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A Preliminary Investigation into the Relationship Between Under-Rug Temperatures and Sleep-Related Behavior in Stabled Horses Using Non-Invasive Temperature Measures

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Abstract

Stabled horses are managed within a domestic environment, where the effects of artificial lighting and bedding on sleep have been reported. Beyond the environment, equine husbandry practices such as rugging or clipping are influential on equine thermoregulation. However, the influence of these practices on sleep and related behaviors is unknown, despite the link between core body temperature and the occurrence of sleep. The aim of this pilot study was to investigate the viability of using novel temperature recording equipment to determine whether a relationship between under-rug temperature and sleep-related behavior could be detected. Under-rug temperatures were measured using Thermachron iButtons© at 10-minute intervals across five nights, while closed-circuit television camera equipment enabled continuous focal observations of sleep-related behavior. Duration of behavioral states according to a pre-determined ethogram was recorded between the hours of 00:00 and 07:00 for four stabled horses. Overnight environmental temperatures were reported between -6 °C and 4 °C. Mean under-rug temperature from all horses across five nights was 22.91 ± 0.12 °C (minimum 14.0 °C, maximum 34.0 °C) and was different between nights and between individual horses. No significant relationships were identified between under-rug temperatures and total duration of behavioral states. While the iButtons demonstrated the capacity to measure temperatures, several recommendations are made for future studies based on this foundational work. The relationship between under-rug temperature and sleep behavior warrants further investigation, which in the future could include data on sleep onset or sleep quality.

Keywords

Body temperature; equine; rugging; thermoregulation; under-rug microclimate

1. Introduction

Sleep is defined as a reversible behavioral state of perceptual disengagement and unresponsiveness to the environment [1], that is imperative for the welfare of all mammals due to its regulatory, restorative, and memory consolidation functions [2,3]. Sleep occurs in two states: Non-Rapid Eye Movement (NREM) and Rapid Eye Movement (REM). The occurrence of sleep is controlled by two systems: sleep homeostasis is determined by preceding sleep and wakefulness, and circadian rhythms of rest and activity are strongly entrained to the light–dark cycle [4]. As a prey animal, the average total sleep time for the horse is lower than that of most other mammals, with reports of between three and six hours within 24 h [5,6]. The horse is most often observed sleeping between 00:00 and 04:00 [7–9] but can sleep at any time within a 24-h period. The light–dark cycle is considered a universal sleep cue for mammalian circadian oscillations, with strong connections to sleep regulation [10]. The influence of light on equine sleep has been described through changes to behavioral profiles when lights are left on in the stable overnight compared to when they are turned off [11], and through a lack of circadian synchronization when the light–dark cycle is interrupted during the night [12].

In addition to light as a cue for sleep, reductions in core temperature occur together with sleep onset [13], such that reductions in body temperature have been described as a sleep cue in a range of mammals [14,15]. Warm ambient environments have been shown to simultaneously trigger sleep and body cooling through the activation of neural pathways in mice [16]; however, higher ambient temperatures are shown to negatively correlate with sleep duration in humans [17]. Thermoregulatory behaviors in smaller mammals, such as nest building or shelter seeking, enable individuals to prepare for environmental temperature fluctuations such that energy expenditure during sleep is limited [18]. In larger mammals such as horses, the circadian rhythm of temperature has been shown to maintain strong stability even without environmental cues [19]. In accordance with circadian rhythmicity, a trough in body temperature occurs around 08:00 with an acrophase observed at 22:00 [20]. Despite this, very little evidence exists detailing the influence of temperature as a cue for sleep in horses. This is further influenced by traditional equine husbandry practices that involve human caregivers affecting equine thermoregulation through clipping and/or rugging practices. Rugged horses cannot efficiently use evaporative heat loss as a cooling mechanism compared to unrugged horses [21], but beyond this, little is known about the thermal microclimate of the rugged horse, especially its impact on sleep-related behaviors. In human sleep, the effect of different types of sleepwear and bedding materials on the sleep thermal microclimate is recognized but under-researched [22].

Core body temperature is typically measured using repeated rectal temperature measurements [18,19]. Published literature also highlights the use of the jugular vein to measure deep body temperature [23], and an infrared sensor device to measure gastrointestinal (core) temperature and skin temperature following ingestion of an indigestible pill [24]. A less invasive method is necessary when measuring temperatures and equine sleep behavior to avoid constant interruptions that could affect the sleep behavior profile. The Orscana sensor is now commercially available as the Winderen rug (www.winderen.com) and has been cited in research [25], but validity tests are required to support further research with this sensor–rug combination. Additional commercially available products include thermometer stickers for rugs (e.g., https://www.coleparmer.co.uk/p/cole-parmer-reusable-temperature-indicating-strips/46369). This pilot study aimed to use a novel, non-invasive temperature reading button placed under the rug of stabled horses to profile temperatures per night and per horse, and to measure the relationship between under-rug temperatures and sleep-related behavior duration.

2. Methods

2.1. Subjects

A convenience sample of four horses aged from 14 to 22 years, of mixed breed (cob or Welsh × type), height, and weight (three geldings and one mare), stabled on the yard at Hartpury Equestrian, were observed over five nights in November and December 2023. All horses had been health-assessed by the yard staff who managed them and deemed fit for work. None of the horses displayed stereotypic behavior. Each horse was clipped (high trace clip or blanket clip, depending on the individual) and wore a rug deemed appropriate to its individual needs based on the environmental temperature, as approved by the yard manager (qualified as a BHS Stage 4 coach with an equine science degree). Horses were accustomed to wearing rugs, the weight of which ranged from lightweight fleece (typically 1.5–3 kg) to medium weight (typically 2–4 kg). The lowest overnight environmental temperatures ranged from −6 °C to 4 °C during the data collection period, according to retrospective data for the Gloucester area available from weatherspark.com. All horses had been housed in the same stable for two months prior to the start of the study, and observations occurred in these stables, which measured 3.6 m × 3.6 m and were arranged in an American barn with a walkway in the center. The stables were partitioned by wooden panels, with metal bars at the front and an open-top stable door facing into the central aisle. All horses were bedded on wood shavings (depth 5–10 cm) covering approximately half of the stable floor, with rubber matting beneath covering the full floor. The stables were cleaned each morning between 07:00 and 08:00 and intermittently throughout the day until 19:00. Horses had *ad libitum* access to water provided in a large bucket and refreshed regularly throughout the day. Forage was provided in a quantity dictated by the yard managers at 07:00, 12:00, and 19:00. Horses were stabled continuously, without turnout due to weather and field conditions, but were exercised daily for one to two and a half hours, which comprised light ridden flat or jumping work, or groundwork in an arena. Ethical approval was granted by the Hartpury University Ethics Committee (ETHICS2023-73-LR).

2.2. Study Equipment and Design

One Sony Super HAD Bullet Closed-Circuit Television (CCTV) camera was mounted in each of the stables of the horses in the study. A 650 TV Line Infrared Night vision Hikvision 4 Channel H.263 960H USB DVR was used to record the behavior of stabled horses, resulting in a total of 112 hours of footage. Duration of specific behaviors was measured using continuous focal sampling against a pre-existing ethogram adapted from [26] (Table 1). Recordings were taken between 00:00 and 07:00 when high proportions of sleep behavior have been observed [9,27], and these were watched retrospectively, enabling increased accuracy of data recorded. Total duration of each behavior was calculated for each horse on every observed night by one observer, an undergraduate student who had been trained to use the ethogram. CCTV video footage was reviewed retrospectively using VLC media player, and start/end times of state behaviors were recorded into a spreadsheet that enabled calculation of cumulative totals.

Table 1: Ethogram adapted from [26].

Behaviors	Definition for the purpose of the study
Lateral recumbency	Recumbent, either lateral thoracic area parallel to and in contact with the ground, head immobile and in contact with the ground, legs extended.
Sternal recumbency	Recumbent, with the sternum in contact with the ground, legs folded beneath the body.
Standing rest	Standing immobile, relaxed tail, relaxed head and neck position (either level with or below the withers), limited leg movement.

Thermachron iButtons© (**Figure 1A**) were used to measure under-rug temperature, which allows high-accuracy data collection, with an accuracy of ± 1 °C from –30 °C to 70 °C, and the capability to measure temperature at user-programmable intervals (Thermachron iButton Device | Analog Devices, 2015). The iButton© is both reliable and valid when measuring human skin temperature [28]. A validity test, conducted prior to the current study to ensure accuracy of temperature measures, placed iButtons© in an incubator for comparison of temperatures against incubator temperature. Results confirmed that the buttons could detect temperatures accurately in the local environment. Small pockets were sewn into the inside of rugs to the left of the withers in each horse, into which iButtons© were placed (**Figure 1B**). This location was chosen to minimize irritation [29]. As horses largely wore rugs only at night, temperature data collection was limited to this period. The buttons recorded temperature data at 10-minute intervals each night, and data were downloaded daily. Due to equipment limitations, it was not possible to record over consecutive nights; however, nights one and two recorded temperatures starting at 19:00 on 30/11 and finishing at 07:00 on 02/12, while nights three to five recorded temperatures starting at 19:00 on 05/12 and finishing at 07:00 on 08/12.

2.3. Data Analysis

Statistical analysis was completed using IBM SPSS© (version 29.0.0.0). Data are presented as means ± standard deviation, and statistical significance was set at $P < 0.05$. Linear mixed models (LMMs) were used to account for repeated measures within horses, with horse included as a random effect. To test for differences in overnight mean under-rug temperatures between nights, night was included as a fixed effect. Additional LMMs were used to examine relationships between environmental overnight temperature and under-rug temperature, and between behavioral state variables and under-rug temperature. Residuals were approximately normally distributed, and plots showed no evidence of heteroscedasticity or nonlinearity.

3. Results

The mean under-rug temperature from all horses across five nights was 22.91 ± 0.12 °C (minimum 14.0 °C, maximum 34.0 °C). A significant effect of night ($F[4,8.303] = 15.35$, $P < 0.001$) was detected, indicating that measurements differ significantly across nights even when accounting for variation between horses. Estimated marginal means analysis indicated that Nights 1 (21.40 ± 0.76 °C) and 2 (20.72 ± 0.84 °C) were significantly lower ($P < 0.001$) than Night 5 (25.43 ± 2.44 °C). Night 3 (23.25 ± 0.76 °C) was also significantly lower ($P = 0.018$) than Night 5. Night 4 (24.93 ± 0.78 °C) was not significantly different ($P = 0.534$) compared to Night 5. The model-based estimates were slightly higher than the raw means due to adjustments for between-horse variability and some missing data. The estimated variance between horses was 22.45, indicating substantial differences between individual horses.

Although under-rug temperature tended to increase with increasing environmental temperature (**Table 2**), the fixed effect of environmental temperature was not statistically significant ($F[1,15.23] = 1.93$, $P = 0.185$), indicating no strong evidence that environmental temperature predicted under-rug temperature in this dataset. The repeated measures residual variance was estimated at 33.60, with a low autocorrelation across nights ($\rho = 0.051$), suggesting little temporal dependency.

Figure 1: (A) Thermachron iButtons© (B) Placement pocket on rugs.

Table 2: Mean and standard deviation for under-rug temperatures (°C) per horse, per night. Lowest environmental temperatures are shown in brackets against each night.

	Horse 1	Horse 2	Horse 3	Horse 4	Total average per night
Night 1 (–5 °C)	20.05 (± 1.16)	18.87 (±1.46)	28.04 (±1.21)	18.63 (±1.73)	21.40 (±4.12)
Night 2 (–6 °C)	20.53 (±0.88)	No data	27.73 (±1.45)	16.47 (±1.20)	21.58 (±4.82)
Night 3 (4 °C)	21.78 (±1.46)	20.5 (±1.75)	29.69 (±0.92)	21.04 (±0.96)	23.25 (±3.98)
Night 4 (–4 °C)	21.95 (±0.88)	21.94 (±1.02)	33.16 (±0.37)	22.66 (±1.70)	24.93 (±4.89)
Night 5 (4 °C)	24.36 (±1.17)	23.35 (±0.97)	No data	21.67 (±0.87)	23.13 (±1.50)
Total average per horse	21.74 (±1.88)	21.16 (±2.14)	29.66 (±2.41)	20.09 (±2.62)	

3.1. Relationship between Behavior and Under-Rug Temperature

The mean total duration of sternal recumbency (128.5 ± 59.53 minutes per night) was higher than the mean total duration of lateral recumbency (7.5 ± 11.5 minutes per night) and standing rest behavior (111.1 ± 85.1 minutes per night). This pattern was consistent across all nights but with variable individual variation in duration of behavioral states (**Table 3**).

The fixed effect of under-rug temperature on duration of sternal recumbency across repeated nights was not significant (F[1,12.80] = 0.000, *P* = 0.997), indicating no association between temperature and this behavior. The estimated intercept was 102.26 (SE = 50.17, t = 2.04, *P* = 0.61, 95% CI [−5.41, 209.93]). The regression coefficient for temperature (β = 0.01, SE = 2.12, t = 0.004, *P* = 0.997, 95% CI [−4.58, 4.60]) indicates that each 1 °C increase in temperature was associated with an increase of approximately 0.01 seconds in sternal recumbency behavior, but this is not statistically significant. The repeated measures covariance structure showed a moderate autocorrelation across nights (ρ = 0.609) and large residual variance (σ2 = 4098.86), suggesting substantial variability in behavior not explained by temperature.

The effect of under-rug temperature on lateral recumbency approached statistical significance (F[1,11.29] = 3.95, *P* = 0.072), suggesting a potential trend-level relationship between temperature and this behavior. The estimated intercept was 14.44 (SE = 6.18, t = 2.34, *P* = 0.046, 95% CI [0.32, 28.55]). The regression coefficient for temperature (β = −0.40, SE = 0.20, t = −1.99, *P* = 0.072, 95% CI [−0.85, 0.04]) indicates that each 1 °C increase in temperature was associated with a decrease of approximately 0.40 seconds in lateral recumbency behavior, but this is not statistically significant. The repeated measures component showed a strong autocorrelation across nights (ρ = 0.873), indicating that behavior was highly consistent from one night to the next. The residual variance was estimated at 102.72.

The effect of temperature was not statistically significant (F[1,9.72] = 0.549, *P* = 0.476), indicating no evidence of an association between under-rug temperature and standing rest. The estimated intercept was 88.73 (SE = 71.61, t = 1.24, *P* = 0.236, 95% CI [−65.21, 242.67]). The regression coefficient for temperature (β = 1.37, SE = 2.94, t = 0.46, *P* = 0.648, 95% CI [−4.99, 7.73]) indicates that each 1 °C increase in temperature was associated with an increase of approximately 1 minute and 20 seconds in a standing rest position, but this is not statistically significant. The autocorrelation across nights was low (ρ = 0.071), suggesting standing rest behavior varied considerably from night to night within horses. However, between-horse variance was substantial (σ^2 = 6764.33), indicating individual differences in overall standing rest behavior levels.

4. Discussion

In this pilot study, the Thermacron iButtons were able to record under-rug temperatures, which were analyzed alongside sleep-related behavior. The premise of the study was based on the link between core body temperature and sleep onset, and how a non-invasive tool could be used to begin exploring this without the need for disruptive invasive temperature measurements. Sleep, under entrained conditions, is typically initiated on the declining portion of the core body temperature curve, when its rate of change and body heat loss are maximal [**30**]. It is possible that under-rug temperatures could be indicative of heat dissipation resulting from reductions in core body temperature, but further research is still required to understand this relationship [**31**], with consideration of skin and/or rectal temperature also being necessary.

Recumbent behaviors were measured in the current study due to their inferred association with sleep states [**11**]. All horses in the study displayed recumbent postures, although some failed to engage in lateral recumbency. While horses need to engage in recumbent postures to address the muscle atonia associated with REM sleep, they can achieve this sleep state in sternal recumbency [**32**]. Where lateral recumbency was observed, there appeared to be a relationship between its duration and under-rug temperatures. A recumbent posture could help reduce convective heat loss in colder environments by reducing blood flow to the periphery and the rate of breathing through stationary postures [**33**,**34**] but also via NREM sleep [**35**]. In contrast, higher under-rug temperatures could cause thermal discomfort, as evaporative heat loss is less effective when rugged [**20**], where a recumbent posture could help via conductive heat loss between the horse and the stable floor surface. The efficiency of this heat exchange would depend upon the dimensions of the rug, the thickness and hair formation of the coat, and relative air humidity [**33**,**36**]. A heat map of the stable could identify where cold and hot spots exist; for example, it has been suggested that wood shavings do not have the same insulative properties as straw [**37**], such that bedding could influence sleep-related behavioral strategies beyond the provision of comfort through depth [**11**].

Horse three had the highest under-rug temperatures and engaged in recumbent behaviors for the longest average duration. Whether this behavioral profile would change under a different rugging strategy remains unclear. Differences in sleep-related behavior profiles between horses may also be influenced by human caregivers through decisions regarding rug allocation. After a relatively warm evening (night 3 = 4 °C), where under-rug temperatures averaged 23 °C, the temperature on night 4 dropped by 8 °C; however, the highest average under-rug temperature was recorded on this night. It is possible that the rugging strategies employed to mitigate against the temperature drop were the cause; therefore, the use of under-rug temperature recordings could help horse caregivers make reasoned judgments about which rugs to employ.

Table 3: Duration of behaviors (minutes) per night per horse.

	Horse	Duration of lateral recumbency	Duration of sternal recumbency	Duration of standing rest behavior	Total duration resting behavior
Night 1	1	4.2	163.1	75.3	242.6
	2	0	48	18.3	66.3
	3	20.6	188.7	53.6	262.9
	4	0.5	104.2	190	294.7
Night 2	1	4.1	98.6	134.1	236.8
	2	No data	No data	No data	No data
	3	7.8	174.9	64.4	247.1
	4	0	20.5	240.5	261
Night 3	1	1.8	165.3	280.6	447.7
	2	0	132.2	12.7	144.9
	3	22.7	210.7	47.5	280.9
	4	No data	No data	No data	No data
Night 4	1	0	141.4	115.9	257.3
	2	0	72.1	30.3	102.4
	3	22.8	159.3	152.3	334.4
	4	No data	No data	No data	No data
Night 5	1	0.3	98.1	112.4	210.8
	2	0	119.1	48	167.1
	3	38.5	234.1	61.3	333.9
	4	3.6	54.3	251.9	309.8

The general lack of lateral recumbency observed in this study is an interesting point to consider, as this posture is commonly associated with the REM sleep state, during which body thermoregulation is greatly reduced [22]. If thermoregulation is less effective during REM sleep, then a reduction in this sleep state could represent a strategy for preserving heat in stabled horses. Similar lower durations of recumbency have been reported [38] when horses were moved from their home stables measuring 4.8 m × 4.8 m to stables within a veterinary hospital measuring 3.8 m × 3.6 m, similar to the size of the stables in the current study. The lack of lateral recumbency observed may also be a direct consequence of wearing a rug, as horses at pasture wearing rugs engage in less locomotion [39], suggesting that rugs could physically restrict movement. As the process of adopting and rising from recumbency is physically demanding, it is possible that rugs impede movement required to facilitate recumbency or cause discomfort during lateral recumbency specifically.

Significant differences in under-rug temperatures were observed between nights. When ambient temperatures rise during sleep, humans typically regulate by increasing their exposed surface area [13], which is not a strategy readily available to rugged horses, highlighting a lack of agency and the importance of appropriate rugging decisions. Although no relationship between environmental and under-rug temperatures was detected in the current study, environmental temperatures were not recorded in real time. Instead, overnight environmental temperatures were identified retrospectively (weatherspark.com), which was not specific to the barn or surrounding rural environment. Future studies are advised to measure environmental temperatures across the night, ideally recording ambient temperatures within the stable to determine whether under-rug temperatures are responsive to these external factors. The iButtons used in this study could also be used for this purpose.

Overall, the Thermacron iButtons© proved to be a useful non-invasive tool with which to capture under-rug temperature; however, there were some limitations to data recording. Both the buttons and the CCTV equipment were unable to reliably record across consecutive nights due to technical issues. Data collection was also affected by a horse that removed the rug containing the button. To increase validity, being able to check the feed from the button and CCTV in real time would decrease the likelihood of missed data. Future studies may also investigate how to attach buttons to the horse directly to reduce any secondary complications associated with the addition or removal of rugs. Although buttons were sewn into locations deemed less likely to irritate the horse, we cannot rule out that the horse that removed its rug was irritated by the button. A period of habituation to buttons is recommended in future studies. Not relying on the rug to carry the button could help with this and would also enable the inclusion of a control group. While the influence of the thermal environment as a key determinant of sleep and sleep regulation is broadly known [40], the lack of a control group in the current study affects our ability to confirm that the behaviors displayed were directly linked to under-rug temperatures.

Additional limitations of the study include the small, convenience-sampled population and the lack of detail regarding body condition score, coat length/density, and thermal sensitivity, all of which could influence body temperature. Horses were exercised as per their usual routine, but details regarding this and turnout were not recorded, partially limiting meaningful interpretation of sleep behavior. It is also worth noting that this was an aging population of horses, observed at only one time point within a year when the thermal environment was below the equine thermoneutral zone. Future studies should gather temperature information at different time points during the year, when the thermoneutral zone is affected by seasonal differences.

The small sample size may have affected statistical power. Mixed-effects model assumptions were assessed via inspection of residual diagnostics, which indicated that residuals were approximately normally distributed. However, the standard errors were moderate to large relative to covariance parameter estimates, indicating high uncertainty. Visual inspection of scatterplots suggested an approximately linear relationship between predictors and outcomes for under-rug temperature and lateral/sternal recumbency, except for standing rest behavior. Repeated-measures correlation also indicated inter-individual differences in under-rug temperatures. Thus, while the data reasonably met the assumptions of the Linear Mixed Model, these limitations prevent generalization beyond the observed sample. Results should therefore be interpreted cautiously, within the context of the exploratory nature of this study.

Finally, the lack of daytime behavior observations was not deemed detrimental, as equine sleep largely occurs during the night in stabled horses [32], although resting behaviors, including sternal NREM and REM, have been observed during the day [10,41]. We cannot therefore eliminate daytime resting as a reason for reductions in lateral recumbency or standing rest at night. Similarly, it is unknown how much natural light horses received during the study. Melatonin synthesis and secretion are closely associated with the sleep–wake cycle, with melatonin secretion increasing as daylight fades and rapidly decreasing in the presence of light [42,43]. Furthermore, horses tend to sleep longer during shorter daylight hours and reduced temperatures [32]. Different levels of resting behavior compared with other studies [41] may be the result of seasonal differences, as similar recumbent durations have been reported during winter months under comparable environmental conditions [26]. Future studies are recommended to address these issues and to consider the use of different sleep metrics. Latency to sleep onset has proven to be a useful measure of the relationship between temperature and sleep [13]. Sleep quality metrics [44] could also improve our understanding of how rugging may affect behavior and sleep, due to the link between core body temperature and sleep quality in humans [45].

5. Conclusions

This pilot study demonstrated the potential of Thermacron iButtons© as a relatively easy and non-invasive way of measuring under-rug temperature in rugged horses while they are stabled. Findings suggest that under-rug temperature may reflect thermoregulatory processes associated with sleep, highlighting the importance of correct rugging decisions. Variability in under-rug temperatures across nights, and the absence of real-time environmental temperature data, highlight the need for more controlled environmental monitoring in future studies. Additionally, technical challenges and a small, aging sample population limit the generalizability of the results. However, the study lays foundational groundwork for future research, which might also aim to identify how to attach the iButtons, or similar equipment, to the horse without the need for a rug, thereby enabling the inclusion of a control group. Future investigations should also aim to include larger and more diverse horse populations, real-time ambient monitoring, and alternative sleep metrics, such as sleep onset latency and sleep quality. With respect to heat transfer, it could be useful to identify "cold" and "hot" spots within the stable that may also influence lying behavior. Overall, this study supports the use of under-rug temperature as a useful proxy for exploring the thermal influences on equine sleep behavior and provides direction for more robust future research in this underexplored area.

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Authors' Contributions

I.B.: Conceptualization, Methodology, Formal analysis, Data curation, Visualization, Validation. L.G.: Conceptualization, Formal analysis, Writing – original draft, Writing – review & editing, Visualization, Project administration. L.C.: Software, Validation, Resources, Writing – review & editing.

Data Availability

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

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Conflicts of Interest

The authors declare that there are no conflicts of interest.

Ethical Approval

Ethical approval was granted by the Hartpury University Ethics Committee (ETHICS2023-73-LR). The authors confirm that the study followed the guidelines of the Declaration of Helsinki.

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