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ORIGINAL ARTICLE

Infrared Clinical Thermography: Normal Foot Growth Parameters

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Background: Clinical thermography is a relatively novel technique in wide use in different medical fields because of its versatility and ease of application. It inflicts no pain and it entails no contact with the pediatric patient, which assuages anxiety and fear in subjects when undergoing diagnostic exploration. The use of infrared clinical
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thermography being suggested here is to establish normality patterns, which have not been described in the relevant literature. These patterns may be extrapolated to pathological study by means of future research lines.

Methods: An observational, cross-sectional study (descriptive in nature) has been carried out, with a sample population of 328 children divided into two age groups; 6-7 and 13-16 years old, all of them schooled in the province of Cáceres (Spain). The variables analyzed here are: age, sex, and temperature. A FLIR E60bx® thermographic camera has been used to study foot temperature.

Results: Results show that the temperature varies among the different study areas established for the foot, although they remain constant bilaterally. In addition, the highest temperature is found to be located in the area of the first toe (29.8°C), and the lowest at the heel (28.8°C).

Conclusions: It can be concluded that both feet have the same thermal behavior, despite the variation in temperature among the different areas that were established in the foot for the purposes of this study.

Podopaediatrics is the branch of podiatry devoted to the prevention, diagnosis, and medical treatment of disorders and deformities of the foot during the growing process of children. This clinical branch has been consistently neglected, especially as regards
prevention, from a scientific point of view. As a result, the relevant literature and related scientific studies are relatively scarce.\textsuperscript{1}

The onset of foot disorders during infancy, followed by the lack of proper diagnosis and treatment, entails the development of pathologies that may become irreversible in adults. Hence the importance of early diagnosis and periodical clinical monitoring during later development stages\textsuperscript{1}, since it may prevent growth-related disorders such as osteochondritis and flat feet\textsuperscript{2-6}.

Thermography is a non-invasive clinical tool, in addition to its being accurate, testable, and quantifiable. It is used to visualize and quantify changes in surface skin temperature by using high-performance thermal image cameras\textsuperscript{7-11}.

Although relatively novel, their use is already common practice in some branches of medicine. This study argues for their use in pediatrics, because thanks to a single photograph (i.e., in a non-invasive way), one can obtain a wide array of data on the changes of temperature in different areas of the foot. This data can be extrapolated to many pathologies that are associated to infancy, such as child flat feet\textsuperscript{9}, where local blood flow may be altered\textsuperscript{12}.

The literature does not cover the normal temperature of the foot in pediatric patients. This premise accounts for the research goal here: trying to determine the normal temperature parameters in different areas of the foot. The selected areas are directly connected with the onset of the pathologies with the highest prevalence.
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among infants. Thus, by establishing normal temperature patterns, this study would set the foundations for future research linking deviation from normal temperature and different pathologies.

Methods

This is an observational, cross-sectional study (descriptive in nature), with a sample population of 328 children aged between 6-16 years, all of them schooled in the province of Cáceres (Spain).

The subjects who have undergone medical growth tests or surgery have been excluded from the present study. Children who suffer from structural, functional, and/or traumatological alterations affecting the lower limbs have also been excluded.

The present study complies with the standards of the Ethics Committee of the Universidad de Extremadura (Spain).

A total of fifteen different variables have been considered, among which age, sex, core body temperature, room temperature (24 °C) and humidity (50%) are especially relevant. Room humidity was measured with a FLIR MR77 moisture meter. The temperature of the different study areas of the foot was also measured: heel, first and fifth metatarsal heads, and hallux. A FLIR E60bx® camera (FLIR® Company, Boston, USA) was used for the purpose of measuring the temperature of each area.
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Intervention Protocol

Forty-eight hours prior to the data collection, the legal guardians of the children were advised to follow certain recommendations so as not to eschew the results of the test; e.g., avoid the application on the skin of any moisturizing or alcohol-based cream, since they may alter heat radiation on the skin\textsuperscript{13-15}.

The room where the data was collected met certain criteria as regards humidity, temperature and comfortability, so that the images could be obtained correctly\textsuperscript{14-16}. According to the parameters described in the relevant literature, the room was at a temperature ranging between 23°C and 25°C, with a relative humidity close to 50% \textsuperscript{17-19}.

Special attention was paid to avoiding physiological or postural attitudes during data collecting that may compromise the results of the research. All the subjects were at rest so as to ensure thermal balance because perspiration may cause their skin to yield inaccurate temperature readings and, consequently, eschew the results of the study. Actions such as crossing one’s legs, or raising them above heart level may alter blood flow in the lower limbs and, as a result, also alter skin temperature\textsuperscript{17}.

Temperature measurements were taken in the mornings in order to minimize the influence of temperature variation among patients\textsuperscript{18}.

Likewise, sunlight was avoided onto the camera lens or onto reflecting objects in its field of view\textsuperscript{17}.

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Once the thermographic camera was set up, the temperature settings were adjusted and calibrated. This is done by pointing the camera towards a foot that has a normal temperature at a distance of 1 meter from the object. If we consider the color scale of the thermal image, it is worth noting that the temperature range of the human body is rather limited. Therefore, we can see an iridescent scale ("rainbow") where red is hot and blue/black is cold. All images were analyzed with the software suite FLIR Tools, taking into consideration four major areas of the foot sole (heel, first and fifth metatarsal heads, and hallux). The software editor was used to calculate the arithmetic mean of the temperature in the four designated spots.

Statistical Tools

Data have been managed with the software suite IBM SPSS Statistics v. 21 for iOS. The inferential statistical tools that have been utilized consist of nonparametric tests because the characteristics that have been considered, whether qualitative or quantitative, are not normally distributed. More specifically, here we apply the chi-square test (for qualitative characteristics) and the Kruskal-Wallis and Friedman tests for quantitative data—between groups (paired samples) and in-group (independent samples), respectively. Tukey’s multiple comparison test was also performed. Finally, the Shapiro-Wilk test was run in order to check whether the quantitative...
characteristics are normally distributed.

The distribution of the whole sample (328 subjects) by gender is the following: 168 girls and 160 boys—thus displaying a rather clear balance between them. If this data is compared to the ratio of girls in the whole of Extremadura (0.5042, see National Statistics Institute) and in the age range between 6 and 16 years (0.4877), no significant differences can be observed (p-value 0.407 and 0.203, respectively. Binomial test).

The age range for the subjects is further subdivided into two groups: namely, 6-7 and 13-16—the first group being slightly larger, with an observable significance as a result of their uneven distribution (p-value 0.098. Chi-square test).

Some statistical significance may be ascribed to gender distribution between age groups (p-value 0.065. Chi-square test). Specifically, there are more girls than boys in the 6-7 age group, whereas the reverse is true in the 13-16 group.

Results

The foot skin temperature data is not normally distributed, which is why the statistical study has been made through non-parametric tests. The average temperature in all areas of both feet was observed to be around 29°C (Table 1). At any rate, temperature variation—as shown in Figure 3—within the same foot was found to be significant. (p-value below one per thousand. Friedman test).
Specifically, the highest temperature is found on the 1st metatarsal head, and the lowest at the heel (p-values < 0.001. Multiple comparison). The difference to the temperature of the 5th metatarsal head and the first toe is statistically significant p-values < 0.001. Multiple comparison).

By contrast, there is no significant difference in temperature between these two areas (5th metatarsal head and the first toe), in either the left or the right foot (p-value 0.496 and 0.774, respectively. Multiple comparison).

Finally, after checking each of the areas in both feet, only the first toe presents a difference that is statistically significant Figure 4 (p-value 0.048. Friedman test)—while there may be indications of statistical significance in the 5th and 1st metatarsal heads (p-values 0.076 and 0.09, respectively. Friedman test).

On the other hand, there is no significant difference in the heel between both feet. (p-value 0.694. Friedman test).

However, differences in thermal behavior is indeed significant in all areas of the foot in terms of the age variable. This study demonstrates that temperature increases with age at the least by 1.5°C on average in the first toe and at most by 3.4°C at the heel. See Figure 5 and Table 2 (p-values < 0.001. Kruskal-Wallis test). This applies to both feet.
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Thus, we are able to determine the average temperature in each section of the foot based on the age range, which allows to establish the thermal normality pattern for those areas in relation to the age variable.

Discussion

Our analysis of the specific temperature of the foot leads to the conclusion that its average temperature lies around 29°C, although these data cannot be compared with results by other authors, since there is no literature on the subject. It can safely be said that there is a difference of 7-8°C with respect to body temperature, because authors like Morrison state that the average body temperature lies around 36-37°C²³.

Likewise, it can be said that the first metatarsal head presents a higher temperature than the rest of the areas under scrutiny, a fact that can be connected with Viladot’s findings that the first head is one of the points of the sole that endures the highest pressure because it serves as the supporting pillar of the external longitudinal arch²⁴. This may account for the temperature increase in that area.

The age of the study population is a key variable for the statistical analysis of data, since the pathologies that affect the growing foot are clearly described for the different stages of development²⁵. This premise informed the decision to separate the study population into age groups—i.e., not randomly but based on the principles of the existing literature²⁶,²⁷.
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The statistical data analysis shows how the normal temperature of the foot at age 6 lies between 27.5°C – 28.6°C, while it is noted a slight increase between ages 13-15 (30.3°C-31.2°C) later to decrease again from age 16 onward (28.7°C-29.9°C).

Body temperature usually drops steadily as age increases, as we transition from children into adults, as reported by authors like Petrofsky and Kenny. This is due to the deterioration of vasodilation and vasoconstriction, and the resulting decline in the ability to release body heat. However, it must be noted that during childhood temperature increases with age because of the hormonal changes induced by puberty.

It must also be noted that what has been said applies to body temperature but not to foot temperature—and that the temperature recorded in core areas is higher than that of acral areas because of the comparative lack of vascularity of the latter (as they are usually more exposed to environmental elements). Therefore, based on the premise that the higher the blood flow of a given area, the higher its temperature, one must suppose that as the child grows and the fusion of the epiphyseal plates takes place, the blood flow necessary for this process will slowly wane in the mature areas.

Thus, the results of this study are coherent with the existing literature, because the ages at which the temperature is the highest are those with the highest bone activity, due to the complete fusion of the primary and secondary ossification.
centers\textsuperscript{35,36}. In view of this, this study may be said to lay the foundations for further research on the processes of osteochondritis, where a decrease in temperature at an age where it should be at its highest may be an indication of deficient blood flow and of the onset of a pathology that derives from the anomalous development of the area although it is very important to take into account the hormonal change at that age, which according to we have observed in our study also has relevance in temperature. Clinical infrared thermography may reveal itself as very useful in this regard.

Conclusions

According to the variables under analysis, and in light of the statistical tests that have been carried out, it can be concluded that there is no significant difference in temperature between both feet. There is indeed a similar thermal behavior between the soles of the left and right foot, with an average of 29\textdegree{}C (6-7 degrees cooler than the average temperature of the body).

In addition, significant differences have been found among the study areas on the sole of both feet—with higher temperatures being recorded in the metatarsal area of the first toe; and lower temperatures at the heel, with differences of up to 1\textdegree{}C between them.
Temperature varies markedly during the growth process of the foot. The normal temperature of the foot in the first group (6-7 years) oscillates between 27.5°C and 28.6°C; it increases slightly during the second group (13-15) (30.3°C-31.2°C).

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Conflict of Interest: None reported.

References


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<table>
<thead>
<tr>
<th></th>
<th>RIGHT FOOT</th>
<th>LEFT FOOT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average (°C) ± SD</td>
<td>Average (°C) ± SD</td>
</tr>
<tr>
<td>1st METATARSAL HEAD (A)</td>
<td>29,72 ± 2,41</td>
<td>29,83 ± 2,50</td>
</tr>
<tr>
<td>5th METATARSAL HEAD (B)</td>
<td>29,27 ± 2,56</td>
<td>29,19 ± 2,62</td>
</tr>
<tr>
<td>1st TOE (C)</td>
<td>29,01 ± 2,91</td>
<td>29,12 ± 2,97</td>
</tr>
<tr>
<td>HEEL (D)</td>
<td>28,79 ± 2,66</td>
<td>28,80 ± 2,67</td>
</tr>
</tbody>
</table>

*Table 1: Average temperature of both feet*

<table>
<thead>
<tr>
<th>AGE</th>
<th>6-7</th>
<th>13-16</th>
</tr>
</thead>
<tbody>
<tr>
<td>AREA</td>
<td>A ±SD</td>
<td>L</td>
</tr>
<tr>
<td>1st MH</td>
<td>28,7 ± 2,1 (23,2-33)</td>
<td>30,1 ± 2,2 (25,2 - 35,6)</td>
</tr>
<tr>
<td>5th MH</td>
<td>27,9 ± 2,1 (23,6-32,7)</td>
<td>30,7 ± 2,1 (25,6 - 35,0)</td>
</tr>
<tr>
<td>HEEL</td>
<td>27,5 ± 2,14 (23,1-33,7)</td>
<td>30,2 ± 2,3 (25,7-34)</td>
</tr>
<tr>
<td>1st TOE</td>
<td>28,5 ± 2,7 (20,6-33,1)</td>
<td>29,6 ± 2,9 (20,3-35)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>AREA</th>
<th>1st MH</th>
<th>5th MH</th>
<th>HEEL</th>
<th>1st TOE</th>
</tr>
</thead>
<tbody>
<tr>
<td>RIGHT FOOT</td>
<td>28,6 ± 2,2 (23-33,2)</td>
<td>31,2 ± 2,2 (23,8 - 34,4)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LEFT FOOT</td>
<td>27,8 ± 2,2 (23-33,8)</td>
<td>30,8 ± 2,3 (24,3 - 34,1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>27,5 ± 2,1 (22,8 - 32,4)</td>
<td>30,9 ± 2,3 (26,1 - 34,4)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>28,6 ± 2,7 (20,6 - 33,5)</td>
<td>30,3 ± 3,3 (19,3 - 34,4)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*A (Average temperature in Celsius) ± SD (Standard deviation by age in years) L (Lowest temperature) H (Highest temperature)*

*Table 2: Thermal analysis of a child’s foot.*
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Figure 1. Thermal image of both feet.
Figure 2. Image analyzed with the software suite FLIR Tools
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Figure 3: Box plot of the temperature of the left foot (left) and of the right foot (right)

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Figure 4. Box plot of the temperature of the first toe in both feet.
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**Figure 5:** Box plot of temperature values at different ages.