La evaluación de las secuelas neuromusculares post daño cerebral mediante termografía. Un estudio piloto

The assessment of neuromuscular sequels post brain damage by thermography. A pilot study

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RESUMEN

Introducción: las secuelas relacionadas con el daño cerebral son la tercera causa de discapacidad en el mundo y la segunda de muerte. La subjetividad del evaluador en la valoración del tejido trófico es siempre un elemento a tener en cuenta. En este sentido, los objetivos de este estudio piloto fueron observar la fiabilidad y validez de la técnica termográfica en pacientes con secuelas motoras tras daño cerebral. *Material y método:* se reclutaron 28 pacientes con afectación neuromuscular. Un investigador ciego especializado en la evaluación del daño neuromuscular midió la afectación según la Escala de Ashwort, determinando el grado de restricción y resistencia a la flexión del tobillo, mientras que 2 investigadores registraron los patrones térmicos. *Resultados:* en el primer momento de la medición, la temperatura de las dos piernas por separado no superó los 30,2 ºC en el 75 % de los casos y en el segundo momento no superó los 29,7 ºC. Las mediciones medias en la pierna izquierda y derecha ofrecen valores máximos inferiores a 31,9 ºC para ambas. En conjunto, las mediciones fueron de una media de 28,4 ºC con una desviación típica de 1,928. En el 75 % del total de las mediciones hubo una temperatura igual o inferior a 29,8 ºC, por lo que la temperatura en estos pacientes patológicos parece generalmente inferior a 32 ºC. *Conclusión:* la termografía podría ser una herramienta fiable y válida en la valoración de pacientes con daño neuromuscular; sin embargo, son necesarios más estudios con un mayor tamaño muestral para clarificar el papel de esta técnica en relación con el daño neuromuscular.

Palabras clave: termografía, daño cerebral, ictus, neuromuscular.

ABSTRACT

Introduction: *sequelae related to brain damage are the third leading cause of disability worldwide and the second cause of death. The subjectivity of the evaluator in assessing trophic tissue is always an element that must be taken into account. In this regard, the objectives of this pilot study were to observe the reliability and validity of the thermographic technique in patients with motor sequelae after brain damage.* Material and method: *twenty-eight patients with neuromuscular involvement were recruited. A blinded researcher, specialised in the assessment of neuromuscular damage, measured the impairment according to the Ashwort Scale determining the degree of restriction and resistance to bending of the ankle, while two researchers recorded thermal patterns.* Results: *in the* *first measurement, the temperature of the two legs separately did not exceed 30.2 °C in 75 % of cases, and in the second measurement it did not exceed 29.7 °C. The average of the measurements on the left and right legs offered maximum values of less than 31.9 °C for both. Overall, measurements had an average of 28.4 °C with a standard deviation of 1.928. In 75 % of the total measurements, the temperature was equal to or lower than 29.8 °C indicating that the temperature in these pathological patients generally appears to be lower than 32 °C.* Conclusion: *thermography is a reliable and valid tool for assessing patients with neuromuscular damage; however, further studies with a larger sample size are needed to clarify the role of this technique in relation to neuromuscular damage.*

Keywords: *thermography, brain damage, stroke, neuromuscular.*

AVAILABITY OF THE STUDY'S DATA

The data generated or analyzed in this study are included in this article.

ABBREVIATIONS

ATM: Atmosphere
BMI: Body Mass Index
CT: Computerized Tomography
ΔT: Difference of temperature
HYP: Hypotonia
LH: Left hemiplegia
LL: Left leg
PMI: Psycomotor impairment
RL: Right leg
RH: Right hemiplegia
ROI: Region of interest
SD: Spastic diplegia
TE: Tetrapelegia
TISEM: Thermographic Imaging in Sports and Exercise Medicine
WHO: World Health Organisation

INTRODUCTION

According to the WHO, sequelae related to brain damage are the third leading cause of disability worldwide and the second leading cause of death(1, 2). With 13 million new cases reported each year, of which over a third are associated with permanent functional dependency(3, 4), neuromuscular disfunctions secondary to brain damage pose a significant challenge for both patients and healthcare personne l(5). The initial step in providing appropriate treatment and follow-up for each patient involves assessing the motor and sensory sequelae post-injury(6). Despite the numerous numerical scales used for this purpose, the subjectivity of the evaluator is always an factor to consider(7–10). This is why diagnostic imaging techniques are always the preferred choice for evaluating trophic tissue(11–13).

While infrared thermography has been proposed in recent studies as a valid tool for assessing and monitoring the treatment of patients with atrophy and weakness secondary to brain damage(14, 15), or even for assessing muscle tissue and functional response in neurodegenerative diseases(16), its high cost, the challenge of interpreting imagines accurately and the time required for certain tests have led to its consideration. Thermography is a diagnostic technique that records infrared radiation emitted by tissues, and converts it into a thermal pattern. It is currently considered a reliable, cost-effective, portable and the used technique for quantifying and tracking numerous pathologies(17, 18).

However, despite its wide use in diseases related to the integumentary system(19, 20), endocrine system(21), or vascular system(22), there are no studies in which this technique has been used as a tool to assess and quantify functional response and tissue at a neuromuscular level following brain damage.

In this context, the objectives of this pilot study were twofold: first, to observe the reliability and validity of the thermographic technique in patients with motor sequelae after brain damage, correlating the thermal data with a specific and validated assessment scale; and second, asses the diagnostic capacity based on the temperature criterion in healthy patients.

MATERIAL AND METHOD

Study design

A longitudinal descriptive observational study was carried out. Thirty patients with neuromuscular involvement secondary to brain damage were recruited from the Astrapace Centre (Asociación para el Tratamiento de Personas con Parálisis Cerebral y Patologías Afines, an association for the treatment of individuals with cerebral palsy and related pathologies). The study received approval from the Ethics Committee of the Catholic University of San Antonio of Murcia, Registration Number CE102107, and informed written consent was obtained from the patient or their relatives. A health worker specialising in brain damage classified patients according to age, sex, BMI and functional diagnosis through medical observations.

Inclusion criteria and exclusion criteria

All patients who had suffered brain damage with more than 5 years of evolution and had motor impairment in at least one anatomical region were included. Patients who were infected by SarsCovid-19 in the last year were excluded, as its potential influence on thermography is unknown. Patients who did not comply with the recommendations of the TISEM[23] protocol, as outlined in the information sheet, and those who could not understand the commands given throughout the tests were also excluded. The TISEM protocol is a check-list published in 2017 that describes the key variables to be considered in order to execute a thermographic measurement that generates less possible biases are described. For instance, it includes variables related to the intake of drugs, alcoholic beverages or drugs that could affect the thermographic measurement, which the examiner must control according to the parameters outlined in this evaluation list.

Population

Ten patients with psychomotor impairment, ten patients with spastic diplegia, five patients with right spastic hemiplegia, three patients with spastic quadriplegia, one patient with left spastic hemiplegia and one patient with generalised hypotonia were included in the study. A blinded researcher specialised in the assessment of neuromuscular damage measured the impairment according to the Ashwort Scale[24], determining the degree of restriction and resistance to bending of the ankle, while two researchers recorded thermal patterns.

Thermography

Before the thermography measurement, all patients had to acclimatise to the environment for a period of 15/20 minutes in a room that was 15 m^2, at a temperature between 20 °C and 23 °C, humidity of 40 % (± 0.8 %), and atmospheric pressure of 1 ATM[25–27]. The room was free of electronic devices and received sunlight through a window far from the measuring point. During this period, patients underwent a body temperature check (with a digital thermometer) to rule out alterations in basal temperature, and information was collected to ensure compliance with the TISEM[23] protocol. Patients were placed in shorts on a 1.5 meter-thick cotton pad to avoid direct contact with the floor and thus generate temperature changes in the lower limbs. In order to perform the most reliable measurements and analysis possible, two blinded researchers with more than two years of experience in thermography recorded and analysed images of the back of the leg on different days and hours, with one week between measurements. ROIs were identified from the lower edge of the popliteal fossa up to 15 cm above the lower edge of the heel, thus analysing the gastrocnemius region[28, 29]. Image processing was performed using Flir's IR research program/software[30].

Thermograph

The thermograph used for this work is the Flir E75 model. This thermograph has an infrared resolution of:

320 × 240 pixels, thermal sensitivity: < 0.04 °C and registers from −20 °C to +120 °C. To enable the machine to calibrate itself accurately for the room conditions, the principal investigator turned it on one hour before conducting the initial scan, placing it on a tripod at a distance of 1 m from the patient registration point, with a 10° to 15° inclination. The emissivity was set to 0.98, as recommended by the manufacturer and corroborated in other studies[31, 32].

Data analysis

The sample was described by reporting the frequencies for qualitative or categorical variables and presenting mean, standard deviation, median, interquartile range, and the minimum and maximum values for quantitative variables. Additionally, the Krustal-Wallis test was used to examine differences in all variables among pathologies, and the Fisher's exact test was employed to study the relationship between sex and the diagnosed pathology. The software analysis was conducting using R (version 4.1).

Reliability of the instrument

To assess the reliability of thermography as a diagnostic test, paired Student's T tests, Wilcoxon tests and Interclass Correlation Coefficient (ICC) were applied to investigate the following:

1. Whether the values of ΔT were affected by the time of measurement.
2. If the ΔT of the right leg between the two measurement times was significantly different from the difference in the left leg between the two times.
3. If the ΔT found between the right leg and left leg at one time was statistically different at another time.

Due to such as camera error, capture error, non-flat body shape, and variability in defining the left and right ROI, ΔT values were categorized as follows: high reliability if ≤ 0.5, moderate reliability if between 0.5 and 1, and low or unreliable if > 1 degree[33, 34].

Converged validity.
Relationship between Temperature and Movement Restriction (Ashworth Scale)

Spearman's correlations were used based on the results of the Shapiro-Wilk normality tests, and graphs were created for visualisation. The significance of the correlations was assessed (other than 0), and the Cohen[35] criterion was used to estimate the size of the correlation effect: a large effect corresponds to r = 0.50, a medium effect to r = 0.30 and small effect to r = 0.10.

Validity of the instrument referred to judgement

As bibliography after publication of the TISEM[23] protocol does not provide an absolute reference value for thermographic patterns of normality on the gastrocnemius, older reference values were used, setting the normality threshold at 32ºC, based on previous studies[36, 37]. Thus, we studied temperature values in each leg for each time point and as a whole. In general, thermography showed lower temperatures in pathological patients than those in the reported in the literature for healthy patients. The approach to the normal distribution of these variables was assessed by means of the Shapiro Wilk, followed by the Student´s T test and the Wilcoxon test for a single sample.

RESULTS

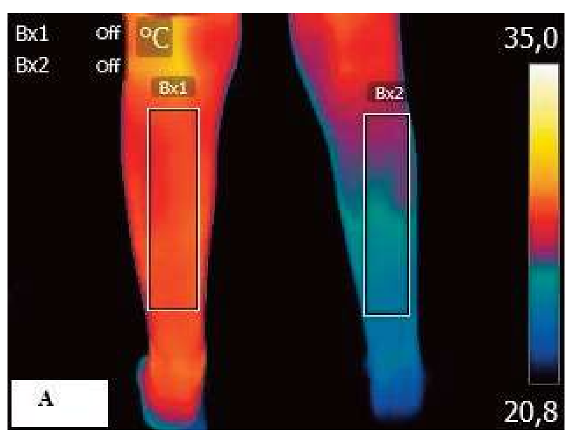

IMAGE 1. **Thermographic image of patient with right hemiparesis secondary to brain damage.**

TABLE 1. **General data.**

	Total (n = 28)	SD (n = 9)	HR (n = 5)	HL (n = 1)	HYP (n = 1)	PMI (n = 9)	TE (n = 3)	p-value
GENDER								0.0201
W	16 (57.1%)	3 (33.3%)	3 (60.0%)	1 (100.0%)	1 (100.0%)	8 (88.9%)	0 (0.0%)	
M	12 (42.9%)	6 (66.7%)	2 (40.0%)	0 (0.0%)	0 (0.0%)	1 (11.1%)	3 (100.0%)	
AGE								0.52
Mean ± SD	33.6 ± 7.5	32.4 ± 5.6	31.8 ± 6.6	34.0 ± NA	33.0 ± NA	32.3 ± 5.4	44.3 ± 15.5	
Median [25%-75%]	32.0 [28.8-35.5]	31.0 [31.0-32.0]	32.0 [26.0-33.0]	34.0 [34.0-34.0]	33.0 [33.0-33.0]	31.0 [28.0-37.0]	38.0 [35.5-50.0]	
BMI								0.0852
Mean ± SD	26.4 ± 5.4	23.7 ± 4.3	26.7 ± 8.5	32.7 ± NA	20.6 ± NA	28.2 ± 3.5	28.6 ± 5.1	
Median [25%-75%]	26.0 [22.6-30.8]	24.1 [23.1-25.7]	22.5 [21.7-26.0]	32.7 [32.7-32.7]	20.6 [20.6-20.6]	27.6 [27.1-31.2]	31.0 [26.9-31.5]	
LL 1º								0.42
Mean ± SD	29.2 ± 1.4	28.8 ± 1.3	29.8 ± 1.5	28.0 ± NA	28.0 ± NA	29.5 ± 1.6	29.2 ± 0.9	
Median [25%-75%]	28.8 [28.2-30.2]	28.5 [27.7-29.7]	29.9 [28.7-30.0]	28.0 28.0-28.0]	28.0 [28.0-28.0]	28.8 [28.6-30.8]	29.0 [28.8-29.6]	
LL 2º								0.42
Mean ± SD	27.9 ± 2.0	27.5 ± 1.6	29.2 ± 1.3	28.7 ± NA	24.8 ± NA	28.2 ± 2.2	27.2 ± 2.6	
Median [25%-75%]	28.5 [26.2-29.3]	26.6 [26.1-28.7]	29.3 [28.6-29.3]	28.7 [28.7-28.7]	24.8 [24.8-24.8]	28.5 [26.2-29.3]	27.9 [26.1-28.6]	
RL 1º								0.52
Mean ± SD	29.0 ± 1.8	29.0 ± 1.7	27.6 ± 2.7	28.9 ± NA	27.9 ± NA	29.8 ± 1.2	29.4 ± 0.6	
Median [25%-75%]	29.1 [27.9-30.2]	28.7 [27.3-30.7]	27.9 [25.8-29.5]	28.9 [28.9-28.9]	27.9 [27.9-27.9]	29.9 [29.5-30.5]	29.1 [29.0-29.6]	
RL 2º								0.42
Mean ± SD	27.7 ± 2.2	27.6 ± 2.1	27.0 ± 2.0	29.8 ± NA	24.4 ± NA	28.5 ± 2.1	27.3 ± 2.9	
Median [25%-75%]	28.2 [25.8-29.7]	26.8 [25.8-29.7]	27.0 [25.4-28.0]	29.8 [29.8-29.8]	24.4 [24.4-24.4]	29.4 [26.3-29.7]	28.6 [26.2-29.0]	
ASHWORT RIGHT								0.0012

TABLE 1. **General data** (continuation).

	Total (n = 28)	SD (n = 9)	HR (n = 5)	HL (n = 1)	HYP (n = 1)	PMI (n = 9)	TE (n = 3)	p-value
Mean ± SD	1.8 ± 1.4	2.6 ± 1.1	3.2 ± 0.4	1.0 ± NA	0.0 ± NA	0.3 ± 0.7	2.0 ± 0.0	
Median [25%-75%]	2.0 [0.0-3.0]	3.0 [2.0-3.0]	3.0 [3.0-3.0]	1.0 [1.0-1.0]	0.0 [0.0-0.0]	0.0 [0.0-0.0]	2.0 [2.0-2.0]	
ASHWORT LEFT								0.0032
Mean ± SD	1.4 ± 1.3	2.6 ± 1.1	0.2 ± 0.4	2.0 ± NA	0.0 ± NA	0.6 ± 0.9	2.3 ± 0.6	
Median [25%-75%]	1.0 [0.0-2.0]	3.0 [2.0-3.0]	0.0 [0.0-0.0]	2.0 [2.0-2.0]	0.0 [0.0-0.0]	0.0 [0.0-1.0]	2.0 [2.0-2.5]	

SD: Spastic diplegia; RH: Right hemiplegia LH: Left hemiplegia, HYP: Hypotonia, PMI: Psycomotor impairment,
TE: Tetrapelegia, LL:Left leg, RL:Right leg, BMI: Body mass index. 1 Fisher's exact test; 2 Kruskal-Wallis rank sum tes.t

The main hypothesis of this study was to find evidence of reliability and validity that would demonstrate the suitability and effectiveness of thermography as a diagnostic test for this type of patient. This involved operationalizing these results to show temperatures significantly lower than the criteria used for healthy patients, a significant correlation with the scores on the Ashworth scale, and temperature differences that, although they varied significantly between moments, did not exceed 0.5ºC between legs and moments.

The final sample consisted of 16 women and 12 men, as 2 subjects were excluded for meeting one of the exclusion criteria (SarsCovid-19). The median age and a BMI were 33.6 ± 7.5 and 26.4 ± 5.4, respectively. In the comparative analysis between pathologies, no variables, such as age or BMI, or any thermographic measurements, showed significantly different values between pathological groups, except for the Ashworth Scale ($p < 0.05$ for both legs). PR patients had mean values lower than 1, unlike the rest of pathologies (table 1).

In the first moment of measurement, the temperature of the two legs separately did not exceed 30.2 ºC in 75 % of cases, and in the second moment, it did not exceed 29.7 ºC. The average measurements on the left and right legs offered maximum values of less than 31.9 ºC for both. Overall, measurements had an average of 28.4 ºC with a standard deviation of 1.928. In 75 % of the total measurements, there was a temperature equal to or lower than 29.8 ºC, so the temperature in these pathological patients generally appears lower than 32 ºC (table 1). To determine whether these observed temperatures were significantly lower than 32 ºC, a one-sample Student´s t-test was carried out for the left unilateral contrast, except for the RL measurements at the 2nd moment, for which the Wilcoxon one-sample test was applied as it did not meet the assumption of normality ($W = 0.9626$; $p < 0.05$).

All contrasts showed significant differences (RL 1o: $t = -9.0537$, $p < 0.05$; LL 1o: $t = -10.861$, $p < 0.05$; RL 2o: $V = 0$, $p < 0.05$; LL 2o: $t = -11.019$, $p < 0.05$), thus, it could be rejected with 95 % confidence that the sample temperature is equal to or higher than 32 ºC.

Relationship between Temperature and Ashwort Scale

Ashwort Scale data for both legs did not follow a normal distribution ($W_{RL} = 0.879$, $p < 0.05$; $W_{LL} = 0.851$, $p < 0.05$) so Spearman correlations were calculated. In this case, the correlations were significantly different from 0 in the right leg at the first moment ($rho_{RL1o} = -0.407$, $p < 0.05$) unlike the right leg at the

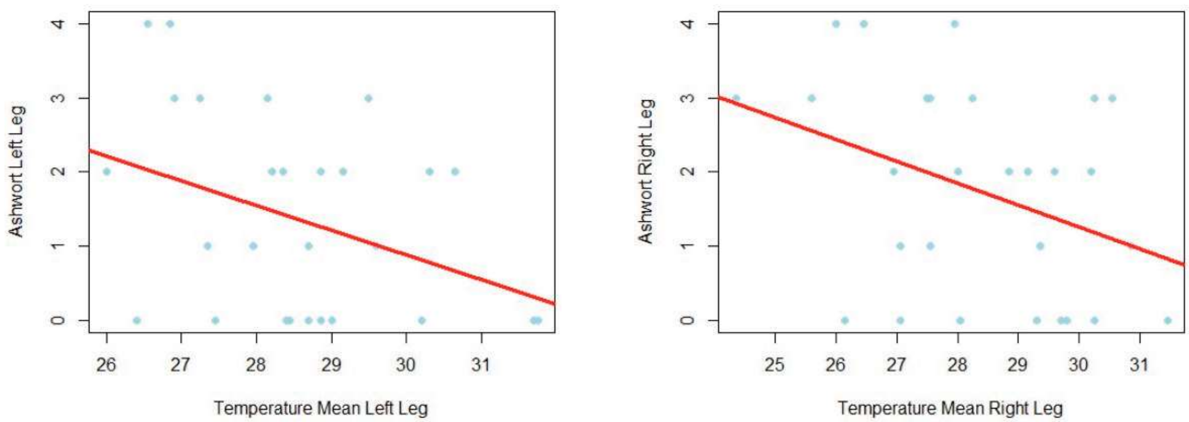

IMAGE 2. **Relationship between Ashwort Scale and Average Temperature of Left Leg and Right Leg.**

second moment and the left leg in both (rhoRL2o = -0.270, p = 0.165; rhoLL1o = -0.291, p = 0.132; rhoLL2o = -0.296, p = 0.126). According to the criterion proposed by Cohen, the first correlation mentioned would be considered of medium-high magnitude, and the other 3 of average magnitude. Image 2 shows how the relationship was negative.

Reliability of the instrument

As see in Image 3, the values of the thermography are not significantly equal at the two temporal moments (V RL = 53.5, $p < 0.05$, ICC= 0.505; t LL = -4,109, $p < 0.05$, ICC = 0.421), but it seems that, although there are differences between the two moments for each individual leg, those differences are not significantly distinct form one leg to the other (t DifRL-DifLL = -0.604, p = 0.551, ICC = 0.976). Similarly, the differences between the two legs at any given time are not significantly different between time 1 and time 2 (V DifT1-DifT2 = 174, p = 0.501, ICC= 0.965).

As shown in table 1, the differences between the legs were significantly greater than 0.5 both at time 1 (t = 2,7328, $p < 0.05$) and at time 2 (V = 313, $p < 0.05$). A total of 5 cases, representing 17.86 % of the sample, exhibited differences greater than 0.5 ºC between moments for the differences between the legs, indicating a low reliability of the test.

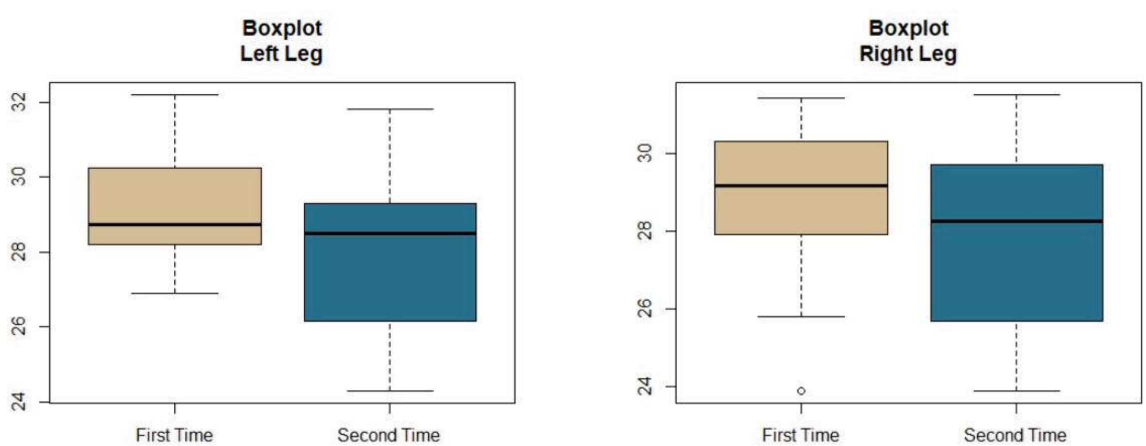

IMAGE 3. **Temperature differences between moments on the left and right leg.**

Within this subgroup, only 1 person (3.57 %) obtained values of 1, indicating low reliability, while the other 4 (14.29 %) were considered to have intermediate reliability values (between 0.5 and 1 ºC). Among these 5 cases, 3 were diagnosed with RH, 1 with PMI and one with TE. In contrast 82.14 % of the sample, exhibited differences between the legs that did not vary by ± 0.5 ºC between one time and another, indicating a high reliability. Statistically, these differences between moments of the differences between legs were not significantly greater than 0.5º (t = -4,688, p = 1).

DISCUSSION

The objectives of this pilot study were to evaluate the diagnostic ability based on temperature values in healthy patients, observe the reliability and validity of the thermographic technique in patients with motor impairment after brain damage, and describe the possible relationship between the thermal challenge and the Ashworth scale.

Diagnostic capacity

It is known by other authors that thermal asymmetries (between sides) in the same subject and thermal differences in the same anatomical region between different subjects could be evidence of pathological situations, both acute and chronic. Therefore, numerous reliability and validity studies have been carried out in both pathological subjects[38–40] and in healthy subjects[41, 42], to de-

TABLE 2. **Temperature differences in absolute value.**

Case	Patology	1ª ΔT RL & LL	2ª ΔT RL & LL	ΔT 1ª & 2ª	Case	Patology	1ª ΔT RL & LL	2ª ΔT RL & LL	ΔT 1ª & 2ª
1	PMI	0.4*	0.4*	0.0	15	SD	0.5	0.8	0.3
2	SD	0.5	0.6	0.1	16	PMI	2.5	2.1	0.4
3	SD	0.8	0.6	0.2	17	SD	0.2*	0.2*	0.0
4	TE	0.0*	0.0*	0.0	18	RH	2.9	3.9	1.0**
5	RH	0.5	0.7	0.2	19	RH	4.4	3.8	0.6**
6	SD	1.0	1.0	0.0	20	TE	0.6	0.7	0.1
7	SD	1.0	1.1	0.1	21	LH	0.9	1.1	0.2
8	HYP	0.1*	0.4*	0.3	22	TE	0.2*	0.4*	0.2
9	SD	0.3*	0.5	0.2	23	PMI	0.3*	0.5	0.2
10	PMI	0.2*	0.3*	0.1	24	RH	1.5	1.5	0.0
11	SD	0.5	1.3	0.8**	25	PMI	0.9	1.2	0.3
12	PMI	1.0	0.8	0.2	26	RH	2.0	1.3	0.7**
13	PMI	0.7	1.3	0.6**	27	PMI	1.1	1.0	0.1
14	SD	1.5	1.2	0.3	28	PMI	1.6	1.2	0.4

SD: Spastic diplegia; RH: Right hemiplegia LH: Left hemiplegia: HYP: Hypotonia; PMI: Psycomotor impairment, TE: Tetrapelegia, LL: Left leg; RL: Right leg; *Temperature differences between legs < 0.5 ºC; **Differences between moments of the differences between legs > 0.5 ºC termine normal and clinical reference values. In this sense, our results support previous research. When comparing a sample with neuromuscular involvement after brain damage and thermal references in the literature of healthy patients(36, 37), we have observed lower temperatures in the first group compared to the second. In fact, in 75 % of the total measurements there was a temperature equal to or lower than 29.8 ºC, so the temperature in these pathological patients generally appears lower than 32 ºC. A muscle that is spastic, stunted, or with sarcopenia(43, 44) is known to present physiological and functional alterations of a different nature compared to a healthy structure(45–47). The difference in blood supply between affected and healthy muscles could justify, on the one hand, the thermal mismatch between the two groups and, on the other hand, the increase in the Ashworth score in patients with lower temperatures. This is because healthy muscle tissue is more elastic, efficient, and vascularised than trophic, rigid and poorly vascularized tissue, whether hypertonic, spastic, or hypotonic. In fact, recent studies carried out with CT scan and thermography in patients with degenerative neuromuscular dystrophy have shown that as(48–51) the disease progresses the trophic nature of the disease increases, and the temperature in the anterior and posterior regions of the lower limbs decreases. This thermal decrease was associated with a decrease in muscle functionality in terms of strength-resistance(52, 53).

However, the age of the healthy groups taken as reference is different from the age of the groups analyzed in our study, something that, according to the most current thermographic protocols, could be affecting the thermographic responses. Nevertheless, we believe that although age is an important factor to take into account in thermographic measurements, in this case the range of ΔT between healthy and affected patients is wide enough to determine that we are not analysing a physiological change due to age(54) but due to pathological status. In fact, there are no known previous studies where there is a ΔT greater than 2 ºC among healthy populations in similar metabolic conditions(55) even at different ages, as previous studies have shown that the thermographic difference between young and adult women in the posterior region of the leg does not exceed 1.5 ºC.

Using normality values as a comparative thermographic tool has generated a lot of controversy in previous years. In fact, Uematsu et al.(56), suggested not using thermal ranges of normality but the asymmetric thermal degree between opposite sides of the same body region, as the possible standardisation of normality patterns could lead to a biased interpretation of thermal results. Today, thanks to the TISEM(23) scale and the continuous development in terms of precision and reliability of thermographic equipment, this technique has acquired a much greater sensitivity, significantly limiting the risk of bias(57, 58). However, it should be noted that although there are studies that offer normality reference values of the posterior region of the leg in healthy populations, so far there is no full consensus on the thermographic values of the lower limbs of healthy patients(59, 60). This aspect highlights the need to investigate and have reference values of normal thermographic patterns based on differences in anatomical regions, ages, and genders, to have a basis on which to base future studies.

Reliability and validity of the thermographic technique

The primary findings of this preliminary study (indicate) suggest that thermography may be a valid and reliable method for (evaluating) assessing thermal variations in the posterior leg region of individuals with neuromuscular impairments after brain damage. It is important to note that the observed thermal difference between the two measurements in within the same patient is likely attributable to the time gap between the two readings. It is known that, as the day progresses, thermoregulation and physiological processes in the human body change, resulting in varying thermographic patterns within the same patient throughout the day(61). However, despite the observed temperature variation within the same patient and the same leg region on different days, statistically, this variation is not significantly different from one leg to the other. This suggests that the temperature change is likely associated with the time difference between measurements on different days. Moreover, the temperature difference between legs remains constant over time. This could indicate that physiological changes are influenced more by the thermal patterns at different times of the day than by variations in the quantity or quality of affected muscle tissue, which appear to remain stable regardless of the time or day. Nonetheless, we believe that this aspect warrants further investigation in future research, as it could provide valuable insights onto understanding the phycological response based on time differences and help optimize therapeutic treatment protocols.

Thermography and Ashworth scale

The results show a poor correlation between the Ashworth scale and the thermographic data since there is a statistically significant correlation between the Ashworth scale and thermography in just one moment and in a single leg. Numerous studies have demonstrated the reliability of the Ashworth scale in the assessment motion restriction associated with spasticity or hypertonia in patients with neuromuscular sequelae[62, 63]. However, some authors[64] have suggested not using this scale due to its low inter-evaluator reliability and poor reliability in assessing reflex muscle activity compared to electromyography[65]. These facts show the need to compare a numerical scale of assessment with an objective tool, given the subjective nature of the examiner when quantifying the clinical assessments. Although this study has shown that thermography does not correlate with the assessment of neuromuscular damage using the Ashworth scale, we believe that the small size of the sample could be the fundamental reason for this lack of total significance, since all correlations have been negative and of medium magnitude, demonstrating that as the temperature decreases, the scale increases. Based on previous studies that have shown that the average temperature of analyzed ROIs varies as the musculoskeletal system is affected, even in trophic diseases[66, 67], it would be interesting to explore whether a larger sample with more specific characteristics might reveal a common thermal pattern for specific functional diagnoses. In this study, such conditions were not available, and only one patient was included for certain pathologies.

According to these results, it has not been possible to determine whether the skin temperature challenge could be a useful element in assessing the degree of neuromuscular involvement after brain injury. However, we believe that the small sample size in this study is a significant limiting factor and may have reduced the statistical value. Future studies are needed to assess the involvement of the nervous and musculoskeletal systems, as this could influence the cutaneous thermal response. This would help to understand how different levels of functional involvement could lead to different cutaneous thermal patterns. If future studies can establish a significant correlation between the quantification of neuromuscular sequelae and thermographic images, it would be possible not only to streamline the process of evaluating such sequelae, but also this could be of extreme importance for monitoring the effects of rehabilitation protocols and pharmacological therapies that want to act on the motor sequelae in patients with these characteristics.

CONCLUSION

Thermography is a fast, economic, non-invasive, and objective tool. This study has analysed the potential role of this technology in a small group. A large-scale study, based on these initial results, and conducted with appropriate instruments, standardised protocols, and well-trained professionals, would be highly recommended to objectively quantify the neuromuscular sequelae after brain damage. This approach would utilize a cost-effective and reliable tool, patients and therapists with a more precise diagnostic method. Furthermore, we believe that these findings could assist various healthcare professionals in assessing the most current rehabilitaron techniques, ultimately contributing to reducing the financial expenses associated with the evaluation process and the development of clinical protocols.

ETHICAL RESPONSIBILITIES

Protection of people and animals. The procedures followed in this study comply with the basic principles of the Declaration of Helsinki of the World Medical Association, updated in 2013 in Fortaleza (Brazil) and completed with the Taipei declaration of 2016 on ethical considerations on the bases of health data and biobanks.

Confidentiality and informed consent. The authors declare that they are responsible for carrying out the protocols established by their center to evaluate the participating subjects for the purpose of research and scientific dissemination, and guarantee that they have met the requirement of having informed verbally and in writing all the participants who formed part of the study, being in possession of the informed consent signed by the subjects.

Data confidentiality and right to privacy. The authors declare the guarantee of the privacy of the volunteers' data and state that the published manuscript does not violate personal data protection regulations. No names, initials, or medical record numbers (or any type of research data that could identify the participants) are used.

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Author contributions. Alessio Cabizosu: contributed with the idea, data collection, writing the document. Daniele Grotto: participated in data collection and analysis, document review. María José López Esteban: has participated in data collection and analysis, document review. Raúl Castañeda Vozmediano has participated in data analysis, writing the document. The authors declare that they have read and accepted the published version of the manuscript, meeting the requirements for authorship.

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