Isolated Meniscus Allograft Transplantation with soft-tissue technique effectively reduces knee laxity in the presence of previous meniscectomy: in-vivo navigation of 18 consecutive cases.

Stefano Di Paolo, Gian Andrea Lucidi, Alberto Grassi, Luca Macchiarola, Luca Ambrosini, Piero Agostinone, Giacomo Dal Fabbro, Stefano Zaffagnini

PII: S2059-7754(23)00559-X
DOI: https://doi.org/10.1016/j.jisako.2023.09.004
Reference: JISAKO 161

To appear in: Journal of ISAKOS

Received Date: 3 July 2023
Revised Date: 5 September 2023
Accepted Date: 15 September 2023


This is a PDF file of an article that has undergone enhancements after acceptance, such as the addition of a cover page and metadata, and formatting for readability, but it is not yet the definitive version of record. This version will undergo additional copyediting, typesetting and review before it is published in its final form, but we are providing this version to give early visibility of the article. Please note that, during the production process, errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.

© 2023 The Author(s). Published by Elsevier Inc. on behalf of International Society of Arthroscopy, Knee Surgery and Orthopedic Sports Medicine.
Isolated Meniscus Allograft Transplantation with soft-tissue technique effectively reduces knee laxity in the presence of previous meniscectomy: in-vivo navigation of 18 consecutive cases.

Stefano Di Paolo a, Gian Andrea Lucidi b, Alberto Grassi c, Luca Macchiarola c, Luca Ambrosini c, Piero Agostinone c, Giacomo Dal Fabbro c, Stefano Zaffagnini c,d.

a Dipartimento di Scienze per la Qualità della Vita QuVi, Università di Bologna, Bologna, Italy.
b Dipartimento di Scienze Biomediche e Neuromotorie DIBINEM, Università di Bologna, Bologna, Italy.
c II Clinica Ortopedica e Traumatologica, IRCCS Istituto Ortopedico Rizzoli, Bologna, Italy.
d Corresponding author. Via G. C. Pupilli 1, Bologna, 40136, Italy. Tel.: +39-0516445034. E-mail address: stefano.zaffagnini@unibo.it (S. Zaffagnini)

The investigation was performed at II Clinica Ortopedica e Traumatologica, IRCCS Istituto Ortopedico Rizzoli, Bologna, Italy.
Isolated Meniscus Allograft Transplantation with soft-tissue technique effectively reduces knee laxity in the presence of previous meniscectomy: in-vivo navigation of 18 consecutive cases.

Abstract

Objectives: Although meniscal allograft transplantation (MAT) is a well-established procedure with satisfactory clinical results, limited in vivo kinematic information exists on the effect of medial and lateral MAT performed in the clinical setting. The purpose of the present study was to evaluate the biomechanical effect of arthroscopic isolated medial and lateral MAT with a soft-tissue fixation on pre- and post-operative knee laxity using a surgical navigation system.

Methods: 18 consecutive patients undergoing MAT (8 medial, 10 lateral) were enrolled. A surgical navigation system was used to quantify the anterior-posterior displacement at 30 and 90 degrees of knee flexion (AP30 and AP90), the varus-valgus rotation at 0 and 30 degrees of knee flexion (VV0 and VV30) and the dynamic laxity on the pivot-shift test (PS), which was determined through the anterior displacement of the lateral tibial compartment (APlat) and posterior acceleration of the lateral tibial compartment during tibial reduction (ACC). Data from laxity before and after MAT were compared through paired t-test (p<0.05).

Results: After medial MAT, there was a significant decrease in tibial translation of 3.1 mm (31%; p=0.001) for AP30 and 2.3 mm (27%; p=0.020) for AP90, a significant difference of 2.5° (50%; p=0.002) for VV0 and 1.7° (27%; p=0.012) for VV30. However, medial MAT did not determine any reduction in the PS kinematic data. Lateral MAT determined a significant decrease in the tibial translation of 2.5 mm (38%; p<0.001) for AP30 and 1.9mm (34%; p=0.004) for AP90 as well as a significant difference of 3.4° (59%; p<0.001) for VV0 and of 1.7° (23%; p=0.011) for VV30. There was also a significant reduction of the PS of 4.4 mm (22%; p=0.028) for APlat and 384.8 mm/s² (51%; p=0.005) for ACC.
Conclusion: MAT with soft-tissue fixation results in a significant laxity reduction in an in-vivo setting. Medial MAT improved knee kinematics by determining a significant reduction with particular emphasis to AP translation and VV maneuver. Conversely, Lateral MAT determined a massive reduction of the PS and a mild decrease of the AP translation and VV maneuver.

Study design: Controlled laboratory study.

Keywords: meniscus, meniscectomy, meniscus allograft transplantation, surgical navigation system, knee kinematics.

What are the new findings?

- In patients with previous isolated total or subtotal monocompartmental meniscectomy, soft-tissue MAT technique determines a significant laxity reduction in an in-vivo setting from the pre- to the postoperative assessment.
- The medial MAT showed a significative reduction in knee AP translation and VV maneuver, but did not have any effect on rotational instability.
- The lateral MAT reduced the global knee laxity with particular emphasis on the rotatory knee parameters.

Introduction

The primary function of the menisci is to provide shock absorption and load transmission across the knee [1]. However, the menisci also play a synergistic role together with the bony morphology, the ligaments and the soft tissue envelope in providing knee joint stability [2]. The medial and the lateral meniscus are important secondary knee stabilizers for both rotational and antero-posterior (AP) translation. The patients with combined ligamentous and meniscus lesion show significantly increased laxity, greater pivot shift (PS), and AP translation than the patients with intact menisci [3–6].
However, despite the overwhelming evidence about the crucial role of the meniscus, meniscectomy is still the most performed knee surgery across the globe [7–9].

While MAT procedures have been performed for over 40 years and are now widely accepted as a possible treatment to reduce pain, preserve knee function and delay osteoarthritis progression, the biomechanical behavior of the MAT is still unknown as well as its effectiveness in restoring knee stability similarly to the native meniscus in the real clinical setting [10,11].

Moreover, the soft tissue MAT technique was evaluated only in one robotic study (only lateral meniscus) [12], and in one in-vivo study performed on patients with previous ACL-reconstruction [13]. Additionally, the latter reported results partially in contrast with the literature and evaluated patients only with clinical exam and telos-stress x-rays [13]. Therefore, even though commonly performed, there is a lack of biomechanics studies evaluating the effect of isolated MAT using soft tissue fixation.

The aim of the present study was to assess the biomechanical effect of arthroscopic isolated medial and lateral MAT with soft-tissue fixation on pre- and post-operative knee laxity using a surgical navigation system. The hypotheses of the study were that (1) medial MAT reduces significantly AP laxity but does not influence the PS, and (2) lateral MAT results in a significantly greater PS reduction when compared with medial MAT.

Methods

Patient Selection

Eighteen patients undergoing isolated medial or lateral MAT were prospectively enrolled in the study from August 2018 to November 2021. The inclusion criteria were stricter than the general indications for MAT: patients with no need for an associated surgical procedure or previous history of knee surgery rather than isolated medial or lateral meniscectomy were screened for eligibility. Detailed inclusion and exclusion criteria are shown in Table 1.
<table>
<thead>
<tr>
<th>Table 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inclusion and Exclusion Criteria.</td>
</tr>
</tbody>
</table>

**Inclusion Criteria**
- Previous isolated total or subtotal monocompartimental meniscectomy
- Symptomatic “Post-Meniscectomy syndrome” with Kellgreen-Lawrence grade up to II
- Age between 18 and 50 years
- Axial malalignment lower than 4°
- Complete kinematic evaluation using the intraoperative navigation system

**Exclusion Criteria**
- History of knee surgery other than isolated monocompartimental meniscectomy
- Need for associated concomitant ACL reconstruction, knee osteotomy or cartilage procedures
- Intraoperative Kellgreen-Lawrence grade III-IV
- Patients not willing to participate in the present study

Note: ACL = Anterior Cruciate Ligament.

**Ethics**
All patients undergoing MAT were adequately counseled regarding the risks and benefits of the procedure and surgical alternatives. Patients willing to participate in the study also received information regarding the navigation system, the intraoperative evaluation protocol, and the aims of the present study.

All the enrolled patients signed informed consent forms to undergo surgical procedure, and the research study was approved by the Institutional Review Board (IRB approval: 0008900).

**Surgical technique**
Fresh-frozen (−80°) non-irradiated and non-antigen-matched allografts were used in all the cases.
The MAT was performed by a single surgeon (S.Z.) arthroscopically using a double-tunnel technique without bone plugs. Peripheral suture to the capsule was performed with “all-inside” stitches (non-absorbable ULTRABRAID #0 wire and poly-l-lactide bio-absorbable implants, Smith & Nephew, Andover, MA, USA) and (non-absorbable, polyether ether ketone, PEEK, anchors, DePuy-Mitek,
Raynham, MA, USA). The anterior and posterior horn were secured with a transosseous suture (Figure 1). Further details on meniscus sizing, surgical step, and rehabilitation are provided in previous studies [14,15].

Figure 1: Arthroscopic images of lateral meniscal allograft transplantation with soft tissue fixation. (A) Meniscus-deficient lateral compartment (B) Transplant after definitive fixation.

Testing protocol

A surgical navigation system (BLU-IGS, Orthokey, Lewes, Delaware, DE, USA) was used to reconstruct the real-time anatomy of the tibiofemoral joint and conduct the intraoperative kinematical assessment. The kinematical assessment was carried out through a dedicated software within the surgical navigation system (KLEE, Orthokey, Lewes, Delaware, DE, USA). Two clusters of 3 optical trackers each were fixed one into the proximal tibia and one into the distal femur. The kinematic assessment was performed before MAT, i.e., in meniscus-deficient status (MAT pre-op), and after transplantation (MAT post-op). A set of laxity tests was manually performed at maximum force by the surgeon according to the method developed by Martelli et al. [16]:

- Anterior/posterior displacement at 30° of flexion (AP30);
- Anterior/posterior displacement at 90° of flexion (AP90);
- Varus/valgus rotation at 0° of flexion (VV0);
- Varus/valgus rotation at 30° of flexion (VV30);
- Pivot-shift (PS) test, to assess the dynamic laxity.

The pivot-shift test was quantified, according to the literature [17], through two different parameters: the anterior displacement of the lateral tibial compartment (named APlat) and the posterior acceleration of the lateral tibial compartment during tibial reduction (named ACC).

The validity and reliability of the device for the kinematic assessment of knee joint laxity was evaluated in previous studies [16]. A single experienced surgeon conducted all the kinematic tests. Kinematics was reconstructed offline based on the trackers position and orientation in a custom MATLAB script (The MathWorks Inc, Natick, Massachusetts, USA).

**Statistical analysis**

The Shapiro-Wilk test was used to verify the normal distribution of the data. Continuous variables were presented as mean ± SD with 95% confidence intervals (CI) and categorical variables were presented as percentage over the total. The paired t-test was used to compare the pre-op and post-op for each kinematic variable. The differences were considered statistically significant if p<0.05. The Cohen’s d effect size was reported alongside the p-value and was considered small, medium, and large for values 0.2, 0.5, 0.8, respectively.

An a-priori power-analysis was performed based on the results of a study with similar setup but performed on cadavers [18]. A mean difference of 7° with a standard deviation of 6° for IE rotation at 30° was considered between intact menisci group and MAT group. Based on this analysis, at least 10 patients were required to have a power of 90% and a type I error of 0.05. All the statistical analyses were performed in MATLAB.
Results

Overall, 18 patients were included in the analysis. Of these, 10 patients underwent a lateral MAT, and 8 patients underwent a medial MAT. The detailed patients’ demographics is shown in Table 2.

Table 2

<table>
<thead>
<tr>
<th>Patients’ demographics</th>
<th>Medial MAT</th>
<th>Lateral MAT</th>
</tr>
</thead>
<tbody>
<tr>
<td>N° of patients</td>
<td>8</td>
<td>10</td>
</tr>
<tr>
<td>Age at surgery, y</td>
<td>44.9 ± 7.6</td>
<td>35.5 ± 10.1</td>
</tr>
<tr>
<td></td>
<td>[40.1 - 49.6]</td>
<td>[29.3 - 41.8]</td>
</tr>
<tr>
<td>Sex, M/F</td>
<td>7/1</td>
<td>9/1</td>
</tr>
<tr>
<td>Limb, R/L</td>
<td>4/4</td>
<td>7/3</td>
</tr>
</tbody>
</table>

Medial MAT

After the Medial MAT there was a significant decrease in tibial translation of 3.1 mm (31%; \( p=0.001 \), large effect, Figure 2) for AP30 and 2.3 mm (27%; \( p=0.020 \), large effect, Figure 2) for AP90, as well as a significant difference of 2.5° (50%; \( p=0.002 \), large effect, Figure 2) for VV0 and 1.7° (27%; \( p=0.012 \), large effect, Figure 2) for VV30 (Table 3). However, the medial MAT did not show any reduction in the PS kinematic data (moderate-to-small effect, Table 3).

Lateral MAT

The Lateral MAT determined a significant decrease in tibial translation of 2.5 mm (38%; \( p<0.001 \), large effect, Figure 2) for AP30 and 1.9 mm (34%; \( p=0.004 \), large effect, Figure 2) for AP90 as well as a significant difference of 3.4° (59%; \( p<0.001 \), large effect, Figure 2) for VV0 and of 1.7° (23%; \( p=0.011 \), large effect, Figure 2) for VV30 (Table 3). There was also a significant reduction of the PS of 4.4 mm (22%; \( p=0.028 \), moderate effect, Figure 3) for APlat and 384.8 mm/s² (51%; \( p=0.005 \), large effect, Figure 3) for ACC (Table 3).
### Table 3
Kinematic assessment before (Pre-op) and after (Post-op) MAT

<table>
<thead>
<tr>
<th></th>
<th>Medial MAT</th>
<th>Lateral MAT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre-op</td>
<td>Post-op</td>
</tr>
<tr>
<td>AP30 (mm)</td>
<td>9.6 ± 2.5 [7.9 - 11.4]</td>
<td>6.5 ± 1.9 [5.2 - 7.8]</td>
</tr>
<tr>
<td>AP90 (mm)</td>
<td>6.7 ± 2.3 [5.1 - 8.3]</td>
<td>4.5 ± 1.4 [3.5 - 5.5]</td>
</tr>
<tr>
<td>VV0 (°)</td>
<td>5.0 ± 2.1 [3.5 - 6.4]</td>
<td>2.4 ± 1.6 [1.3 - 3.5]</td>
</tr>
<tr>
<td>VV30 (°)</td>
<td>5.5 ± 1.5 [4.5 - 6.6]</td>
<td>3.8 ± 1.0 [3.1 - 4.5]</td>
</tr>
<tr>
<td>PS - Aplat (mm)</td>
<td>16.7 ± 2.7 [14.9 - 18.6]</td>
<td>15 ± 5.5 [11.2 - 18.8]</td>
</tr>
<tr>
<td>PS - ACC (mm/s^2)</td>
<td>240.1 ± 177.2 [117.3 - 362.9]</td>
<td>131.8 ± 54.9 [93.8 - 169.9]</td>
</tr>
</tbody>
</table>

Note: Data are presented as mean and standard deviation with 95% confidence intervals. n.s. = non-significant difference (p>0.05)

**Figure 2**: Anterior/posterior translation at 30° (AP 30) and 90° (AP 90) and varus/valgus rotation at 0° (VV0) and 30° (VV30) of knee flexion evaluated before (red, MAT Pre-op) and after (blue, MAT Post-op) MAT. Asterisks represent significant differences (p<0.05) between MAT Pre-op and MAT Post-op.
Figure 3: Pivot-shift test dynamic laxity through anterior displacement (APlat) and posterior acceleration of the lateral tibial compartment during tibial reduction (ACC) evaluated before (red, MAT Pre-op) and after (blue, MAT Post-op) MAT. Asterisks represent significant differences (p<0.05) between MAT Pre-op and MAT Post-op.

Discussion

The most important finding of the present study was that the MAT with soft-tissue technique determines a significant laxity reduction in an in-vivo setting from the pre- to the postoperative assessment. The lateral MAT reduced the global knee laxity with particular emphasis on the rotatory knee parameters, while the medial MAT reduced the AP and VV laxity but did not control the PS test.

The results of the present study showed that both the medial and the lateral MAT are similarly able to reduce the AP translation of about 2-3mm at different flexion angles (Figure 2, Table 3). Previous in vitro studies investigated the stabilizing effect of the medial meniscus and found an
increased anterior tibial translation of about 4 mm after a complete medial meniscectomy under axial load [19,20]. Similarly, an in-vivo study performed under anesthesia found an increase of AP laxity of 3 mm immediately after medial meniscectomy in patients with an ACL-intact knee [21]. Considering that the amount of increased laxity after meniscectomy reported in these studies is similar to the AP reduction obtained after medial MAT, it is possible to hypothesize that such a surgical procedure could counteract the biomechanical effects of a medial meniscectomy.

The stabilizing effect of medial MAT found in the present study becomes even more interesting if we consider one of the main indications for meniscus transplant: based on the international meniscus transplant guidelines, the medial MAT is indicated “as a concomitant procedure to revision ACL reconstruction to aid in joint stability when meniscus deficiency is believed to be a contributing factor to ACL failure” [22]. However, this recommendation is not directly supported by clinical trials but is mainly based on in-vitro biomechanical studies: an increased AP translation caused by a medial meniscus deficiency could further stress the ACL graft and predispose it to failure [3,23]. On the other hand, the present study showed a relevant stabilizing effect on AP translation after medial MAT, even in an ACL-intact knee. Although not directly investigated, it could be hypothesized that the stabilizing effect of medial MAT found in the present study results could determine a positive biomechanical effect on an ACL graft and thus, give strength to the IMREF recommendation.

Regarding the AP stabilizing effect of the lateral MAT compared to the medial one, most of the authors reported a limited effect of partial lateral meniscectomy on AP translation [4,24,25]. However, two recent cadaveric study showed the importance of circumferential meniscus fibers on the lateral meniscus kinematics [26,27]. One study shows that a lateral meniscal posterior root tear significantly increased the anterior tibial translation of about 1 mm even after ACL-reconstruction [26]. A similar increase in anterior tibial translation was observed in another robotic study after a complete radial tear of the lateral meniscus [27].
Finally, an in-vivo biomechanical analysis by Yoon et al. reported that the lateral MAT performed after ACL reconstruction was able to reduce the Lachman and the Anterior-drawer tests at manual examination two years after surgery [13]. However, the same authors failed to confirm these results when they objectively quantified the AP translation with the Telos stress device [13].

In the present study, the medial MAT did not show any significant effect on the kinematics of the PS. Conversely, after lateral MAT, there was a reduction of 4.4mm (-22%) of the translation of the lateral compartment and a massive reduction of the acceleration (-51%) during the PS test.

These data are in line with several in-vitro and in-vivo studies showing that only lateral meniscectomy or lateral meniscus tears impact knee rotatory instability [25,28]. Interestingly, the only other in-vivo study evaluating the biomechanical effect of MAT found that only the medial MAT improved the rotational stability, while the lateral MAT had no influence on the magnitude of the PS test [13]. Such differences could be related to different study protocols and surgical techniques: while Yoon et al. [13] evaluated the patients using a clinical PS grading two years after surgery, in the present study, the PS was quantified using the surgical navigation system which is considered the gold standard for intraoperative kinematic assessment [29]. Additionally, in our study, the PS was performed with the patients under anesthesia, which has been demonstrated to be more reliable, reproducible, and accurate because not influenced by the patient’s level of consciousness and pain [30]. Finally, in these two studies, different techniques were used for the MAT and only the soft-tissue one showed a PS reduction after lateral MAT. These data appear to be clinically relevant since graft fixation is one of the most debated topics in the last years [22,31,32]. In fact, while early in-vitro biomechanical studies found that bone-block techniques were superior in terms of contact pressures [33], more recent robotic and clinical studies found no difference in terms of kinematics and patient outcomes [12,31].

The present study has some limitations. First, the reduced number of patients enrolled. The recruitment of patients was complex since the navigation system is an invasive tool, MAT is not a common arthroscopic procedure, and often patients were excluded because they required previous or concomitant surgeries (such as revision ACL or HTO) that could have altered the kinematical analysis.
of MAT [34]. Nonetheless, this strict selection allowed to investigate the biomechanics of the sole MAT without biases. Moreover, there are two limitations with respect to robotic studies. First, it was impossible to analyze the same knee in the healthy, meniscectomized and transplanted condition, because it would have been unethical in vivo. The second is related to the setting of laxity evaluation, which was performed manually rather than with robotic devices with standardized simulated movements. To reduce this bias, all the tests were performed by a single senior surgeon with more than 15 years of experience in intraoperative surgical navigation, whose reliability in manual kinematic assessment was already evaluated [4,35–37].

The present study also has several strengths. First, it was performed in an in-vivo setting and therefore, all the surgical steps, including the meniscus harvesting and sizing, the meniscectomy, the capsular fixation, and the tunnel drilling and horns fixation, are an authentic representation of the clinical scenario. Additionally, all the in vitro evaluations of MAT available in the literature were performed on specimens from older donors, including only amputated knee, and were performed using additional surgical steps such as arthrotomy or capsular dissections, which are not required in the actual setting. Finally, the present paper is the second to evaluate the kinematical effect of MAT in-vivo condition but is the first to provide to be performed on patients with intact ACL and the only one that uses soft-tissue MAT fixation.

**Conclusions**

MAT with soft-tissue fixation results in a clinically significant laxity reduction in an in-vivo setting. In addition, Medial MAT improved knee kinematics by determining a substantial decrease with particular emphasis on AP translation and VV maneuver. Conversely, Lateral MAT determined a massive reduction of the PS and a mild decrease of the AP translation and VV maneuver.

**References**


https://doi.org/10.1177/1941738111429419.


Table 1
Inclusion and Exclusion Criteria.

**Inclusion Criteria**
- Previous isolated total or subtotal *monocompartmental* meniscectomy
- Symptomatic “Post-Meniscectomy syndrome” with Kellgreen-Lawrence grade up to II
- Age between 18 and 50 years
- Axial malalignment lower than 4°
- Complete kinematic evaluation using the intraoperative navigation system

**Exclusion Criteria**
- History of knee surgery other than isolated *monocompartmental* meniscectomy
- Need for associated concomitant ACL reconstruction, knee osteotomy or cartilage procedures
- Intraoperative Kellgreen-Lawrence grade III-IV
- Patients not willing to participate in the present study

Note: ACL = Anterior Cruciate Ligament.
Table 2. Patients’ demographics. MAT = (monocompartmental) meniscus allograft transplantation

<table>
<thead>
<tr>
<th></th>
<th>Medial MAT</th>
<th>Lateral MAT</th>
<th>p-value</th>
<th>d</th>
</tr>
</thead>
<tbody>
<tr>
<td>N° of patients</td>
<td>8</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age at surgery, y</td>
<td>44.9 ± 7.6</td>
<td>35.5 ± 10.1</td>
<td>0.047</td>
<td>1.1</td>
</tr>
<tr>
<td></td>
<td>[40.1 - 49.6]</td>
<td>[29.3 - 41.8]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sex, M/F</td>
<td>7/1</td>
<td>9/1</td>
<td>0.871</td>
<td>0.1</td>
</tr>
<tr>
<td>Limb, R/L</td>
<td>4/4</td>
<td>7/3</td>
<td>0.401</td>
<td>0.8</td>
</tr>
</tbody>
</table>
## Table 3
Kinematic assessment before (Pre-op) and after (Post-op) MAT

<table>
<thead>
<tr>
<th></th>
<th>Medial MAT</th>
<th></th>
<th>Lateral MAT</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre-op</td>
<td>Post-op</td>
<td>P-value</td>
<td>Cohen’s d</td>
</tr>
<tr>
<td>AP30 (mm)</td>
<td>9.6 ± 2.5 [7.9 - 11.4]</td>
<td>6.5 ± 1.9 [5.2 - 7.8]</td>
<td>0.001</td>
<td>1.4</td>
</tr>
<tr>
<td>AP90 (mm)</td>
<td>6.7 ± 2.3 [5.1 - 8.3]</td>
<td>4.5 ± 1.4 [3.5 - 5.5]</td>
<td>0.020</td>
<td>1.2</td>
</tr>
<tr>
<td>VV0 (°)</td>
<td>5.0 ± 2.1 [3.5 - 6.4]</td>
<td>2.4 ± 1.6 [1.3 - 3.5]</td>
<td>0.002</td>
<td>1.4</td>
</tr>
<tr>
<td>VV30 (°)</td>
<td>5.5 ± 1.5 [4.5 - 6.6]</td>
<td>3.8 ± 1.0 [3.1 - 4.5]</td>
<td>0.012</td>
<td>1.3</td>
</tr>
<tr>
<td>PS - Aplat (mm)</td>
<td>16.7 ± 2.7 [14.9 - 18.6]</td>
<td>15 ± 5.5 [11.2 - 18.8]</td>
<td>0.437</td>
<td>0.4</td>
</tr>
<tr>
<td>PS - ACC (mm/s²)</td>
<td>240.1 ± 177.2 [117.3 - 362.9]</td>
<td>131.8 ± 54.9 [93.8 - 169.9]</td>
<td>0.085</td>
<td>0.8</td>
</tr>
</tbody>
</table>

Note: Data are presented as mean and standard deviation with 95% confidence intervals.
Declaration of interests

☐ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☒ The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

| S.Z. reports a relationship with DePuy Mitek Inc that includes: consulting or advisory. S.Z. reports a relationship with Smith and Nephew Inc that includes: consulting or advisory. |  |