MECHANICAL PARAMETERS OF SPRINT IN FEMALE SOCCER PLAYERS AT DIFFERENT SKILL LEVELS

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Abstract:

\textbf{Aim:} The purpose of the present study was to evaluate the relationships between sprint mechanical parameters and sprint performance among female soccer players at different skill levels.

\textbf{Materials and methods:} Sixty-six female soccer players (age = 23.1 ± 5.1 years) performed a 30-m sprint to assess sprint performance and mechanical variables. Speed was measured by radar technology for 5, 10, 20, and 30 m and was used to calculate the theoretical maximal velocity (V\textsubscript{0}), theoretical maximal horizontal force (F\textsubscript{0}), maximal horizontal power (P\textsubscript{max}), decrease in the ratio of horizontal to resultant force (DRF), and peak ratio of horizontal to resultant force (RF\textsubscript{peak}).

\textbf{Results:} Different force-velocity (F-V) profile parameters are determinants of sprint performance at various distances. RF\textsubscript{peak} (r = -0.99), P\textsubscript{max} (r = -0.93), and F\textsubscript{0} (r = 0.92) had the strongest associations with sprint performance at shorter (5-m) distances, while at longer (20-m) distances, V\textsubscript{0} (r = -0.73), P\textsubscript{max} (r = -0.94), and RF\textsubscript{peak} (r = -0.88) were largely associated with sprint performance.

\textbf{Conclusion:} The results of this study show that as the skill level in female soccer players increases, an increase in maximal theoretical horizontal force during sprinting can be observed.

Introduction

Sprinting is one of the most important activities in soccer [1]. It is a crucial motor skill for effective defensive and offensive actions in the game [2]. It means that in modern soccer, both male and female, and regardless of playing position, sprinting is an important part of a player’s physical performance [1,3,4]. Previous studies have shown that in female soccer, the average sprint distance covered during the game ranged from 140 m to 777 m depending on velocity [5] and was 168 ± 82 m at velocities of more than 25 km/h [4]. Furthermore, the analysis of match performance in female soccer showed that most sprints were short (up to 10 m) [4]. Haugen et al. [6] indicated that short sprints occur frequently in soccer games and the straight sprint is the most frequently occurring action before scoring a goal.

Improving sprint performance should be one of the most important objectives in soccer training. The knowledge about which parameters determine sprint performance could be used to develop more targeted training interventions. Consequently, interventions aimed at improving sprint performance (acceleration and maximal sprint speed) and valid
and reliable methods are needed [7]. For this purpose, a new approach based on a force-velocity (F-V) relationship could be used [8]. Maximal sprint running may be illustrated by an inverted linear F-V relationship. This relationship describes the mechanical properties of the body and can be based on several variables that can be calculated from velocity data measured by radar or laser devices [9]. The F-V profile (e.g., maximal theoretical force (F0), maximal theoretical velocity (V0), F-V slope, and maximal power (Pmax)) can be used to implement individualized training programs [10–13]. In female soccer players, sprint performance (time to run 20-m) was determined by V0 and Pmax [14]. However, previous studies have not analyzed correlations between F-V parameters and sprint performance at short sprint distances (e.g., time to run 5-m or 10-m). Only Buchheit et al. [15] showed strong correlations of F0, V0, and Pmax with acceleration and maximal sprinting speed. Morin and Samozino [8] showed that F0 determines sprint performance at short distances and V0 and the decrease in the ratio of horizontal to resultant force (DRF) at longer distances. We hypothesized that in female soccer players, mechanical parameters of sprint related to force would determine sprint performance at short sprints (5-m or 10-m) and those parameters related to the velocity component would determine sprint performance at longer (20-m) sprint distances. The confirmation of such hypotheses can provide a theoretical basis for effective training interventions in female soccer players, particularly because previous studies have shown that short-distance sprints occur most frequently during female soccer games [4]. The main purpose of this study was to evaluate the relationship between sprint mechanical parameters and sprint performance among female soccer players.

The main limitation of previous studies in this field was a small number of analyzed competitive divisions among female soccer players: two senior divisions in the study by Jiménez-Reyes et al. (16) and Haugen et al. (2) and one senior division in the study by Baumgart et al. (17). Only Devismes et al. (7) conducted a similar study with more than two divisions (four levels of competition leagues). Despite the small number of competitive leagues, the main finding of these studies was that players from the highest divisions had greater levels of the following parameters: V0 and Pmax [7]; V0, Pmax, DRF, and the peak ratio of horizontal to resultant force (RFpeak) [16]; and V0, Pmax, the slope of the F-V relationship (Sfv), DRF, and RFpeak [2]. However, unexpectedly, there were no differences between players from different divisions in terms of F0, a parameter that could be crucial from the perspective of developing sprint performance in female soccer [7] and various populations of athletes [8]. In this regard, it could be valuable for strength and conditioning coaches using the F-V method in practice to have reference data of sprint mechanical F-V parameters of female soccer players at various competitive levels. Only a few studies have provided data that may be useful as a reference [2,7,16,17]. Another aim of this study was to evaluate F0 in different skill classes in female soccer players and expand the current reference data about F-V profiles in female soccer players. We hypothesized that F0 (maximal theoretical horizontal force) is different in female players at different skill levels. This cross-sectional study was designed to determine the main sprint mechanical determinants of sprint among female soccer players. Moreover, the second aim was to compare the level of mechanical parameters of the sprint and the level of sprint performance between female soccer players competing at different levels.

**Methods**

**Participants**

The present study included 66 female soccer players (including goalkeepers) who were competing in a Polish soccer league at the time of the study. There were four playing levels: Top Division (n = 12; age: 25.15 ± 3.54 years; training experience: 10.12 ± 3.85 years), Division I (n = 26; age: 20.54 ± 2.4 years; training experience: 8.34 ± 2.03 years), Division II (n = 10; age: 22.5 ± 2.98 years; training experience: 8.10 ± 2.88 years), and Division III (n = 18; age: 26.16 ± 7.65 years; training experience: 9.13 ± 6.77 years). All players were free from any injury at the time of testing. Before measurements were taken, all participants were informed about the testing procedures, and they signed a written informed consent form prior to participating in the study.. All research procedures were carried out according to the Declaration of Helsinki.

**Somatic measurements**

Each participant's body height (BH), body weight (BW), and percentage of fat mass (FM) were measured at the beginning of the testing session. The anthropometric data was collected by an ALUMET (BH) anthropometer (with accuracy to the nearest 0.1 cm) and body composition analyzer (TANITA BF-350, Japan) (with accuracy to the nearest 0.1 kg and 0.1 %). The measurements of the anthropometric data were conducted according to the ISAK standards [18]. All players were measured before the physical performance testing. The height and weight measurements were taken with bare feet in a team dressing room. The somatic features data is presented in Table 1.
All participants performed a 15-min warm-up consisting of the following: (1) 5 min jogging, (2) lower limb activity exercises (3) lower limb mobility exercises, and (4) progressive sprints at 50%, 70%, and 90% effort. After 4 min of rest, participants performed two maximal sprints: a 30-m distance starting from a crouching position with 4 min of rest between each trial. The velocity-time data was collected by a STALKER ATS II radar gun at 46.9 Hz (Applied Concepts, Dallas, TX, USA). The device was attached to a tripod 10 m from the starting line at a height of 1 m, corresponding approximately to the height of participants’ centers of mass. The sprint tests were conducted on artificial grass. Split times at 5, 10, and 20 m were measured. Sprint test results were processed and averaged according to the suggestions of Simperingham et al. [9].

### Force-velocity relationship

The data file for each trial together with the body height and mass of each participant were imported to Lab-View (Version 13, National Instruments Corporation, TX, USA) software, which was used to calculate all outcome variables according to Samozino’s method [18]: maximal theoretical horizontal force (F0), maximal theoretical horizontal velocity (V0), maximal theoretical horizontal power (Pmax), the slope of the F-V relationship (Sfv), decrease in the ratio of horizontal to resultant force (DRF), peak ratio of horizontal to resultant force (RFpeak), and split times between 0 and 20 m (5-m, 10-m, and 20-m splits were used for further analysis). For reliability analysis, the coefficient of variation (CV) and intraclass coefficient correlation (ICC) were calculated using a custom-made spreadsheet available online [19]. The thresholds for interpreting ICC values were: 0.2 ÷ 0.49 (low), 0.5 ÷ 0.74 (moderate), 0.75 ÷ 0.89 (high), 0.90 ÷ 0.98 (very high), and > 0.99 (extremely high) [20]. A CV was considered small when its value was ≤ 10%. The average reliability of each measure was interpreted as acceptable for ICC ≥ 0.75 and a CV ≤ 10%, moderate for ICC < 0.75 and CV > 10%, and unacceptable for ICC < 0.75 and CV > 10% [9]. Reliability results are presented in Table 2.

### Statistical analyses

Descriptive data is presented as mean and standard deviations. For between-group comparisons, we used the one-way ANOVA with Welch adjustment (level of significance was set at *p* < 0.05). During the post-hoc analysis, the least significant difference (LSD) test was used. Additionally, the Cohen’s *d* effect size (ES) with 95% confidence interval was evaluated to compare sprint mechanical profiles (F0, V0, Sfv, DRF, RFpeak, Pmax) and sprint performance (time at 5
m, time at 10 m, time at 20 m) between skill levels. The criteria for interpreting ES values were as follows: trivial (< 0.2), small (0.2 ÷ 0.6), moderate (0.6 ÷ 1.2), and large (> 1.2) [19]. The relationship between mechanical parameters and sprint performance variables was evaluated using the Pearson correlation coefficient (level of significance was set at $p < 0.05$) with 95% confidence intervals. The thresholds for interpreting correlation values were trivial (< 0.1), small (0.1 ÷ 0.3), moderate (0.3 ÷ 0.5), large (0.5 ÷ 0.7), very large (0.7 ÷ 0.9), and almost perfect (0.9 ÷ 1.0) [19]. The main interpretation of statistical analyses was based upon confidence intervals, effect sizes, and practical significance [20].

**Results**

The time at 5 m variable was significantly correlated with $F_0$ ($r = -0.92$), $P_{max}$ ($r = -0.93$), and $RF_{peak}$ ($r = -0.99$). Time at 10 m was correlated mostly with $P_{max}$ ($r = -0.97$), $RF_{peak}$ ($r = -0.97$), and $F_0$ ($r = -0.85$). Finally, time at 20 m was correlated with $P_{max}$ ($r = -0.94$), $RF_{peak}$ ($r = -0.88$), and $V_0$ ($r = -0.73$). All of these correlations were significant at $p < 0.05$. Moreover, the correlation analysis showed a reducing contribution of $F_0$ and a strengthening contribution of $V_0$ as sprint distance increased. Only $P_{max}$ and $RF_{peak}$ had similar impacts on sprint performance throughout the distance. Also, the impacts of $P_{max}$ and $RF_{peak}$ on sprint performance were higher than of $V_0$ and $F_0$ parameters at each split time. Correlations between mechanical parameters showed that $V_0$ was trivially to moderately linked with $P_{max}$ and $RF_{peak}$, but $F_0$ associations with $P_{max}$ and $RF_{peak}$ were stronger. This indicates that sprint performance (up to a 20-m distance) in female soccer players could be determined more by force than velocity. The associations between sprint performance and mechanical variables are presented in Table 3.

**Table 3. Correlations (with 95% confidence intervals) across analyzed variables.**

<table>
<thead>
<tr>
<th></th>
<th>$V_0$ (m/s)</th>
<th>$F_0$ (N/kg)</th>
<th>$S_{fv}$</th>
<th>$P_{max}$ (W/kg)</th>
<th>DRF</th>
<th>$RF_{peak}$</th>
<th>Time to 20m (s)</th>
<th>Time to 10m (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$F_0$ (N/kg)</td>
<td>0.06 ± 0.24</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>$S_{fv}$</td>
<td>0.45 ± 0.2*</td>
<td>-0.86 ± 0.07*</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$P_{max}$ (W/kg)</td>
<td>0.52 ± 0.18*</td>
<td>0.88 ± 0.06*</td>
<td>-0.52 ± 0.18*</td>
<td>1</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>DRF</td>
<td>0.56 ± 0.17*</td>
<td>-0.77 ± 0.1*</td>
<td>0.97 ± 0.01*</td>
<td>-0.38 ± 0.21*</td>
<td>1</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>$RF_{peak}$</td>
<td>0.33 ± 0.22*</td>
<td>0.93 ± 0.03*</td>
<td>-0.66 ± 0.14*</td>
<td>0.95 ± 0.02*</td>
<td>0.97 ± 0.16*</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>time to 20m</td>
<td>-0.73 ± 0.12*</td>
<td>-0.7 ± 0.13*</td>
<td>0.25 ± 0.23*</td>
<td>-0.94 ± 0.03*</td>
<td>0.13 ± 0.24*</td>
<td>-0.88 ± 0.06*</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>time to 10m</td>
<td>-0.52 ± 0.18*</td>
<td>-0.85 ± 0.07*</td>
<td>0.49 ± 0.19*</td>
<td>-0.97 ± 0.02*</td>
<td>0.39 ± 0.21*</td>
<td>0.96 ± 0.01*</td>
<td>0.02 ± 0.02*</td>
<td></td>
</tr>
<tr>
<td>time to 5m</td>
<td>-0.3 ± 0.22*</td>
<td>-0.92 ± 0.04*</td>
<td>0.66 ± 0.14*</td>
<td>-0.93 ± 0.04*</td>
<td>0.59 ± 0.16*</td>
<td>0.98 ± 0.01*</td>
<td>0.07 ± 0.02*</td>
<td></td>
</tr>
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</table>

**Note.** * – significant differences at $p < 0.05$

Top Division players showed a moderately higher $F_0$ than Division I (ES 1.01, 95% CI: 0.26 to 1.76, $p < 0.05$) and Division III players (ES 0.95, 95% CI: 0.14 to 1.76, $p < 0.05$); moderately higher $P_{max}$ than Division I (ES 1.07, 95% CI: 0.31 to 1.82, $p < 0.05$) and Division III players (ES 1.13, 95% CI: 0.31 to 1.96, $p < 0.05$); moderately higher $RF_{peak}$ than Division I (ES 1.06, 95% CI: 0.31 to 1.81, $p < 0.05$) and Division III players (ES 1.01, 95% CI: ES: 0.20 to 1.82, $p < 0.05$). Furthermore, players from the Top Division performed moderately better for time at 10 m than Division I (ES -0.85, 95% CI: -0.25 to -1.74, $p < 0.05$) and Division III players (ES -0.84, 95% CI: -0.21 to -1.83, $p < 0.05$). The moderate differences between players from lower skill levels were observed between Division I and Division II players, only in terms of $F_0$ (ES -0.76, 95% CI: -0.02 to 1.54, $p < 0.05$) and $S_{fv}$ (ES 0.82, 95% CI: 0.04 to 1.60, $p < 0.05$). The main differences across the analyzed variables are shown in Figure 1. The descriptive outcomes (means ± standard deviations) of sprint performance and its mechanical parameters are presented in Table 3.
This study aimed to evaluate the mechanical determinants of sprint performance at short (5- and 10-m) and longer (20-m) distances in female soccer players and to explore sprint performance and mechanical parameters of sprinting among female soccer players according to their skill levels. Our results indicate a strong relationship of RFpeak, Pmax, and F0 with time at 5 m in the analyzed population of players. Sprint performance up to a 10-m distance was correlated with Pmax, RFpeak, and F0, whereas time at 20 m was correlated with Pmax, RFpeak, and V0. All these correlations met the significance level (p < 0.05). The results show that players from the Top Division had significantly (ES with 95% CI, p-value) greater F0, Pmax, RFpeak, and time at a 10-m distance in comparison to the first division. Comparisons between athletes at other skill levels revealed differences only between the first and second divisions in terms of F0 and Sfv.

The present study analyzed the magnitude of the correlations between sprint performance (times at 5, 10, and 20 m) and mechanical parameters in female soccer players. We hypothesized that, firstly, the mechanical parameters of force (F0, RFpeak) of the F-V profile have a stronger effect on sprint performance at shorter distances (up to 10 m), and, secondly, that the mechanical parameters of velocity (V0, Pmax) of the F-V profile determine times at 20 m. The results of the present study indicate RFpeak, Pmax, and F0 to be predictors of sprint performance up to a 10-m distance. The variable of time at 20 m was correlated with Pmax, RFpeak, and V0. In conclusion, it could be stated that in female soccer players, force parameters determined sprint performance at shorter distances, and parameters linked to velocity determined performance at longer distances. Our results are in agreement with the theoretical interpretation of the relationships between F-V profile parameters and sprinting presented by Morin and Samozino [8]. Furthermore, our results are consistent with those presented by Buchheit et al. [15], who showed F0 as a parameter correlated with sprinting at shorter distances and Pmax as a predictor of sprinting at longer distances in youth male soccer players. The data from the study by Haugen et al. [2] is also in agreement with our results. These authors found that Pmax, RFpeak, and F0 were most strongly correlated with time at a 10-m distance, whereas Pmax, RFpeak, and V0 were most correlated with time at a 40-m distance in soccer players of both sexes.

To date, only Marcote-Pequeño et al. [14] have investigated the correlations between sprint mechanical parameters and sprint performance when only female data was incorporated into correlation analyses. They noted that the Pmax variable had the strongest correlation, followed by V0, and F0, which showed the lowest correlation. The correlation values in the present study are similar to those observed by Marcote-Pequeño et al. [14]. In our study, the variable of time at a 20-m distance was correlated mostly with Pmax, followed by RFpeak, V0, and F0. However, the study by Marcote-Pequeño et al. did not show correlations between mechanical variables and time at a 5-m distance. For this reason, a comparison with our results was not available in this regard.

An important aspect is that this study showed that RFpeak and Pmax were parameters with a significant impact on performance for the entire analyzed distance, which is consistent with the studies by Haugen et al. [2,21]. Furthermore, both parameters were correlated with each other; thus, as Haugen et al. [2] stated, this is “a different explanation of the same story”. Therefore, using both parameters at the same time could be impractical in female soccer players. The results of the present study show that F0 had the strongest correlation with times at 5 m and 10 m and V0.
with time at 20 m, with the relationships of those parameters changing as the distance increased. After the removal of $RF_{peak}$ and $P_{max}$, only $F_0$ and $V_0$ were correlated with shorter and longer distances, respectively. A similar phenomenon was presented in Buchheit et al. [15], who showed that $F_0$ and $V_0$ determined the sprinting acceleration phase (up to 10 m), and $P_{max}$ and $V_0$ determined maximal sprinting speed (more than 20 m). After removing the $V_0$ parameter, performance at a short distance was strongly correlated with $F_0$, while performance at a longer distance was strongly correlated with $P_{max}$ [15]. Thus, the previous conclusion drawn in this study needs to be modified, and it could be recommended to use $RF_{peak}$ and $P_{max}$ interchangeably during testing and training routines. The reliability data suggest that the $RF_{peak}$ parameter could be more accurate than $P_{max}$ (because of better average reliability, especially lower level of CV values). Such procedures should also involve $F_0$ and $V_0$ data interpretation for optimizing individualized training protocols in female soccer. Nevertheless, it should be noted that in a study by Haugen et al. [2], both female and male soccer players were included in correlation analyses, which could influence the results. To the best of the authors’ knowledge, only Marcote-Pequeño et al. [14] have performed an analysis of female soccer players, which showed $P_{max}$ and $V_0$ as stronger predictors of sprint performance at a 20-m distance. Our results confirm these findings.

One of the main objectives of the present study was to examine the hypothesis that $F_0$ would differentiate between female soccer players of different skill levels. The novelty of this study is that our results clearly show that $F_0$ levels were greater in the Top Division than in first- and third-division players (with no differences between the Top and second divisions). This suggests that in Polish female soccer players, a higher skill level has a more force-oriented F-V profile. However, our results are also in contrast to previous studies [2,7,16], which showed no statistical differences in terms of $F_0$ between various skill levels. The differences between our results and those of the aforementioned studies may be due to different nationalities or environments (different training regimens). However, our hypothesis cannot be confirmed, and probably in this specific case, the observed differences could be a trend (because of lack of differences between Top and second-division players). Thus, such a hypothesis should be examined in future research on a larger population.

**Figure 1.** Standardized differences (with 95% confidence intervals) in $F_0$, $P_{max}$, $RF_{peak}$, and time to 10 m between athletes at different skill levels *. – significant differences at $p < 0.05$;
In some aspects, particularly in differences in $P_{\text{max}}$ and $R_{\text{Fpeak}}$ observed between different skill levels, the results of this study are consistent with previous investigations. In the case of $P_{\text{max}}$, all previous studies [2,7,16] have shown greater levels in players at higher skill levels. In terms of $R_{\text{Fpeak}}$, the results of our study are in agreement with those published by Jiménez-Reyes et al. [16] and Haugen et al. [2] but in contrast to Devismes et al. [7]. It is worth mentioning that in previous literature, greater levels of the V0 parameter in female soccer populations at higher skill levels have been reported by Devismes et al. [7], Haugen et al. [2], and Jiménez-Reyes et al. [16]. However, in our study, there were no differences between groups in terms of the V0 parameter. This suggests the similarity of velocity parameters in Polish soccer players, regardless of the competitive level.

When compared to players with other nationalities, the V0 parameter was quite similar (based on data from the Polish, Norwegian [2], Spanish [16], Belgian [7], and German [22] soccer players from Top Divisions). Consequently, those parameters may be crucial indicators in female soccer players (independently of nationality) and probably could be used in a wide population of female soccer players as sprint performance indicators. Thus, the descriptive statistics of $P_{\text{max}}$, $R_{\text{Fpeak}}$, and V0 from previous studies and the present study can be used as reference data by strength and conditioning coaches.

The Sfv and DRF values are partly different from those presented in previous studies. In our study, there were no differences between skill levels in the Sfv parameter (as in the study by Devismes et al.), but Haugen et al. [2] showed more velocity-oriented Sfv in players at higher skill levels. Furthermore, the DRF parameter was better in Top Division players than in their lower-level counterparts in studies by Haugen et al. [2] and Jimenez-Reyes et al. [16]. Our findings and those published by Devismes et al. [7] showed no differences in this regard. It seems that these parameters cannot be used as tools with predictive value in female soccer. Therefore, it is recommended that coaches and technical staff include sprint mechanical variables such as $P_{\text{max}}$, $R_{\text{Fpeak}}$, and V0 in training and testing routines in female soccer.

**Practical applications**

The results of this study suggest that depending on sprint distance used for testing and training procedures in female soccer players, the most informative parameters are $P_{\text{max}}$, $R_{\text{Fpeak}}$, F0, and V0. Furthermore, in practice, the $P_{\text{max}}$ and $R_{\text{Fpeak}}$ parameters could be used interchangeably. The $R_{\text{Fpeak}}$ and F0 levels could be useful for interpreting individualized data from sprint performance at short distances (5 to 10 m), whereas $R_{\text{Fpeak}}$ and V0 should be used when interpreting data from sprint performance at a longer distance (20 m). Female soccer training involving strength exercises with horizontal force vectors can be an effective way to develop better sprint performance at short distances in female soccer players.

**Conclusions**

The different F-V profile parameters are determinants of sprint performance in various distances. The determinants of sprint performance were $R_{\text{Fpeak}}$ ($r = -0.99$), $P_{\text{max}}$ ($r = -0.93$), and F0 ($r = -0.92$) in shorter (5-m) distances and V0 ($r = -0.73$), $P_{\text{max}}$ ($r = -0.94$), and $R_{\text{Fpeak}}$ ($r = -0.88$) in longer (20-m) distances. The results of this study show that with an increase in F0 can be observed with an increase of skill level in female soccer. The sprint mechanical parameters presented in this study can be used by strength and conditioning staff as normative values and as groundwork for developing focused interventions designed to optimize training stimulus for sprint performance enhancement.

**Conflicts of Interest:** The authors declare no conflict of interest.

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**Institutional Review Board Statement:** This study was approved by the local bioethics committee pursuant to Resolution 6/0177/2019

**Informed Consent Statement:** Informed consent was obtained from all subjects involved in the study.
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