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Original research

Early introduction of high-intensity eccentric loading into hamstring strain injury rehabilitation

Jack T. Hickey [a,b,*], Ebonie Rio [c,d,e], Thomas M. Best [f], Ryan G. Timmins [a,b], Nirav Maniar [a,b], Peter F. Hickey [g,h], Morgan D. Williams [i], Christian A. Pitcher [a], David A. Opar [a,b]

[a] School of Behavioural and Health Sciences, Australian Catholic University, Australia
[b] Sports Performance, Recovery, Injury and New Technologies Research Centre, Australian Catholic University, Australia
[c] La Trobe Centre for Sport and Exercise Medicine Research, La Trobe University, Australia
[d] The Australian Ballet, Australia
[e] Victorian Institute of Sport, Australia
[f] Division of Sports Medicine, Department of Orthopaedics, UHealth Sports Medicine Institute, University of Miami, United States of America
[g] Advanced Technology and Biology Division, WEHI, Australia
[h] Department of Medical Biology, University of Melbourne, Australia
[i] School of Health, Sport and Professional Practice, University of South Wales, United Kingdom

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ABSTRACT

Objectives: This study aimed to investigate the number of days following hamstring strain injury (HSI) taken to introduce high-intensity eccentric loading (HIEL) into rehabilitation based on exercise-specific progression criteria, and whether pain resolution during isometric knee flexion strength testing occurred before or after this milestone.
Design: Cohort study.
Methods: We included 42 men (mean ± sd; age = 26 ± 5 years; height = 181 ± 8 cm; mass = 86 ± 12 kg) with HSIs, who performed fully supervised rehabilitation twice per week until they met return to play clearance criteria. Isometric knee flexion strength testing was completed before every rehabilitation session and HIEL was introduced via the Nordic hamstring exercise and unilateral slider once participants could perform a bilateral slider through full eccentric knee flexion range of motion. We reported the median (IQR) number of days following HSI taken to introduce HIEL, along with participant's pain rating during isometric knee flexion strength testing before that rehabilitation session. We also reported the median (IQR) number of days following HSI taken for participants to achieve pain resolution during isometric knee flexion.
Results: HIEL was introduced 5 (2–8) days following HSI, despite 35/42 participants reporting pain during isometric knee flexion strength testing immediately prior to that rehabilitation session, which was rated as 3.5 (3–5) on a 0–10 numeric rating scale. Pain resolution during isometric knee flexion strength testing was achieved 11 (9–13) days following HSI.
Conclusion: HIEL can be safely introduced into early HSI rehabilitation based on exercise-specific progression criteria, without needing to wait for pain resolution during isometric knee flexion strength testing before doing so.

Practical implications

- The unilateral slider and NHE, which both involve high-intensity eccentric loading, can be safely introduced into early hamstring strain injury rehabilitation, once the bilateral slider exercise can be performed through full eccentric knee flexion range of motion
- Pain and/or between-leg asymmetries during isometric knee flexion strength testing should not be barriers to the introduction of high-intensity eccentric loading into HSI rehabilitation
- Practitioners may have greater scope to address modifiable HSI risk factors, such as biceps femoris long head fascicle length, during brief periods of rehabilitation by introducing high-intensity eccentric loading based on exercise-specific progression criteria

1. Introduction

Athletes participating in running-based sports commonly suffer hamstring strain injuries (HSIs)[1] and their risk of recurrence is greatest in the initial months following return to play (RTP).[2–4] Rehabilitation practitioners aim to reduce this recurrence risk by targeting modifiable

* Corresponding author at: School of Behavioural and Health Sciences, Australian Catholic University, Australia.
E-mail address: jack.hickey@acu.edu.au (J.T. Hickey).

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variables associated with HSI, such as eccentric knee flexion strength and biceps femoris long head fascicle length.[4,5] These variables can be altered via eccentric resistance training,[6] typically involving high-intensity loading like the Nordic hamstring exercise (NHE),[7,8] which reduces HSI risk when included in injury prevention protocols.[9] Although contemporary rehabilitation protocols commonly include the NHE,[10] practitioners need clarity on when to introduce such high-intensity eccentric loading, given most athletes RTP in less than three weeks following HSI.[11]

The introduction of high-intensity eccentric loading following HSI, ultimately depends on the criteria used to progress through stages of rehabilitation.[12] Most published HSI rehabilitation protocols do not introduce high-intensity eccentric loading until pain has resolved during isometric knee flexion performed with either 5/5 strength[13–15] or <10 % asymmetry.[16,17] To our knowledge, there is no evidence that the resolution of pain during isometric knee flexion strength testing is necessary to introduce high-intensity eccentric loading into HSI rehabilitation. Consequently, it is worth investigating if high-intensity eccentric loading can be safely introduced without waiting for pain to resolve during isometric knee flexion strength testing.

We recently implemented a HSI rehabilitation protocol that introduced high-intensity eccentric loading based on exercise-specific progression criteria, as part of a randomised controlled trial (RCT).[18] Once participants could perform a bilateral slider exercise through full eccentric knee flexion range of motion, we introduced the unilateral slider and NHE,[18] which both involve high-intensity eccentric loading.[19,20] Isometric knee flexion strength testing was conducted as an outcome measure of this RCT.[18] However, pain reported during isometric knee flexion strength testing was not considered to be relevant in the context of introducing high-intensity eccentric loading, as these tests do not replicate the contraction mode or movements of the unilateral slider or NHE. Therefore, reporting the time taken to introduce the unilateral slider and NHE using this exercise-specific progression criteria, may inform practitioners whether high-intensity eccentric loading can be introduced before pain has resolved during isometric knee flexion strength testing.

Therefore, this study aims to investigate the number of days following HSI taken to introduce high-intensity eccentric loading into rehabilitation based on exercise-specific progression criteria, and whether pain resolution during isometric knee flexion strength testing occurred before or after this milestone.

2. Methods

This study reports novel data collected from a pooled cohort of two groups of participants who were included in a previously published RCT, which compared pain-free to pain-threshold rehabilitation following HSI (ACTRN12616000307404).[18] Ethical approval was granted by the Australian Catholic University Human Research Committee (2015-307H) and participants provided informed written consent prior to their inclusion. Detailed methods and results of the RCT comparing pain-free to pain-threshold rehabilitation following HSI can be found in the primary publication.[18] However, the following section provides a summary of the RCT methods and results that are relevant to the current study.

Participants in the RCT were randomly allocated to a pain-free or pain-threshold rehabilitation group following initial clinical assessment confirming presence of an acute HSI, which had occurred within the past seven days. Immediately following randomisation, all participants commenced a standardised rehabilitation protocol consisting of progressive running (supplementary table) and exercises that load the hamstrings (supplementary figure). The only difference between the two groups was that participants were permitted to perform this rehabilitation protocol if they rated their pain during an exercise as 0 in the pain-free group and ≤4 in the pain-threshold group, according to a 0 to 10 numeric rating scale. The rehabilitation protocol was performed under 1:1 supervision twice per week until participants achieved identical RTP clearance criteria. The primary outcome measure of the RCT was the number of days following HSI taken to achieve RTP clearance criteria, which was not significantly different between the two groups.[18]

Before each rehabilitation session twice per week, all participants underwent isometric knee flexion strength testing for their uninjured and then injured leg, lying supine at 0°/0° (Fig. 1a) and 90°/90° (Fig. 1b) hip/knee flexion. Peak isometric knee flexion force was objectively measured via load cells sampling at 2000 Hz (MLP-750; Transducer Techniques, LLC, Temecula, CA) during these tests using a bespoke apparatus with published reliability.[19] Participants were asked to rate any pain experienced at the site of injury on a 0–10 numeric rating scale during these tests, as resolution of pain during isometric knee flexion strength testing was required to meet RTP clearance criteria. However, pain and objective force data collected during isometric knee flexion strength testing did not inform the introduction of high-intensity eccentric loading, which was instead based on exercise-specific progression criteria. During their first rehabilitation session, all participants were introduced to sub-maximal eccentric knee flexion loading via the bilateral slider (Fig. 1c–d). Once participants could perform this exercise through full eccentric knee flexion range of motion, they were progressed to the unilateral slider (Fig. 1e) and NHE (Fig. 1f). This exercise-specific progression criteria was considered to be safe, as the bilateral slider replicates the eccentric knee flexion movements of the unilateral slider and NHE, but at a sub-maximal intensity.[19]

Custom written code in R version 4.1.1[21] was used to analyse relevant data collected from all participants who completed rehabilitation twice per week until meeting RTP clearance criteria. The first rehabilitation session where the unilateral slider and NHE were introduced was identified for each participant and defined this as the introduction of high-intensity eccentric loading. The median (IQR) number of days following HSI to the introduction of high-intensity eccentric loading was calculated. For the day that high-intensity eccentric loading was introduced, results of isometric knee flexion strength testing were analysed to calculate the number of participants still reporting pain during these tests, the median (IQR) rating of pain during these tests and the median (IQR) peak isometric knee flexion force output of the injured relative to uninjured leg in percentage terms. For each participant, the first day of testing where they reported no pain during isometric knee flexion strength testing was identified. The median (IQR) number of days following HSI to the resolution of pain during isometric knee flexion strength testing was calculated. The “survival” package[22] was used to visually demonstrate the cumulative number of participants relative to the number days following HSI taken to introduce high-intensity eccentric loading and for pain to resolve during isometric knee flexion strength tests.

3. Results

Although 43 participants were included in the previously published RCT,[18] one of these participants was excluded from the current study, as they ceased rehabilitation without meeting RTP clearance criteria. The remaining 42 participants included in this study were men aged 26 ± 5 years, 181 ± 8 cm in height and 86 ± 12 kg in mass. All participants had suffered an acute HSI while competing at a sub-elite level of either Australian football ($n = 32$), soccer ($n = 4$), cricket ($n = 3$), futsal ($n = 2$) or field hockey ($n = 1$). Participants commenced the standardised rehabilitation protocol in a median (IQR) time of 2 (2–4) days following HSI.

High-intensity eccentric loading was introduced 5 (2–8) days following HSI, despite 35/42 participants still reporting pain during isometric knee flexion strength testing immediately prior to that rehabilitation session. Before the rehabilitation session where high-intensity eccentric loading was introduced, participants rated their pain on the 0 to 10 numeric rating scale during isometric knee flexion

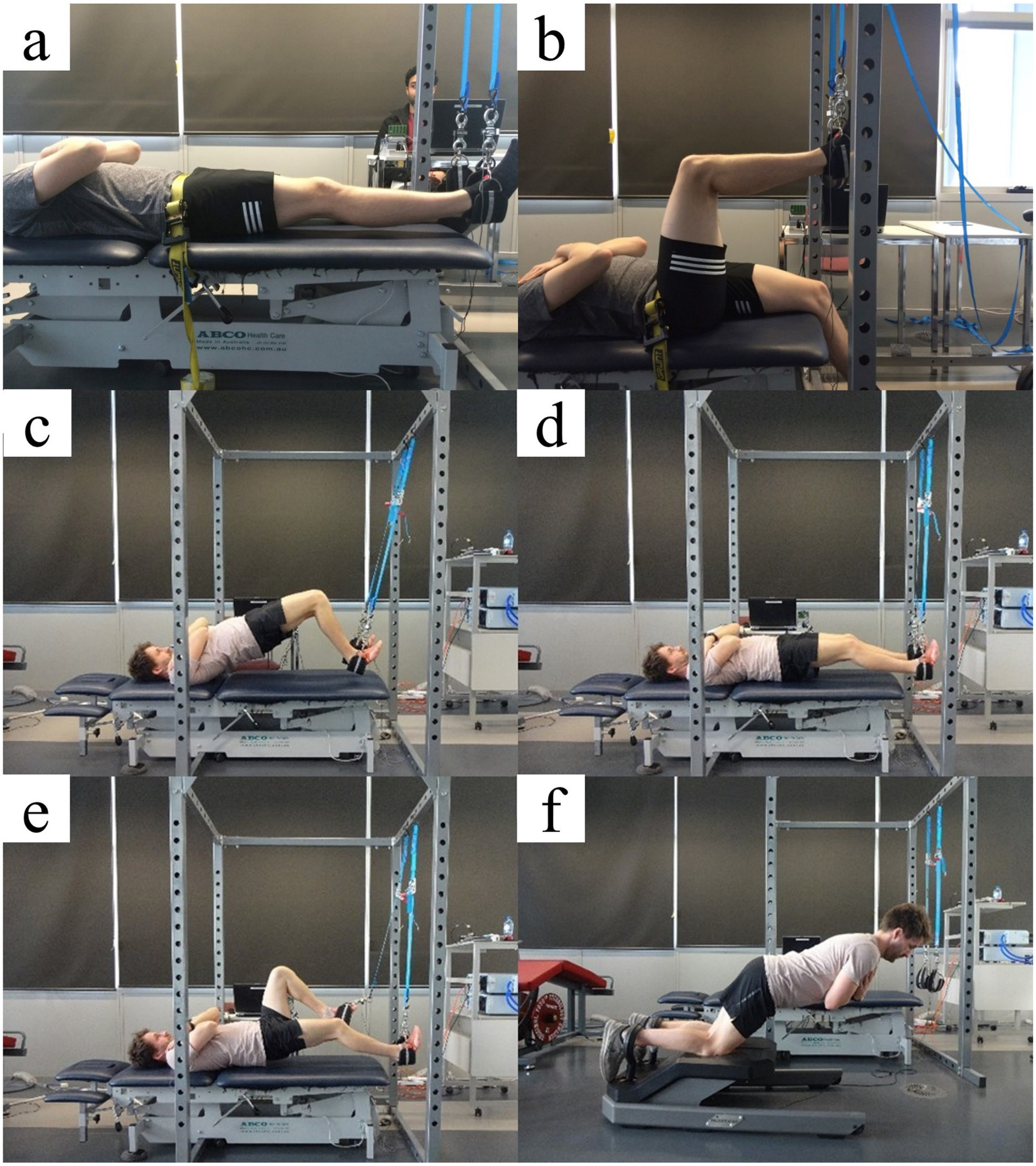

Fig. 1. Isometric knee flexion strength testing at 0°/0° (a) and 90°/90° (b) hip/knee flexion. Introduction of high-intensity eccentric loading based on performance of the bilateral slider through full eccentric knee flexion range of motion (c–d), which determined the introduction of the unilateral slider (e) and Nordic hamstring exercise (f).

strength testing as 1.75 (0–3.75) at 0°/0° hip knee flexion and 3.25 (1.63–4.75) at 90°/90° hip knee flexion. At this timepoint, peak isometric knee flexion force of the injured relative to uninjured leg was 78 % (63 %–89 %) at 0°/0° hip knee flexion and 71 % (51 %–84 %) at 90°/90° hip knee flexion (Fig. 2).

The introduction of high-intensity eccentric loading did not appear to exacerbate symptoms, given that prior to the subsequent rehabilitation session 8 (6–11) days following HSI, participants rated their pain on the 0 to 10 numeric rating scale during isometric knee flexion strength testing as 0 (0–2) at 0°/0° hip knee flexion and 1 (0–3) at 90°9/0° hip knee flexion. In addition, no adverse events (i.e., re-injuries) were reported while performing the unilateral slider and NHE throughout HSI rehabilitation. Resolution of pain during isometric knee flexion strength was achieved 11 (9–13) days following HSI (Fig. 3). Participants met RTP clearance criteria in a median (IQR) time of 15.5 (11.25–19) days following HSI, before subsequently returning to their previous level of sports competition.

4. Discussion

We found that high-intensity eccentric loading can be safely introduced during early HSI rehabilitation based on exercise-specific progression criteria, without needing to wait for pain resolution during isometric knee flexion strength testing before doing so. Our findings challenge common clinical recommendations for the introduction of high-intensity eccentric loading following HSI,[13–16,23] and implementing exercise-specific progression criteria may give practitioners

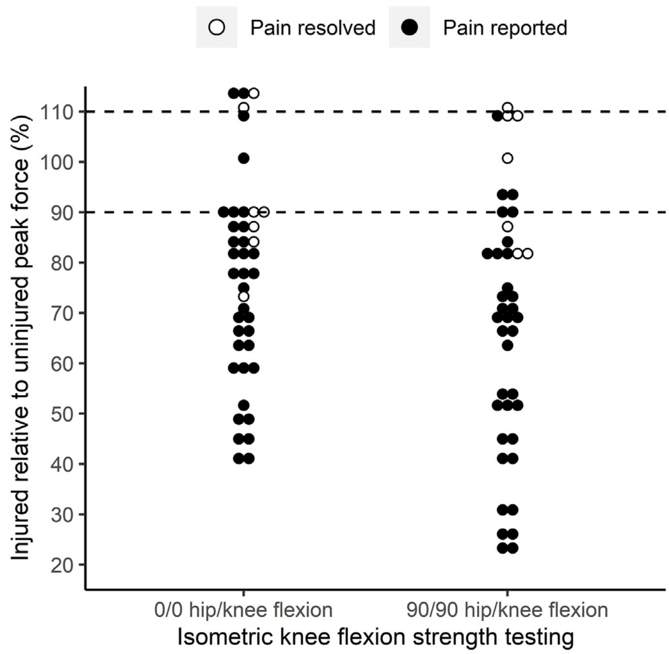

Fig. 2. Results of isometric knee flexion strength testing conducted immediately prior to the rehabilitation session where high-intensity eccentric loading was introduced, in terms of force of the injured relative to uninjured leg (%) on the y-axis. The area between the horizontal dotted lines is within 10 % between-leg asymmetry in force and each data point indicates the results for an individual participant and whether they reported pain (black) or not (white) during these tests.

greater scope to drive potentially beneficial adaptations during brief periods of rehabilitation.

To our knowledge, introducing the unilateral slider and NHE as soon as one day following HSI is the earliest introduction of high-intensity eccentric loading reported in the rehabilitation literature. Most published rehabilitation protocols avoid any hamstring-specific loading until at least five days following HSI[10] and if eccentric exercise is introduced from this stage, it is limited to a sub-maximal intensity.[16,24,25] Protocols

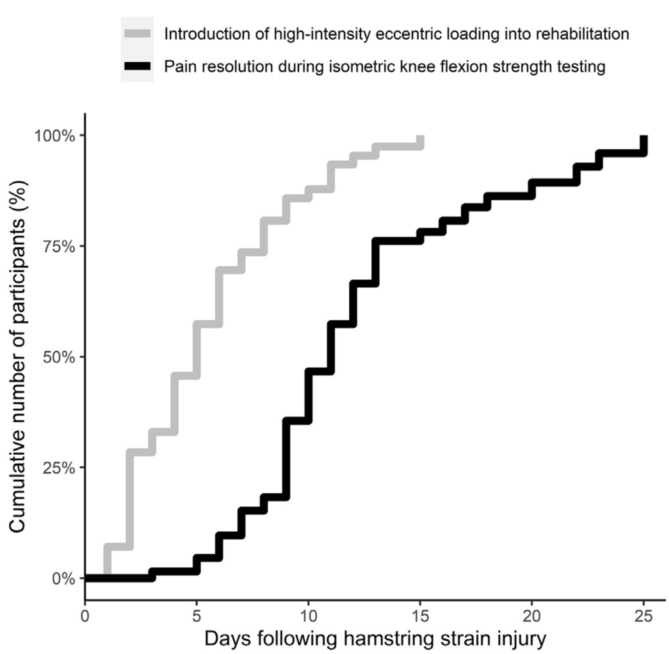

Fig. 3. Survival curves showing the cumulative number of participants (%) on the y-axis achieving introduction of high-intensity eccentric loading into rehabilitation (grey line) and the resolution of pain during isometric knee flexion strength tests (black line) relative to the number of days following hamstring strain injury on the x-axis.

that introduce high-intensity eccentric loading in later stages of rehabilitation usually delay interventions like the unilateral slider and NHE until pain has resolved during isometric knee flexion strength testing.[13,16,17] Based on our data, we suggest high-intensity eccentric loading can be safely introduced into early HSI rehabilitation, without waiting for the resolution of pain during isometric knee flexion strength testing.

In addition to the presence of pain, high-intensity eccentric loading was safely introduced into early HSI rehabilitation despite notable between-leg asymmetries in force output during isometric knee flexion strength testing. These findings refute the additional recommendation of some published HSI rehabilitation protocols, to delay high-intensity eccentric loading until isometric knee flexion strength asymmetry is <10 %.[16,17] Objectively monitoring isometric knee flexion strength asymmetries may be useful following HSI to inform RTP prognosis[26,27] and possibly progression of running intensity during rehabilitation.[28] However, our data suggests that similar to pain, the presence of between-leg force asymmetries during isometric knee flexion strength testing should not be seen as a barrier to the introduction of high-intensity eccentric loading into HSI rehabilitation.

Early introduction of high-intensity eccentric loading may improve the rehabilitation practitioner's scope to alter key variables associated with HSI risk, especially biceps femoris long head fascicle length.[5] Most athletes complete rehabilitation and RTP within three weeks of HSI,[11] and evidence suggests at least two weeks of exposure to high-intensity eccentric loading is required to increase biceps femoris long head fascicle length.[29,30] Participants in our RCT achieved significant increases in biceps femoris long head fascicle length, within relatively brief periods of rehabilitation between HSI and RTP clearance (~two weeks).[18] We doubt whether such increases would have been achieved if we delayed high-intensity eccentric loading until pain had resolved during isometric knee flexion strength testing, which was well into the second week of HSI rehabilitation for our participants.

Although all sexes were eligible to be included in this study, every participant who met the RCT inclusion criteria happened to be male, which may limit application of the current findings in females. Application of the current findings could also be limited beyond the field-based team sports that participants played in this study, which ranged in competitive level from amateur to semi-professional. Finally, there is potential that isometric knee flexion strength testing reduced participants' sensitivity to pain during subsequent rehabilitation exercises, which could have improved their tolerance to high-intensity eccentric loading. However, even if this was the case, it would provide further rationale to not delay high-intensity eccentric loading based on pain during isometric knee flexion strength testing.

5. Conclusion

This is the first study to demonstrate that high-intensity eccentric loading can be safely introduced into early HSI rehabilitation based on exercise-specific progression criteria, without needing to wait for pain resolution during isometric knee flexion strength testing before doing so. Practitioners should reconsider the common recommendation of waiting for pain to resolve during isometric knee flexion strength testing before introducing high-intensity eccentric loading into HSI rehabilitation.

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Declaration of Interest Statement

One of the authors Dr. David Opar, is listed as a co-inventor on a patent, filed by the Queensland University of Technology (QUT), for a field-testing device of eccentric hamstring strength, which is now known commercially as the NordBord. Dr. Opar has received revenue distributions from QUT based on revenue that QUT has generated through the commercialisation of his intellectual property. Dr. Opar is a minority shareholder in Vald Performance Pty Ltd., the company responsible for commercialization of the NordBord, among other devices. Dr. Opar has received research funding from Vald Performance, for work unrelated to the current manuscript. Dr. Opar was previously the Chair of the Vald Performance Research Committee, a role that was unpaid. Dr. Opar has family members who are minor shareholders and/or employees of Vald Performance. All remaining authors have no conflicts of interest to declare.

Confirmation of Ethical Compliance

Ethical approval for this research was granted by the Australian Catholic University Human Research Committee (2015-307H) and participants provided informed written consent prior to their inclusion.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jsams.2022.06.002.

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