Influence of voluntary contractions on the basal sEMG activity of the pelvic floor muscles

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Abstract

Chronic pelvic pain (CPP) is a complex clinical condition that affects many women, being sometimes misdiagnosed or mistreated, which can be treated with the infiltration of botulinum toxin (BoNTA). The pelvic floor musculature (PFM) condition from CPP patients can be assessed by means of surface electromyography (sEMG). The evaluation of the basal activity can help to detect a muscular dysfunction, therefore it is important to ensure that the PFM shows a minimum activation when its sEMG is being analysed. In this study, we recorded the sEMG of 25 women with CPP before and 8, 12 and 24 weeks after their treatment with BoNTA while they performed a protocol of 5 voluntary contractions. The root mean square (RMS) and sample entropy (SampEn) of basal segments pre- (B[PRE]), inter- (B[I]) and post- (B[POST]) contractions of the sEMG were computed and normalized according to the minimum (RMS_{norm}) and maximum ($SampE_{norm}$) of the recording. B(PRE) showed the lowest RMS_{norm} median both before and after the treatment with BoNTA, which proved that the activity of the PFM is minimum before the first contraction. As for $SampEn_{norm}$, although results were not so conclusive, they also indicated that B(PRE) should be taken as a reference to analyse the PFM function at its state of minimum activity. Future works aiming to characterize the effects of BoNTA in PFM by means of sEMG should consider basal segments before contractions to assess basal tone conditions.

1. Introduction

Chronic pelvic pain (CPP) is a complex clinical condition with a prevalence between 5.7% and 26.6%, higher for fertile women [1]. It is defined as a recurrent or intermittent pain that lasts more than 6 months and is usually associated to a sexual dysfunction [2]. Due to its complexity, CPP is often misdiagnosed or mistreated, the reason why it is important to manage it from a multidisciplinary scope.

CPP can be treated with surgical or non-surgical methods. In the last case, a possible therapy relies on the infiltration of botulinum neurotoxin type A (BoNTA) in the pelvic floor musculature (PFM). Once injected, the toxin binds to the nerve terminals of a presynaptic motoneuron, blocking the release of acetylcholine and thus synaptic processes. Hence, muscle fibres innervated by that neuron become unable to develop action potentials and, therefore, to contract themselves. Although this is its most well-known mechanism, BoNTA also inhibits the release of substances related to pain and inflammation [3].

CPP is usually associated to a muscular dysfunction, therefore surface electromyography (sEMG) can yield important information about PFM condition [4]. In particular, the dysfunction may be caused by a hypotonicity or a hypertonicity of the PFM at rest [5], so the analysis of the signal acquired while the muscle is relaxed (basal tone) is of great importance, although tests usually include voluntary contractions in the protocol [6]. Many women, even healthy ones, have a poor ability to voluntary contract and relax their PFM when they are asked to [7] and nerves due to the clinical setting and the test can lead to a muscle tension higher than in a normal physiological scenario. Therefore, it is important to ensure that the sEMG signal is analysed while their musculature is minimally activated. On the other hand, vaginal and anal probes are typically used to perform sEMG recordings, since they can detect the activity of the deepest PFM However, intracavitary probes are uncomfortable for patients and not robust to movement artifacts [4]. Our team is aiming to assess the feasibility of monitoring PFM condition and the effect of CPP treatment with BoNTA using adhesive electrodes. These electrodes can be more sensitive to crosstalk of surrounding muscle and hence muscular relaxation can be of greater importance. In this preliminary study, the aim was to determine in which segment/period, of a protocol with voluntary contractions, the PFM shows a state of maximum relaxation (before, between or after contractions).

2. Materials and methods

2.1. Signal acquisition

Twenty-five women with CPP who showed a sexual dysfunction were recruited at Hospital Politècnic i Universitari La Fe (Valencia). They were treated with 80 U.I. of BoNTA (Xeomin, Merz Pharma España S.L.) diluted in 2 mL of lidocaine at 1%, which was infiltrated at a single point in the puborectalis or pubococcygeus. Patients' sEMG was recorded before the infiltration and 8, 12 and 24 weeks later. The skin was gently exfoliated with an abrasive gel (Nuprep, Weaver and Company, USA) and

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four monopolar signals were registered using six disposable Ag/AgCl electrodes (3M Red Dot 2660-5); four on labia majora (M1, M2, M3, M4) and two on both iliac spines (reference [REF] and ground [GND] electrodes), as shown in *Figure 1*. Signals were band-pass filtered between [3, 1000] Hz with a multipurpose amplifier (15 LT, Grass Technologies, USA) and digitalized at a sampling rate of 10 kHz. Patients were asked to perform 5 maximum voluntary contractions of 5s and resting periods of 10s between them during the recordings.

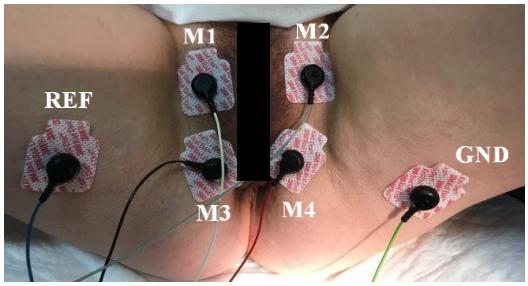

Figure 1. *Electrodes arrangement for the sEMG acquisition.*

2.2. Signal processing

A band-pass (bandwidth = [30, 450] Hz) and a comb filter (50 Hz) were applied to remove the noise and the power interference in the sEMG, respectively. Then, four bipolar signals were obtained: one for each vertical region (right: B1= M1-M3; left: B2 = M2-M4) and horizontal area (upper: B3 = M1-M2; lower: B4 =M3-M4) of the PFM. After that, we manually annotated different basal segments in signals: 1 pre-contractions (B[PRE]), 5 inter-contractions (B[I]) and 1 post-contractions (B[POST]).

When we computed the power spectrum density (PSD) of annotated signal segments, we observed anomalous tonal components in many of them, probably due to electromagnetic interferences at the recording room. We designed an algorithm that detected such tonal interferences and removed them by notch filtering (*Figure 2*).

Two parameters were computed to characterize the basal segments:

- ***Root mean square* (*RMS*):** it measures the power of the signal. Given a discrete time series of N samples, $x[n]$, it is computed as follows:

$$RMS\ (x[n]) = \sqrt{\frac{1}{N} \cdot \sum_{k=1}^{N} x[k]^2} \quad (1)$$

- ***Sample entropy* (*SampEn*):** it quantifies the complexity of the signal. It is calculated as the negative of the natural logarithm of the conditional probability that two series of N samples that are similar at m points keep being similar at the next point, given a tolerance r and without considering self-matchings [8]. To compute *SampEn*, signals were normalized to have zero mean and unit variance and $m = 2$ and $r = 0.15$ were chosen.

In the case of B(I), the value of the 5 segments of the recording was averaged to obtain only one per parameter.

Finally, a statistical analysis was performed to determine if the characteristics of a basal segment significantly vary depending on its relative position to contractions in the signal and in which one the PFM shows a minimal activity. To this end, for each patient, week and bipolar sEMG channel, parameters calculated for B(PRE), B(POST) and B(I) were first normalized. On the one hand, the energy of the sEMG is expected to be minimal with maximal muscle relaxation [9] . The *RMS* computed for B(PRE), B(POST) and B(I) in the same recording was thus divided by the minimum among them, creating the dataset RMS_{norm}. On the other hand, common synaptic input is delivered to multiple motor units of the muscle when it needs to generate force, therefore their action potentials are correlated in time [9]. In other words, the contraction of the PFM involves an increase of the motor units' synchronization, which is the reason why the value of *SampEn* of the three basal segments was divided by the maximum among them, obtaining the dataset $SampEn_{norm}$. After that, parameters from the 4 bipolar channels were grouped together and Kruskal-Wallis test ($\alpha = 0.05$) was performed with the alternative hypothesis that the median of RMS_{norm} (or $SampEn_{norm}$) of a basal segment at a given week depends on its relative position to contractions in the sEMG. An additional multiple comparison test based on the Tukey's honestly significant difference procedure was performed to find medians that are significantly different from each other.

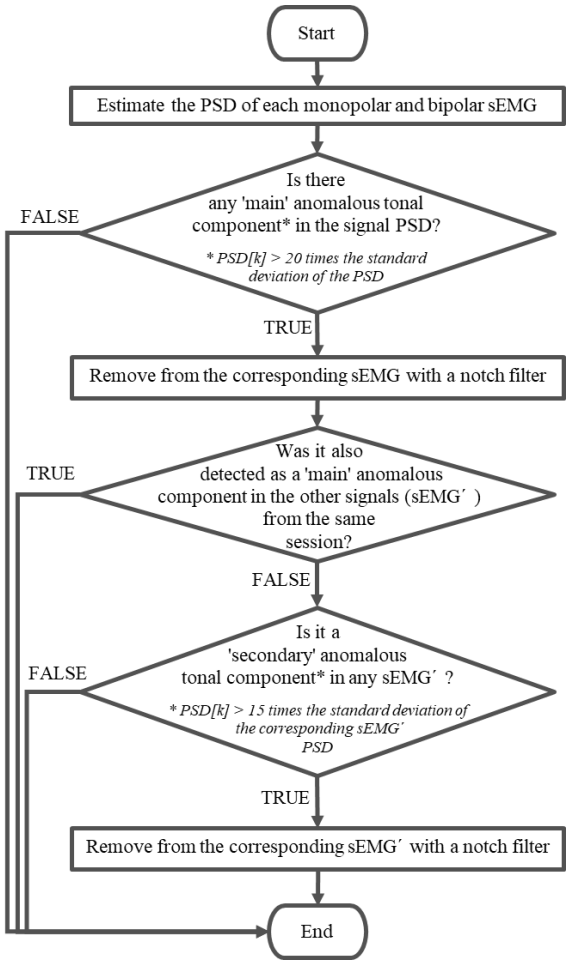

Figure 2. *Flow chart of the algorithm to remove anomalous tonal components from the sEMG.*

3. Results

Figure 3 depicts a patient's bipolar sEMGs, where different basal and contractile segments have been highlighted.

Figures 4-5 display the Box-Whisker plot of RMS_{norm} and $SampEn_{norm}$ datasets for each week of the monitoring, with B(PRE), B(POST) and B(I) as grouping variables. In *Table 1* their medians and 25 and 75 percentiles are shown.

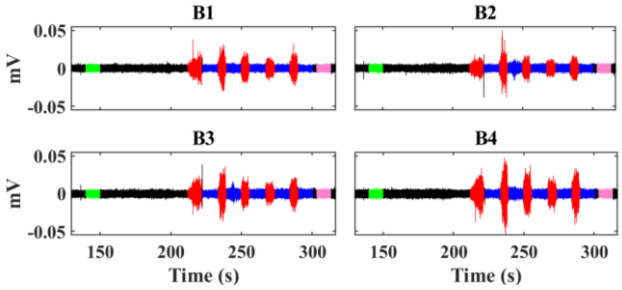

Figure 3. *sEMG of the right (B1), left (B2), upper (B3) and lower (B4) region of the PFM. Segments: contractions (red) and basal segments before (green), between (blue) and after them (pink).*

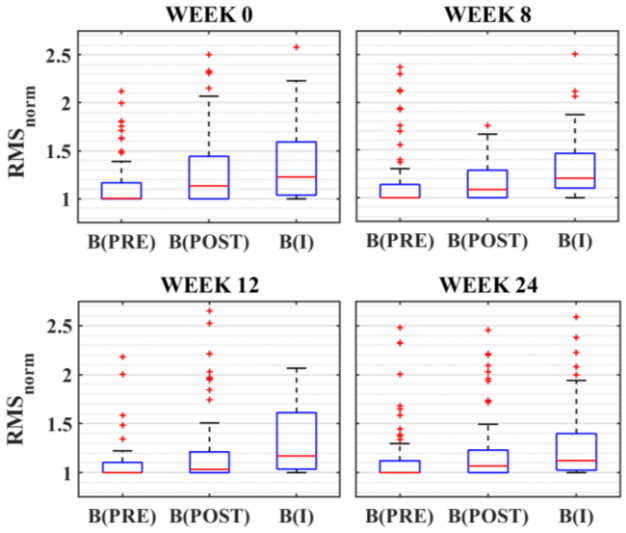

Figure 4. *Box-Whisker plot of RMS_{norm} in B(PRE), B(POST), B(I) for each week of the recording.*

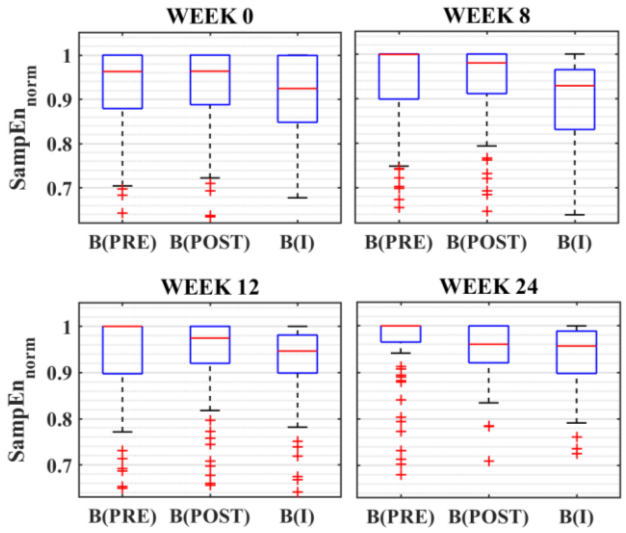

Figure 5. *Box-Whisker plot of $SampEn_{norm}$ in B(PRE), B(POST), B(I) for each week of the recording.*

Due to the presence of some pronounced outliers, it is difficult to visually determine from *Figures 4-5* the box of which basal segment is below or above the others at a given week. However, it can be appreciated in *Table 1* that the median and 75 percentile of RMS_{norm} are lower in B(PRE) than in B(POST) and B(I), both before (W0) and after (W8, W12, W24) the treatment with BoNTA. As for $SampEn_{norm}$, its median and percentiles are very similar between B(PRE) and B(POST) in the different recording weeks, while their values seem to be lower in the case of B(I).

Table 1. *Median (25-75 percentiles) of RMS_{norm} and $SampEn_{norm}$ for each basal segment and week (W).*

	W	B(PRE)	B(POST)	B(I)
RMS_{norm}	0	1.00 (1.00-1.17)	1.13 (1.00-1.44)	1.23 (1.04-1.59)
	8	1.00 (1.00-1.14)	1.09 (1.00-1.29)	1.21 (1.10-1.46)
	12	1.00 (1.00-1.10)	1.03 (1.00-1.21)	1.17 (1.04-1.61)
	24	1.00 (1.00-1.12)	1.07 (1.00-1.23)	1.12 (1.02-1.40)
$SampEn_{norm}$	0	0.96 (0.88-1.00)	0.96 (0.89-1.00)	0.92 (0.82-1.00)
	8	1.00 (0.90-1.00)	0.98 (0.91-1.00)	0.93 (0.83-0.97)
	12	1.00 (0.90-1.00)	0.97 (0.92-1.00)	0.95 (0.90-0.98)
	24	1.00 (0.97-1.00)	0.96 (0.92-1.00)	0.96 (0.90-0.99)

P-values from Kruskal-Wallis tests were lower than 0.05, except for $SampEn_{norm}$ at week 0, so it cannot be assumed that data from B(PRE), B(POST) and B(I) belong to the same distribution. Results provided by multiple pairwise comparison tests are displayed in *Table 2*. As for RMS_{norm}, there is a significant difference between the median of B(PRE) and the other groups before and after the treatment. In contrast, there are no statistical differences between any pair of basal segments at week 0 when $SampEn_{norm}$ is studied, while they appeared weeks later in B(PRE) vs. B(I) and to a lesser extent in B(PRE) vs. B(POST) and B(POST) vs. B(I).

Table 2. *P-value of pairwise comparison test at week W for RMS_{norm} and $SampEn_{norm}$. P-values<0.05 are shown in grey.*

	Segments compared	W0	W8	W12	W24
RMS_{norm}	B(PRE) vs. B(POST)	0.01	0.01	0.04	0.02
	B(PRE) vs. B(I)	<0.01	<0.01	<0.01	<0.01
	B(POST) vs. B(I)	0.14	<0.01	<0.01	0.13
$SampEn_{nor}$	B(PRE) vs. B(POST)	0.98	0.79	0.32	<0.01
	B(PRE) vs. B(I)	0.25	<0.01	<0.01	<0.01
	B(POST) vs. B(I)	0.18	<0.01	0.08	0.41

4. Discussion

It has been observed that the sEMG segment chosen to monitor the basal tone of the PFM may significantly influence the results obtained. We found that *RMS* value is significantly lower in basal segments prior to contractions than in between or after them, regardless the week of the recording (before and after the infiltration of BoNTA). This means that, if the energy of the sEMG is the criterion of evaluation, it can be concluded that the PFM is more relaxed at the beginning of the recording. Therefore, B(PRE) should be the interval selected to monitor the basal tone of the muscle in CPP before and after the treatment. In contrast, when the criterion used is the complexity of the sEMG, the selection is not so clear. The number of significant differences between groups is not so widespread on weeks, especially on week 0. However, the median of $SampEn_{norm}$ in B(PRE) is greater than in B(I) throughout the entire post-treatment period and than B(POST) at week 24. Therefore, we can consider that the basal segment of the sEMG before the contractions is also suitable to analyse the activity of the PFM at its maximum rest according to signal complexity criterion. The reason why the activity of the PFM seems to be higher in sEMG intervals between and after contractions could be that women cannot relax completely their musculature and they may need more time to return to a state of maximum rest after a voluntary activation.

On the other hand, we obtained a great number of outliers when we plotted Box-Whisker diagrams. Considering that the *RMS* and *SampEn* of each basal segment was normalized according to other segment of its same recording, the presence of so many anomalous data manifests the lack of control that some women have over their PFM. They were unable to maintain a maximum state of relaxation throughout the entire acquisition when they were not performing a contraction.

Results of this work do not agree with those by Naess & Bø [10]. They observed that women's intravaginal pressure at rest significantly diminished after the performance of three maximum voluntary contractions in both case and control groups. In the present study, the higher *RMS* values of sEMG obtained after the contractions would be expected to lead to a higher intravaginal pressure, which was not measured though. However, their study was performed on nulliparous women who were 24.3 ± 4.7 years old, had vestibulodynia and were monitored with anal probes. In contrast, women recruited in this work were 43.1 ± 9.3 years old, only one of them was nulliparous and signals were acquired with external adhesive electrodes, so results cannot be directly extrapolated.

Some sEMG segments were discarded due to the presence of intermittent artifacts, so further efforts should be made to improve the quality of recordings. In future work, changes in sEMG signals after BoNTA infiltration will be studied to assess their value to monitor CPP treatment.

5. Conclusions

The characteristics of the PFM sEMG at rest, both before and after the treatment of CPP with BoNTA, vary significantly depending on whether the patient has previously performed a contraction or not. In particular, the signal power is lower and its complexity is usually higher before the voluntary activation of the muscle, which proves that the PFM shows a minimum activity in that period of the sEMG recordings. Therefore, patients' basal tone should be evaluated before carrying out any contraction of the PFM at each clinical follow-up session.

Acknowledgments

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