthop Sports Phys Ther* 2001;31:730–40.