Naif Arab University for Security Sciences
Arab Journal of Forensic Sciences and Forensic Medicine
المجلة العربية لعلوم الأدلة الجنائية والطب الشرعي
https://journals.nauss.edu.sa/index.php/AJFSFM

Estimation of Intra and Inter-Individual Variability of Post Mortem Skin Hydration by Corneometry

تقدير تباين رطوبة الجلد بعد الوفاة في الفرد الواحد و بين الأفراد عن طريق قياس الطبقة القرنية

Aurélien Partoune[1]*, Anne-Françoise Donneau[2], Nadia Dardenne[2], Philippe Boxho[1]
[1]Forensic Institute of Liège, University of Liège, Belgium.
[2]Biostatistics Unit, Public Health Department, Liège University, Belgium..

Received 26 Oct. 2024; Accepted 11 Dec. 2024; Available Online 24 Dec. 2024.

Abstract

Kinetics of post mortem skin desiccation, potentially useful for post mortem interval (PMI) determination, is poorly understood. We therefore propose a preliminary study to assess intra- and inter-individual variability of post mortem skin hydration using a valid method, such as corneometry. Corneometer CM-825® (Courage & Khazaka electronic GmbH, Cologne, Germany) measures the stratum corneum hydration (SCH) by measuring its electrical capacitance, given in arbitrary units (A.U.). To assess intra- and inter-individual variability of SCH, we evaluated SCH at 19 body sites for 30 subjects with known cause of death at 6 ± 2 hours post mortem (hpm). Thirty subjects (20 males and 10 females) were selected. Mean age was 73.6 ± 9.1 years, mean BMI was 23.9 ± 5.2 kg/m^2. There is a significant effect of body site on SCH values. Inter-individual variability appears to be significant, depending on the considered body site. Biological sex does not influence studied parameters, but age, BMI and cause of death influence SCH values, at various degrees depending on the considered body site. This study highlights the significant intra- and inter-individual post mortem variability in skin hydration levels. The intra-individual variability of this parameter means that the skin should not be considered as a homogeneous surface in future studies of post mortem skin desiccation.

Keywords: Forensic sciences, thanatology, anthropology, post mortem interval, skin, skin hydration, stratum corneum, skin capacitance, corneometer CM-825®.

المستخلص

لا يزال فهم حركية جفاف الجلد بعد الوفاة، والتي قد تكون مفيدة في تحديد فترة ما بعد الوفاة، محدودًا. لذلك، نقترح دراسة أولية لتقييم التباين داخل الفردية وخارجها لرطوبة الجلد بعد الوفاة باستخدام طريقة صالحة، مثل القياس القرني. يقيس جهاز القياس القرني CM-825® (Courage & Khazaka electronicGmbH، كولونيا، ألمانيا) رطوبة الطبقة القرنية عن طريق قياس السعة الكهربائية لها، معطاة بوحدات اعتباطية (A.U.). لتقييم التباين داخل الفردية وخارجها في رطوبة الطبقة القرنية، قمنا بتقييم رطوبة الطبقة القرنية في 19 موقعًا بالجسم لـ 30 موضوعًا معروف سبب الوفاة لديهم بعد 6 ± 2 ساعة من الوفاة. تم اختيار ثلاثين موضوعًا (20 ذكرًا و 10 إناث). كان متوسط العمر 73.6 ± 9.1 سنة، ومتوسط مؤشر كتلة الجسم 23.9 ± 5.2 كجم / م^2. هناك تأثير كبير لموقع الجسم على قيم رطوبة الطبقة القرنية. يبدو أن التباين بين الأفراد كبير، اعتمادًا على موقع الجسم المعتبر. لا يؤثر الجنس البيولوجي على المعلمات المدروسة، ولكن العمر ومؤشر كتلة الجسم وسبب الوفاة يؤثرون على قيم رطوبة الطبقة القرنية، بدرجات متفاوتة اعتمادًا على موقع الجسم المعتبر. تسلط هذه الدراسة الضوء على التباين الكبير داخل الفردية وخارجها في مستويات رطوبة الجلد بعد الوفاة. يعني التباين داخل الفردية لهذا المعامل أنه لا ينبغي اعتبار الجلد سطحًا متجانسًا في الدراسات

الكلمات المفتاحية: علوم الأدلة الجنائية، علم التثنية، الأنثروبولوجيا، فترة ما بعد الوفاة، الجلد، رطوبة الجلد، الطبقة القرنية، سعة الجلد، مقيسا القرنية CM-825®.

* Corresponding Author: Aurélien Partoune
Email: apartoune@uliege.be

doi: 10.26735/UMKE3774

The significant inter-individual variability of this parameter probably partly explains the variations in observed PMI for this phenomenon and seems to be a major challenge in using this method to determine PMI.

المستقبلية لجفاف الجلد بعد الوفاة. يبدو أن التباين الكبير بين الأفراد لهذا المعامل يفسر جزئيًا الاختلافات في فترة ما بعد الوفاة الملاحظة لهذه الظاهرة، ويبدو أنه تحدٍ رئيسي في استخدام هذه الطريقة لتحديد فترة ما بعد الوفاة.

1. Introduction

The skin is an extremely interesting organ to study in forensic medicine. It is a large organ easily accessible for non-invasive or minimally invasive measurements and samples, compatible with the respect of human dignity. Paradoxically, however, it has been relatively little studied, even though it is certainly the organ most observed by forensic pathologists [1, 2].

In living individuals, skin hydration is maintained relatively constant by transudation and sweat production. After death, these processes are interrupted and post mortem skin drying process (desiccation) can occur, notably influenced by air movements, ambient temperature, ambient relative humidity, body site, age of the subject, clothing and the presence of a skin abrasion and/or epidermic loss [3]. Historically, the link between skin desiccation and post mortem interval (PMI) has been first described by Galloway [4]. But it is only recently that authors have begun to systematically study the link between PMI and the extent of skin desiccation [5, 6].

It has been pointed out that the lack of knowledge about the post mortem desiccation of the human body may lead to an underestimation of the PMI in forensic practice as it interrupts putrefaction [5–8]. Moreover, it was also noted that the conditions under which skin desiccation occurred remained poorly understood ; and that the terms "mummification" and "desiccation", as well as the differences between indoor and outdoor skin drying processes, suffered from a lack of clear characterisation and definition in the forensic context [7, 8]. For example, Ceciliason et al, in contrast to the Galloway's historical description, describes not one but two distinct possible patterns for indoor desiccation of human bodies: i) a "leather-like" pattern, beginning at the fingers and toes pads, with brownish/blackish skin discolouration and an opaque and thickened appearance of skin ; ii) a "parchment-like" pattern, characterised by the appearance of yellowish/orange skin discolouration "patches" on the trunk, arms and thighs, with a translucent and refined appearance of skin [8].

However, it should be noted that the possible influence of the post mortem desiccation phenomenon has not been considered in recent studies on the determination of the postmortem interval by analysing the expression level of various protein or RNA markers of skin cells, namely immunohistochemical detection of HMGB1 and related proteins (Beclin1 and RAGE) [9], protein and mRNA levels of the apoptosis-related proteins Bax and Bcl-2 [10], the expression of skin-specific mRNA marker late cornified envelope 1C (LCE1C)[11], the expression of matrix metalloproteinase-9 (MMP-9) and long non-coding fatty acid oxidation (lncFAO) RNA [12], or the description of skin histological changes [13–15].

To better understand the different processes involved in post mortem skin desiccation, we believe that it could be beneficial to opt for an objective and quantitative approach through measurement of skin's bioelectrical parameters, rather than a clinical assessment which is subjective and qualitative in nature, as it has been suggested in literature [16, 17]. Especially as the literature suggests a link between PMI and the electrical properties of skin, both in non-human proxies [18] and, more recently, in human donor bodies placed in outdoor conditions [19, 20], in the form of a progressive decrease in electrical impedance. The choice of a paraclinical method, rather than a labora-

tory method, also seems appropriate to us, as such a method has the advantage of being directly usable in the field in a forensic context.

In living subjects, skin hydration can be assessed objectively and quantitatively in a validated way through its electrical capacitance, specifically with the Corneometer CM-825® (Courage & Khazaka electronic GmbH, Cologne, Germany). This device measures the electrical capacitance of the skin at a depth of 30 to 45 μm, which is deemed to correspond to the average thickness of the stratum corneum [21]. This method, usually referred to as corneometry, would have several advantages for the study of skin desiccation process as it is non-invasive, validated in vitro and in vivo in multicentre studies [21–23] and potentially used wirelessly with a laptop at the bedside of the deceased by any examiner in forensic context, Figure 1 [24]. However, this device has not yet been used on deceased subjects.

Before considering the link between PMI and skin hydration level, however, we feel it is important to assess the inter- and intra-individual variability of this parameter. Indeed, inter-individual variability of parameters significantly impacts the accuracy of PMI estimation, as intrinsic biological differences among individuals can lead to inconsistent decomposition rates [16, 17, 25]. The influence of the subject's characteristics is also highlighted in the future research prospects for several promising skin techniques mentioned above [11,13,26]. Consequently,

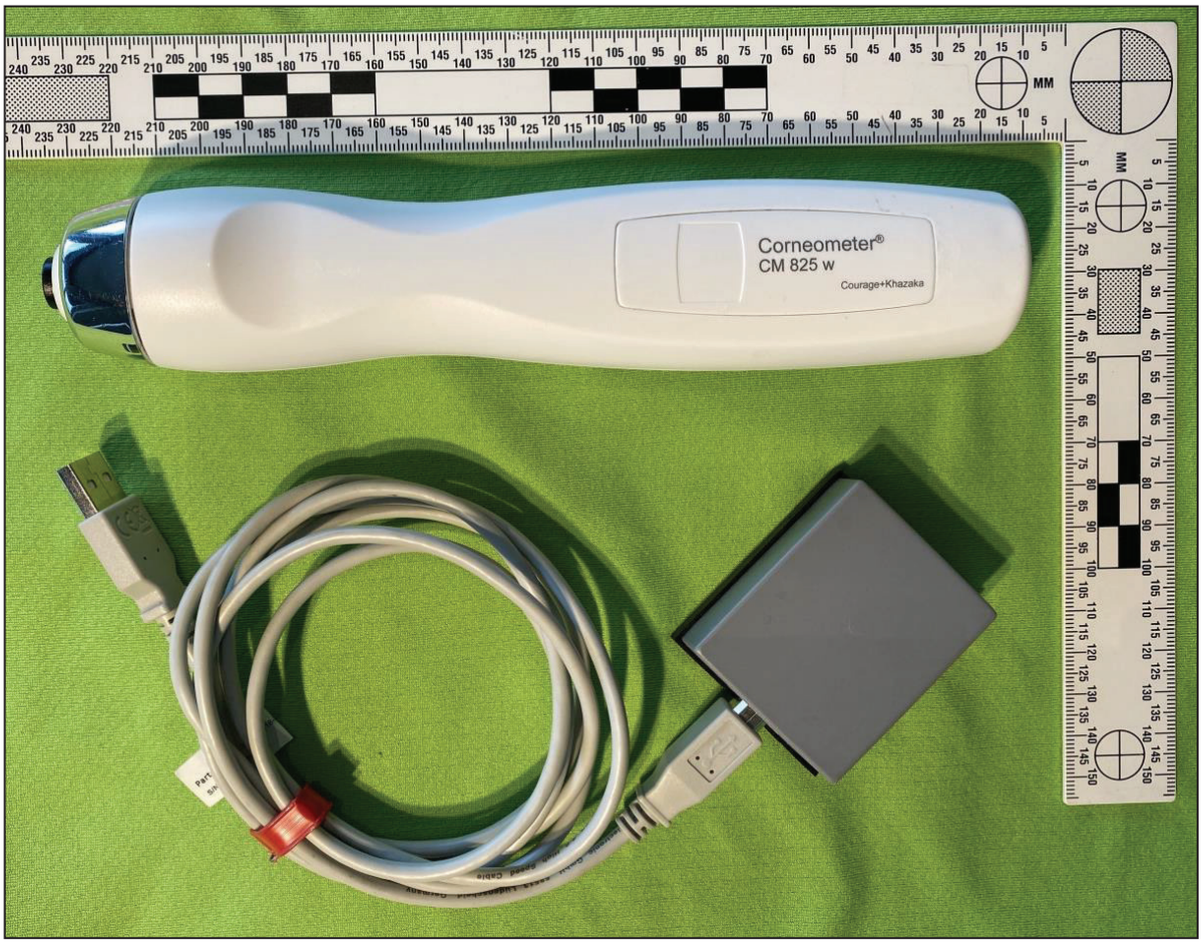

Figure 1- *Photograph of the wireless version of the Corneometer CM-825®, accompanied by the device that must be connected*

the choice of a parameter that is too variable would not be relevant in forensic practice, even if it were shown to vary with the PMI. All the more so as it is generally not possible, in a deceased subject encountered in forensic practice, to know a posteriori the basal antemortem value of a parameter that is not a constant between individuals.

The question of intra-individual variability is also critical insofar as dermatological medical literature teaches us that human skin cannot be considered as a homogeneous whole. The skin has both morphological and functional specificities from one body site to another [27–30]. As well as choosing a skin parameter to study for PMI determination, we also need to determine the body site where we want to study the skin.

Therefore, in the larger context of understanding the post mortem skin desiccation process and before going any further in the study of skin electrical properties for PMI determination, we feel it is necessary to determine basal post mortem stratum corneum hydration (SCH) values at multiple anatomical sites all over the body, within a population with known parameters to quantify the post mortem intra-individual (influence of body site) and inter-individual (influence of subject characteristics) variability of this parameter.

2. Material & Method

2.1. Corneometer CM-825

Corneometer CM-825® (Courage & Khazaka electronic GmbH, Cologne, Germany) is a 22 cm surface probe with a flat surface of 49 mm^2 inside which is a capacitor subjected to an alternating current of 0.9 to 1.2 Mhz. When the skin is attached to this capacitor as a dielectric, it changes its capacitive reactance depending on its dielectric constant (K), which in turn is a function of the skin's moisture content [31]. This instrument does not generate galvanic current, performs a measurement in 1 second and has an inaccuracy rate of ±3% following manufacturer [24]. The maximal measurement depth over 30 μm according to the producer [24] and up to 45 μm according to in vitro measurements by independent source [12]. The level of hydration is not given in absolute electrical capacitance units (Farads (F)), but indirectly, in arbitrary units (a.u.) on a scale from 0 to 120, from the driest to the most hydrated [21]. A skin is considered as normally hydrated >40 a.u., as dry between 30 and 40 a.u. and as “very” dry <30 a.u. [21]. The probe is very sensitive for dry and very dry skin conditions, but less sensitive for high levels of skin hydration [21].

The device is factory calibrated by an in vitro method with a reference pad impregnated with a calibration solution (saturated aqueous NaCl solution). The maximum reference hydration value of 120 is obtained by measuring the hydration level of this impregnated filter pad. The minimum hydration value is determined by covering the surface of the impregnated pad with a layer of 15 μm thick polyurethane foil [31].

As a result of its operating principle, there is an influence of probe application pressure and any interposed substance (including hairs) between the studied skin and the probe. The influence of probe application pressure is partially cancelled by means of a spring system theoretically enabled with a force between 1.1 and 1.8 Newton, with measurement realization indicated by an acoustic signal [24]. To avoid influence of any interposed substance, skin at measurement site must be cleaned and dried before and between measurement(s) by dabbing it with a soft towel [32]. Influence of excessive hairiness can be cancelled out by gentle shaving with a non-electric razor [33].

2.2. Measurements

A panel of 19 different body sites were chosen for SCH measurements in order to compare body

segments to each other, central areas to extremities, fat to nearby lean areas and finally dependent and non-dependent areas: forehead, nose, cheekbone, cheek, sternum, pectoral region, umbilicus, latus, dorsum, scapula, lumbus, paralumbar region, arm (anterior and posterior), index fingertip, thigh (anterior and posterior) and leg (anterior and posterior), Figure 2.

To study the effect of location using a linear mixed model (GLMM), the nineteen sites studied were grouped according to the body segment to which they belonged: the head (forehead, nose, cheekbone, cheek), anterior thorax (pectoral region and sternum), anterior abdomen (umbilicus and latus), posterior thorax (dorsum and scapula), posterior abdomen (lumbus and paralumbar region), the upper limb (arm and index) and the lower limb (thigh and leg).

We also chose to examine the possible correlation between three different arbitrary anatomical ratios of SCH and subject characteristics : one “hypostasis” ratio independent of prone position’s pressure sites (umbilicus/lumbus ratio), one “fat-lean” ratio comparing an area with a thick subcutaneous fat with an area with a thin or non-

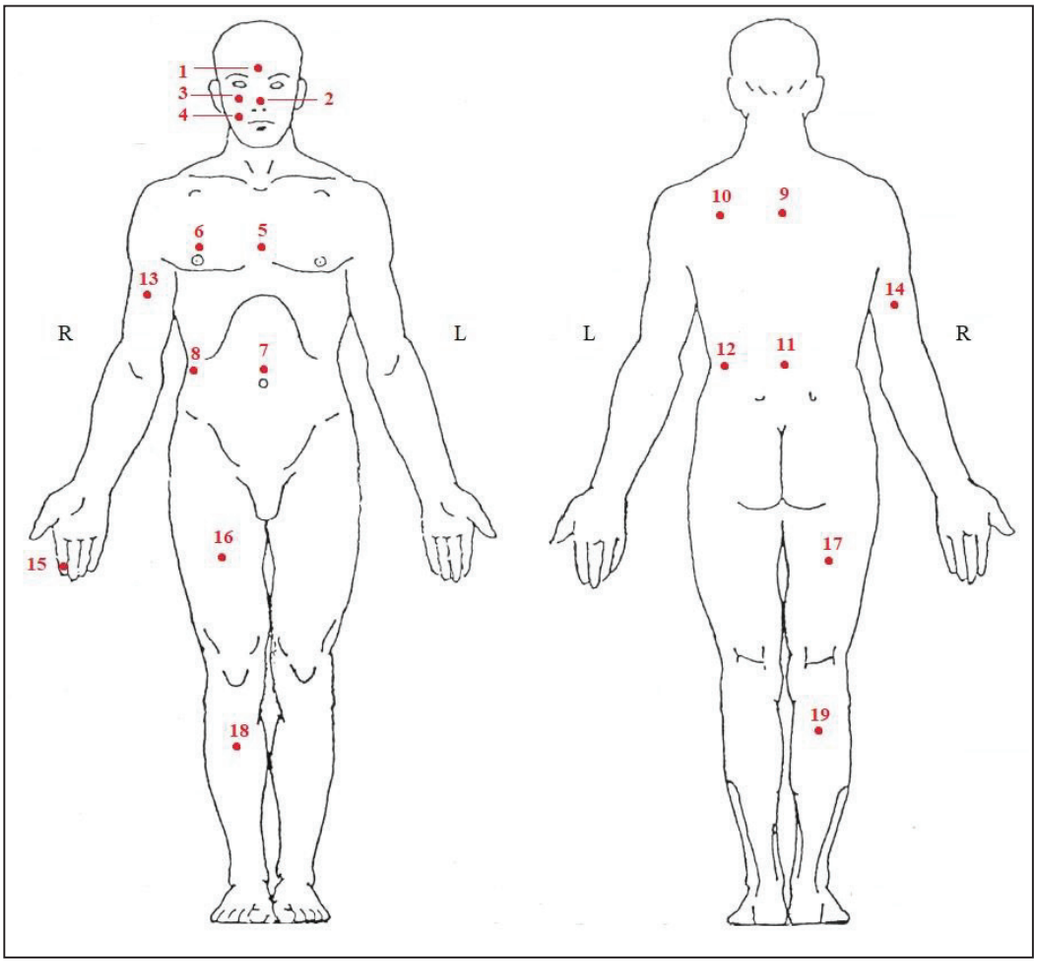

Figure 2 - *Diagram showing the selected body sites: forehead (1), nose (2), cheekbone (3), cheek (4), sternum (5), pectoral region (6), umbilicus (7), latus (8), dorsum (9), scapula (10), lumbus (11), paralumbar region (12), arm (anterior (13) and posterior (14)), index fingertip (15), thigh (anterior (16) and posterior (17)) and leg (anterior (18) and posterior (19)).*

existent subcutaneous fat (umbilicus/forehead ratio) and one “center-to-ends” ratio comparing a central area covered by clothing with an uncovered extremity (umbilicus/index ratio).

Measurements were performed outside of the mortuary fridge in a room with ambient conditions of 20-21°C and 45-55% relative humidity (RH) in less than ten minutes to prevent too much variation in skin temperature. No measurement was made under direct sunlight or any heating device. To avoid occlusion phenomenon, the repeated measurements were made using adjacent skin areas. To avoid influence of any interposed substance, particularly condensation, skin at measurement site was gently cleaned and dried before measurement(s) by dabbing it with a soft cotton towel. To obtain the most repeatable values possible while eliminating the influence of the operator hand pressure, the measurements were carried out using a low and increasing pressure until the minimum threshold for obtaining the acoustic signal from the device was reached. The SCH value retained for each body site is the average of three consecutive measurements made on one site at one second interval. The calibration of the device was checked before and after the study was carried out, in accordance with the manufacturer's instructions.

2.3. Subjects and environment characteristics

All subjects were selected from the mortuary of the University Hospital and studied in the controlled environment of the mortuary’s fridges, at 6 ± 2 hours post mortem (hpm). According to the hospital's protocol, deceased patients remain in their room for an average duration of 2 hours after their death, to allow the family to pay their respects, before entering the mortuary. Selection criteria were the following: age >60 years, skin phototype II, no previous autopsy, natural death, no dermatological pathology at measurement site.

The age criterion was chosen to homogenise the population insofar as the comorbidities and cause of death of the young deceased differed significantly from the usual population of subjects dying in hospital from a natural cause of death.

Given the exploratory nature of the study, as the post-mortem variability of the parameters was not yet known, the sample size of 30 subjects was chosen on the basis of 2 factors: firstly, by comparison with the sample sizes used in studies of this parameter in living subjects in literature [17-19]; secondly, based on a realistic estimate of the number of subjects meeting the inclusion criteria that could be recruited in one season, as some studies mention seasonal variations in SCH [20-22]. In this case, our subjects were recruited during one autumn in Belgium.

Age, biological sex (male or female), body mass index, time of death and cause of death were registered. The body mass index (BMI), expressed in units of kg/m^2, is defined as the body weight divided by the square of the body height. All subjects selected wore the same standardized outfit, made of an hospital gown and an adult diaper. Following usual morgue’s protocol, all subjects received the same post mortem grooming and were stored in the same manner: in an opened plastic bag with a covering of one thin white cotton sheet.

Six categories of cause of death were arbitrarily established for statistical analysis: heart failure, cancer, infection, stroke, internal bleeding and other.

In accordance with the hospital's internal procedure, the deceased is placed in a refrigerated mortuary cell within 3 hours of death. The refrigerated mortuary system measures 240 cm x 210 cm x 204 cm and involves 4 individual mortuary cells, where each deceased person is placed in an open plastic body bag on a stainless steel tray measuring 210 cm x 60 cm, then covered with a white cotton sheet.

Cooling is provided by means of a conventional condensation/expansion/evaporation refrigeration cycle, with an evaporator located in the cell providing cooling by capturing heat and transferring it to a refrigerant, while the heat is extracted via a ventilated air-cooled condenser located above the cell. The stability of the environment is controlled on the basis of temperature only, not humidity, using an electronic temperature controller which is given minimal and maximal reference values of 1 and 6 °C respectively. In the event of an anomaly, an audible alarm alerts the staff of the mortuary. No incident was reported during the study period and no alarm was triggered for the subjects recruited.

To ensure that the system is working properly and that the values supplied are credible, two independent continuous 72 hours-long registrations of temperature (T°) and relative humidity (RH) of fridges were made to obtain local reliable mean T° and RH and gave following mean values: 3.95°C and 3.79°C of T° with 83.63% and 86.94% RH. To find out more about the body's "microenvironment", under the sheet and inside the open body bag, one 2 hours-long registration of T° and RH was also made under cotton sheet, next to a corpse with PMI < 6 hpm and gave 4.43°C of T° and 69.21% RH. These values appear to be consistent with the alleged controls.

2.4. Statistics

The investigated parameters were summarized using the mean, standard deviation (SD), median, interquartile range (Q1-Q3), and range (Min-Max). The normality of the parameters was checked using descriptive (mean-median comparison) and graphical techniques (histogram, Quantile-Quantile plot) and the Shapiro-Wilk test. The qualitative parameters have been summarized by means of numbers and percentages.

Associations between SCH values and qualitative sociodemographic variables (biological sex and cause of death) were tested by means of a one-way analysis of variance (ANOVA-1) (if normally distributed) or the nonparametric Kruskal-Wallis (KW) (if the normality of the distribution is not met). Associations between SCH values and quantitative sociodemographic variables (age and BMI) were tested by means of a Pearson (R) (if normally distributed) or nonparametric Spearman correlation (RS) (if the normality of the distribution is not met). The 95% reference intervals were sought for the measured parameters and were plotted.

Ratios of interest were compared to value 1 using the Student univariate test or the Wilcoxon univariate test in the case of skewed distribution.

The effect of location on the studied parameters was assessed using a linear mixed model (GLMM) to allow both fixed and random effects, with the assumption that there is non-independence in the concerned parameters. Pairwise comparisons were performed, and the results were represented using Least Squares Means (LSM) and standard error (SE).

The uncertainty level is set at $\alpha = 5\%$ ($p < 0.05$). The software used were SAS version 9.4 and RStudio.

2.5. Ethical considerations

The study has been performed with agreement of the local Ethics Committee. The data collection was strictly non-invasive and did not interfere with the normal funeral process or with usual morgue's protocols. Measurements were strictly made outside of visiting hours. Measurements outside the refrigerated compartment took an average of ten minutes, a time that does not result in any alteration to the body. The absence of ante-mortem opposition to the experiment was verified in the national register before recruitment into the study. Informed consent was not sought from the family of

the deceased. Each patient has been anonymized. All data have been numerically stored and managed in an GDPR (General Data Protection Regulation of the European Union) compliant manner.

Table 1- Subjects characteristics (n=30).

Subject	Sex (male/female)	Age (years)	Body Mass Index (kg/m^2)	Cause of death
X1	M	66	27.8	Other (pancreatitis)
X2	M	80	29.1	Cancer
X3	M	83	22.1	Infection
X4	F	79	24.2	Heart failure
X5	F	75	19.1	Heart failure
X6	F	91	19.7	Hypothermia
X7	M	70	22.0	Heart failure
X8	M	72	30.5	Infection
X9	M	76	35.2	Heart failure
X10	M	74	20.4	Stroke
X11	M	91	20.7	Cancer
X12	M	73	20.2	Heart failure
X13	M	69	11.7	Infection
X14	M	63	35.1	Internal bleeding
X15	M	62	22.7	Cancer
X16	M	86	22.2	Heart failure
X17	F	64	18.4	Stroke
X18	F	65	19.0	Infection
X19	M	65	32.1	Infection
X20	F	74	28.2	Stroke
X21	M	73	23.1	Heart failure
X22	F	72	20.3	Infection
X23	M	85	24.9	Internal bleeding
X24	F	61	27.8	Heart failure
X25	F	61	24.7	Heart failure
X26	M	82	19.0	Heart failure
X27	M	90	27.5	Internal bleeding
X28	M	65	25.1	Heart failure
X29	M	68	24.7	Heart failure
X30	M	73	20.8	Stroke

3. Results

3.1. Influence of subject's characteristics

Thirty subjects (20 males and 10 females) were selected. Mean age was 73.6±9.1 years, mean BMI was 23.9±5.2 kg/m^2. The characteristics of the subjects are shown in Table 1.

Age is significantly and positively correlated with SCH values on the anterior arm (RS=0.38, p=0.040) (nonparametric correlation of Spearman) and anterior thigh (R=0.36, p=0.049) (nonparametric correlation of Spearman) (Appendix I), but do not influence other studied parameters.

BMI is positively correlated with SCH value in the forehead (R=0.37, p=0.041) (parametric correlation of Pearson) and with the umbilicus/index ratio (RS=0.40, p=0.027) (nonparametric correlation of Spearman), and negatively correlated with SCH values in pectoral region (R=-0.38, p=0.041) (parametric correlation of Pearson), anterior arm (RS=-0.37, p=0.045), index (RS=-0.47, p=0.0088) and anterior thigh (RS=-0.46, p=0.011) (nonparametric correlation of Spearman) (Appendix I).

Biological sex (Appendix II) does not influence studied parameters.

Cause of death influences the umbilicus/forehead ratio (p = 0.014, n=30) (ANOVA-1), with lower values in cardiac deaths (0.83±0.27, n=12) compared with cancer (1.31±0.34, n=4), infection (1.45±0.40, n=4) and stroke deaths (1.14±0.51, n=4), but no other studied parameter (Appendix III).

Table 2 - Reference ranges and coefficient of variation for studied parameters (n = 30).

Variable	Mean (±SD) (a.u.)	CV (%)	95% reference interval (a.u.)
Forehead	33.52 (±13.41)	40.02	7.24 – 59.80
Nose	31.59 (±16.44)	52.04	-0.63 – 63.81
Cheekbone	55.61 (±14.02)	25.21	28.13 – 83.09
Cheek	35.23 (±14.00)	39.73	7.79 – 62.67
Sternum	47.55 (±10.53)	22.15	26.91 – 68.19
Pectoral region	40.93 (±10.78)	26.34	19.80 – 62.06
Umbilicus	30.96 (±7.06)	22.80	17.12 – 44.80
Latus	31.58 (±8.13)	25.74	15.65 – 47.51
Arm (anterior)	37.66 (±10.24)	27.18	17.59 – 57.73
Index	37.50 (±14.65)	39.06	8.79 – 66.21
Thigh (anterior)	32.01 (±8.48)	26.49	15.39 – 48.63
Leg (anterior)	30.88 (±10.61)	34.35	10.08 – 51.68
Dorsum	49.29 (±16.88)	34.24	16.21 – 82.37
Scapula	42.06 (±13.17)	31.31	16.25 – 67.87
Lumbus	39.38 (±16.05)	40.75	7.92 – 70.84
Paralumbar region	36.53 (±12.82)	35.09	11.40 – 61.66
Arm (posterior)	34.16 (±10.83)	31.71	12.93 – 55.39
Thigh (posterior)	31.76 (±7.88)	24.82	16.32 – 47.20
Leg (posterior)	32.84 (±9.33)	28.40	14.55 – 51.13

The comparison between the different ratios and the unit reveals that umbilicus/lumbus hypostasis ratios is significantly less than 1 ($p = 0.0012$) at 6 hpm while the other ratios are not statistically significantly different from 1 ($p > 0.05$) (Appendix IV).

3.2. Inter- and intra-individual variability

With regard to the inter- and intra-individual variability of SCH values, given in arbitrary units (a.u.), Table 2 shows the values of the coefficients of variation (CV) as well as the 95% reference intervals for the studied parameters.

Comparing the mean results with the values defined as normal or pathological in adult skin (>40 a.u. = "normally hydrated"; 30-40 a.u. = "dry"; <30 a.u. = "very dry"), it appears that fourteen of the nineteen sites studied show pathological values, with skin that can be locally considered "dry" on the forehead, nose, cheek, umbilicus, latus, arm, index, thigh, leg, lumbus and the paralumbar region. The remaining five sites (cheekbone, sternum, pectoral region, dorsum and scapula) can be considered as normally hydrated.

Inter-individual variability appears to be ranging from 22.15 to 52.04% depending on the considered body site. A representation of these intervals and dispersion of the data is shown in Figure 3.

There is a significant effect of body site on SCH values ($p < 0.0001$). The differences between the two-by-two locations (grouped by body segments) are included in Table 3. The segments that do not differ from each other are: i) the anterior abdomen from the lower limb; ii) the posterior abdomen from the head and upper limb.

4. Discussion

These last twenty years, slowly growing literature highlighted the potential of skin as a reliable tissue for PMI estimation, utilizing methods such as histology [13–15], immunohistochemistry [9], electrical [18–20] or mechanical property assessment [26] and molecular analysis [10–12]. But most of these studies use animal models [9,10,12,18,26] or very reduced sample sizes of three [14], four [19], five [20], six [11] and eight [13] subjects, which respectively does not take into account the specific characteristics of human

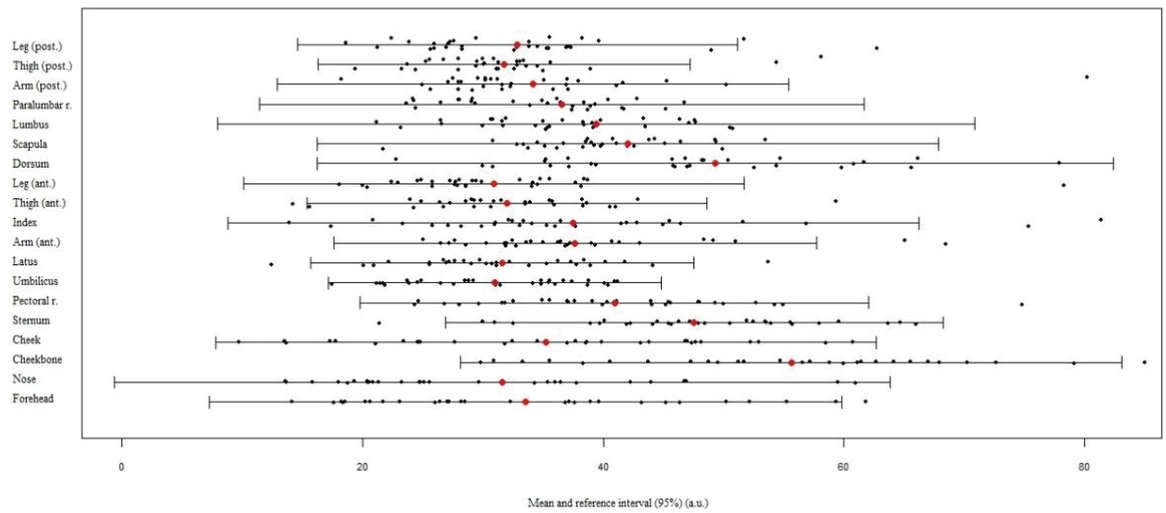

Figure 3 - *Graphical representation of 95% reference intervals.*

Table 3- Intra-individual variability: body site influence on SCH (n = 30).

		LS MEANS ± SE	GLMM p
			< 0.0001
Site	**Head**	38.99 ± 1.50	
	Superior limb (SL)	35.90 ± 1.84	
	Inferior limb (IL)	31.87 ± 1.50	
	Anterior thorax (A-TH)	44.24 ± 1.84	
	Anterior abdomen (A-ABD)	31.27 ± 1.84	
	Posterior thorax (P-TH)	45.67 ± 1.84	
	Posterior abdomen (P-ABD)	37.96 ± 1.84	

Site	**Head**	**SL**	**IL**	**A-TH**	**A-ABD**	**P-TH**	**P-ABD**
Head		0.098	<0.0001	0.0050	<0.0001	0.0004	0.58
SL	3.08±1.85		0.030	0.0001	0.031	<0.0001	0.34
IL	7.12±1.51	4.04±1.85		<0.0001	0.74	<0.0001	0.0012
A-TH	-5.25±1.85	-8.33±2.14	-13.8±1.85		<0.0001	0.50	0.0037
A-ABD	7.72±1.85	4.64±2.14	0.60±1.85	12.97±2.14		<0.0001	0.0020
P-TH	-6.69±1.85	-9.77±2.14	-13.80±1.85	-1.43±2.14	-14.41±2.14		0.0004
P-ABD	1.03±1.85	-2.05±2.14	-6.08±1.85	6.29±2.14	-6.69±2.14	7.18±2.14	

Upper left corner of the diagonal: multiple comparisons p-value
Lower right corner of the diagonal: mean difference (LSMEANS ± SE) between two locations.

skin and the significant inter-individual variability in skin properties. And yet, a recent study carried out in the forensic field and on a larger population of 102 subjects reveals significant heterogeneity in the post mortem evolution of the skin, for reasons that are still poorly understood [7]. Our study provides some interesting insights to answer the question of heterogeneity in the chronology and nature of the appearance of the post-mortem phenomenon of skin desiccation, by revealing significant inter- and intra-individual variation in the hydration of the most superficial layer of the skin.

It appears that age does not affect all parts of the body in the same way, with a positive correlation with SCH values on the anterior arm and the anterior thigh. This correlation diverges from various studies, which report a tendency for SCH values to decrease with age, in areas with or without photo-exposure, from the age of 18 to 70 years [34,35]. Age does not significantly influence the SCH at the other seventeen body sites studied. These results are consistent with the findings of a recent meta-analysis, which found no significant age-related differences in SCH in forehead, cheeks, neck, forearm and the back of the hand [27]. However, the absence of age influence can be explained by our selection criteria, which homogenises our population in terms of age.

We do not observe significant influence of biological sex on SCH values, providing there is an asymmetrical distribution of the sexes within our population. In literature, the influence of biological sex on SCH values is open to debate. In their recent meta-analysis, Samadi et al [27] also conclude that there is no influence of biological sex on SCH values of multiple body sites, contrary to several other studies [36,37].

An effect of BMI on the post mortem desiccation process has been suggested in the literature, either directly or indirectly : i) desiccation would occur more frequently on smaller bodies, which have a higher ratio of skin surface area to body weight (and therefore water content) [1] ; ii) the tendency of extremities (such as fingers, ears and nose) to dry out could be linked to the smaller amount of underlying soft tissue, including subcutaneous fat [38]. However, the results of recent studies do not support these hypotheses: it seems that obesity is associated with lower SCH values and higher rate of transdermal water loss at various body site [39–42]. Henceforth, their lower basal level of skin hydration and their impaired skin barrier function suggest a more rapid post mortem skin desiccation process in obese individuals. Our study also provides an argument in favour of a correlation between BMI and lower SCH values at various body sites, as it is negatively correlated with SCH values in pectoral region, anterior arm, index and anterior thigh. But above all it emphasises that this relationship cannot be generalised to the skin as a whole. For example, our study shows a positive correlation between BMI and forehead's SCH value. This observation could be explained by the increased sebum production in obese individuals [42]. Indeed, sebum production is one of the main determinants of SCH [28] and is reputed to be high on the forehead [43].

About the influence of cause of death, our study shows that cardiac deaths are negatively associated with the umbilicus/forehead SCH ratio ($p = 0.014$), compared with cancer, infection, and stroke deaths. The occurrence of ante-mortem veinous congestion of the upper body segment due to congestive heart failure could explain this observation.

Our results highlight a significant intra-individual variability according to body site in deceased subjects. As suggested in the literature for living individuals, hydration varies according to body site, depending on stratum corneum lipids (including ceramides, cholesterol, and free fatty acids) [44,45], natural moisturizing factors (NMFs) [34], endogenous humectants like glycerol and aquaporin-3 [46], the degree of occlusion [28,47], sebaceous gland density [28,47], degree of corneocyte maturation [47], stratum corneum thickness [30,48], vascular supply and microcirculation [27,49], exposure to environmental factors (like UV radiation and pollution) [34] and microenvironmental conditions, such as relative humidity and temperature [50]. For instance, the cheek exhibits a strong correlation between ceramide profiles and skin electrical capacitance [45] and facial skin in general, particularly around the eyes, is thinner and has a higher hydration state but a poorer barrier function compared to other body parts like the trunk and limb [47]. Facial skin also generally maintains higher NMF levels compared to other body parts to assure constant hydration despite a strong exposure to environmental factors [34].

The stratum corneum and the epidermis thicknesses seem particularly crucial, especially as it introduces a possible bias in what the probe is measuring. The Corneometer CM-825® measures the electrical capacitance of the epidermis from 30 to 45 μm [21,24]. However, the stratum corneum thickness is sometimes less than 45 μm. For example, it is about 17 µm for the cheek, 23 µm for the palmar forearm, 29 µm for the back of the hand, 173 µm at

the thenar eminence [17] and 12 μm at abdominal level [51]. That could influence the result of the measurements insofar as the proportion of water (as a percentage of mass in relation to 100 grams of wet tissue) increases as one goes from the surface to the depth of the epidermis, with a variable rate of 20 to 40% on the surface (stratum corneum), and a stable rate of 70% for the basal stratum granulosum (independently of the body site) [52]. As a result, the values measured by corneometry actually reflect – depending on the chosen body site – sometimes the most superficial portion of the stratum corneum, sometimes the stratum corneum as a whole, and sometimes a portion of the epidermis, whose thickness is estimated between 61 and 84 μm at the umbilic [51], between 101 and 157 μm at forehead and between 59 and 95 μm at cheek [53].

It is interesting to note that very close and clinically similar body sites show very different mean SCH values. For example, the skin of the cheek (35.23±14.00 a.u.) was indeed significantly different from that in the skin over the cheekbone (55.61±14.02 a.u.). This demonstrates the importance of precisely defining the body site studied for future studies using this method.

Hypostasis could influence the post mortem evolution of skin hydration, as all body fluids move according to gravity [54]. It has also been suggested that firm contact between the skin and a garment or surface prevents water evaporation and therefore delays post mortem desiccation [55]. The methodology of our study does not allow us to distinguish the respective influence of these two phenomena. Nevertheless, the hypostasis influence must be put into perspective: at 6 ± 2 hpm, when hypostasis is already clinically evident, the cheekbones remain the most hydrated site in our study, despite being a high and protruding body site in supine position.

Despite a relatively homogeneous group due to our selection criteria, and the lack of influence of age and biological sex, our study suggests a significant inter-individual variability, with coefficients of variation (CV) ranging from 22.15% (sternum) to 52.04% (nose). This variability could be explained by genetic factors [56–58]; ante mortem drug treatment [34]; comorbidities [27], and especially chronic renal failure [59] and diabetes mellitus [60]; chronic exposure to environmental factors like UV radiation and pollution [35]; nutritional status [34]; the vitamin C, collagen and probiotic content of the diet [61]; abnormalities in aquaporin-3 expression [61]; circadian rhythm [61] and chronic stress [62]. We can also mention the influence seasonality [45] and clothing [63,64], but the influence of these factors must have been reduced in our study in consequence of our methodology.

The influence of local skin temperature seems critical, as studies have shown a link between the temperature of a biological tissue and its electrical properties [18,65]. However, the influence of this factor was possibly limited by the choice of a short and fixed PMI and by the standardisation of clothing, ambient temperature, and relative humidity (RH). However, we cannot exclude the influence of this parameter and it would be interesting to quantify the exact relationship between skin temperature and SCH measurement. It will be therefore the subject of a further specific study.

5. Conclusion

The use of the Corneometer CM-825® (Courage & Khazaka electronic GmbH, Cologne, Germany), as an inexpensive, non-invasive, objective and quantitatively validated instrument, certainly offers several advantages for purely academic studies of the post mortem kinetics of skin hydration values. In this case, despite our relatively small sample size,

the choice of short PMIs and the lack of investigation into several subjects characteristics, we were able to easily identify and quantify post mortem intra- and inter-individual variability in skin hydration levels, which could partially explain the PMI heterogeneity of the onset of skin desiccation, as well as the morphological variations of this phenomenon.

The choice of a parameter that is relatively independent of the subject's intrinsic characteristics is essential in PMI research. In fact, in practice, the body of the deceased is subject to the influence of a large number of extrinsic factors, the most important of which are certainly environmental conditions, clothing and the cause of death. All of these factors, whether intrinsic or extrinsic, will compromise the accuracy of any potential PMI determination technique, which is critical in a forensic context. For that reason, the choice of stratum corneum hydration, measured by corneometry, seems questionable.

However, it seems to us that highlighting the significant inter- and intra-individual heterogeneity of skin provides a crucial element in research into the determination of PMI by skin analysis. Indeed, it is very important to stress, for future academic studies on this subject, that human skin should not be considered as a homogeneous surface, and that particular care must be taken in choosing the body site, whatever the parameter being studied.

With regard more specifically to research into the post mortem drying of skin, the evidence of the heterogeneity of skin hydration provided by our study suggest that there are probably several distinct desiccation patterns to identify, depending on considered body site and subject's characteristics.

For future research into understanding the post mortem skin desiccation, we feel it is important to determine the exact relationship between skin temperature and the indirect measurement of its hydration via its electrical properties; and to determine whether or not there is a link between SCH and short PMIs, prior to the clinically evident phenomenon of skin desiccation or mummification.

Conflict of interest

The authors declare no conflicts of interest.

Source of funding

The authors received no financial support for the research, authorship or publication of this paper.

References

1. Reddy K, Lowenstein EJ. Forensics in dermatology: Part I. J Am Acad Dermatol. 2011 May;64(5):801–8.
2. Reddy K, Lowenstein EJ. Forensics in dermatology: Part II. J Am Acad Dermatol. 2011 May;64(5):811–24.
3. Madea B, Henßge C, Reibe S, Tsokos M, Kernbach-Wighton G. Postmortem changes and time since death. In: Handbook of Forensic Medicine. 1st edition. Wiley-Blackwell; 2014. p. 90–1.
4. Haglund WD, Sorg MH. Postmortem Changes in Soft Tissues. In: The Postmortem Fate of Human Remains. New-York: CRC Press; 1997. p. 160–1.
5. Leccia C, Alunni V, Quatrehomme G. Modern (forensic) mummies: A study of twenty cases. Forensic Sci Int. 2018 Jul;288:330.e1-330.e9.
6. Connor M, Baigent C, Hansen ES. Measuring Desiccation Using Qualitative Changes: A Step Toward Determining Regional Decomposition Sequences. J Forensic Sci. 2019 Jul;64(4):1004–11.
7. Ceciliason AS, Käll B, Sandler H. Mummification in a forensic context: an observational study of taphonomic changes and the post-mortem interval in an indoor setting. Int J Legal Med. 2023 Jul;137(4):1077–88.
8. Ceciliason AS, Andersson MG, Lindström A, Sandler H. Quantifying human decomposition in an indoor setting and implications for postmortem interval estimation. Forensic Sci Int. 2018 Feb;283:180–9.
9. De-Giorgio F, Bergamin E, Baldi A, Gatta R, Pascali

VL. Immunohistochemical expression of HMGB1 and related proteins in the skin as a possible tool for determining post-mortem interval: a preclinical study. Forensic Sci Med Pathol. 2023 Jul 25;20(1):149–65.

10. Xie DG, Wang XM, Li JH, Tan ZY, Zhang ZQ, Li ST. Short-term postmortem interval estimation by detection of apoptosis-related protein in skin. Forensic Sci Med Pathol. 2024 Jan 30;20(3):872–7.
11. Ali MM, Ibrahim SF, Fayed AA. Using Skin Gene Markers for Estimating Early Postmortem Interval at Different Temperatures. Am J Forensic Med Pathol. 2017 Dec;38(4):323–5.
12. Ali MM, Ibrahim SF, Elrewieny NM, Elyamany AM, Khalil WKB, Shalby AB, et al. Estimation of Early Postmortem Interval from Long Noncoding RNA Gene Expression in the Incised Cutaneous Wound: An Experimental Study. Biomedicines. 2022 Nov 14;10(11):2919.
13. Wei W, Michu Q, Wenjuan D, Jianrong W, Zhibing H, Ming Y, et al. Histological changes in human skin 32 days after death and the potential forensic significance. Sci Rep. 2020 Oct 30;10(1):18753.
14. Kovarik C, Stewart D, Cockerell C. Gross and Histologic Postmortem Changes of the Skin: Am J Forensic Med Pathol. 2005 Dec;26(4):305–8.
15. Bardale RV, Tumram NK, Dixit PG, Deshmukh AY. Evaluation of Histologic Changes of the Skin in Postmortem Period: Am J Forensic Med Pathol. 2012 Dec;33(4):357–61.
16. Madea B. Methods for determining time of death. Forensic Sci Med Pathol. 2016 Dec;12(4):451–85.
17. Wenzlow N, Mills D, Byrd J, Warren M, Long MT. Review of the current and potential use of biological and molecular methods for the estimation of the postmortem interval in animals and humans. J Vet Diagn Invest. 2023 Mar;35(2):97–108.
18. Querido D. Temperature-correction of abdominal impedance: improved relationship between impedance and postmortem interval. Forensic Sci Int. 2000 Mar;109(1):39–50.
19. Hansen ES, Baigent C, Reck SI, Connor M. Bioelectrical Impedance as a Technique for Estimating Postmortem Interval,,. J Forensic Sci. 2018 Jul;63(4):1186–90.
20. Lennartz AN. Assessing patterns of moisture content in decomposing, desiccated and mummified tissue : a baseline study. [A thesis submitted to the Graduate Council of Texas State University in partial fulfillment of the requirements for the degree of Master of Arts with a Major in Anthropology]. Texas State University; 2018.
21. Barel AO, Clarys P. Skin Capacitance. In: Non Invasive Diagnostic Techniques in Clinical Dermatology [Internet]. Berlin: Springer; 2014 [cited 2022 Nov 14]. p. 357–66. Available from: http://link.springer.com/10.1007/978-3-642-32109-2
22. Clarys P, Clijsen R, Taeymans J, Barel AO. Hydration measurements of the stratum corneum: comparison between the capacitance method (digital version of the Corneometer CM 825®) and the impedance method (Skicon-200EX®). Skin Res Technol. 2012 Aug;18(3):316–23.
23. Heinrich U, Koop U, Leneveu-Duchemin MC, Osterrieder K, Bielfeldt S, Chkarnat C, et al. Multicentre comparison of skin hydration in terms of physical-, physiological- and product-dependent parameters by the capacitive method (Corneometer CM 825). Int J Cosmet Sci. 2003 Apr;25(1–2):45–53.
24. Courage+Khazaka electronic GmbH. Corneometer® CM 825 - Technical Data [Internet]. 2020 [cited 2020 Oct 11]. Available from: https://www.courage-khazaka.de/en/downloads-en?task=callelement&format=raw&item_id=318&element=f85c494b-2b32-4109-b8c1-083cca2b7db6&method=download&args[0]=87b62cd6bf1f9279c7088266a2569685
25. Franceschetti L, Amadasi A, Bugelli V, Bolsi G, Tsokos M. Estimation of Late Postmortem Interval: Where Do We Stand? A Literature Review. Biology. 2023 May 28;12(6).
26. Zahid Saadoon M. An Innovative Approach of Exam-

ining Post- Mortem Skin Changes from a Mechanical Perspective, Stiffness based Novel Analysis. Int J Sci Res IJSR. 2023 Aug 5;12(8):1786–93.

27. Samadi A, Yazdanparast T, Shamsipour M, Hassanzadeh H, Hashemi Orimi M, Firooz R, et al. Stratum corneum hydration in healthy adult humans according to the skin area, age and sex: a systematic review and meta-analysis. J Eur Acad Dermatol Venereol. 2022 Oct;36(10):1713–21.
28. Kleesz P, Darlenski R, Fluhr JW. Full-Body Skin Mapping for Six Biophysical Parameters: Baseline Values at 16 Anatomical Sites in 125 Human Subjects. Skin Pharmacol Physiol. 2012;25(1):25–33.
29. Darlenski R, Sassning S, Tsankov N, Fluhr JW. Non-invasive in vivo methods for investigation of the skin barrier physical properties. Eur J Pharm Biopharm. 2009 Jun;72(2):295–303.
30. Egawa M, Hirao T, Takahashi M. In vivo Estimation of Stratum Corneum Thickness from Water Concentration Profiles Obtained with Raman Spectroscopy. Acta Derm Venereol. 2007;87(1):4–8.
31. Clarys P, Clijsen R, Barel AO. Influence of probe application pressure on in vitro and in vivo capacitance (Corneometer CM 825®) and conductance (Skicon 200 EX®) measurements: Probe pressure during hydration measurements. Skin Res Technol. 2011 Nov;17(4):445–50.
32. Berardesca E, European Group for Efficacy Measurements on Cosmetics and Other Topical Products (EEMCO)2. EEMCO guidance for the assessment of stratum corneum hydration: electrical methods. Skin Res Technol. 1997 May;3(2):126–32.
33. Lodén M, Hagforsen E, Lindberg M. The presence of body hair influences the measurement of skin hydration with the Corneometer. Acta Derm Venereol. 1995 Nov;75(6):449–50.
34. Boireau-Adamezyk E, Baillet-Guffroy A, Stamatas GN. The stratum corneum water content and natural moisturization factor composition evolve with age and depend on body site. Int J Dermatol. 2021 Jul;60(7):834–9.
35. Boireau-Adamezyk E, Baillet-Guffroy A, Stamatas GN. Age-dependent changes in stratum corneum barrier function. Skin Res Technol. 2014;20:409–15.
36. Mehta H, Nikam V, Jaiswal C, Mehta H. A cross-sectional study of variations in the biophysical parameters of skin among healthy volunteers. Indian J Dermatol Venereol Leprol. 2018;84(4):521.
37. Man MQ, Xin SJ, Song SP, Cho SY, Zhang XJ, Tu CX, et al. Variation of Skin Surface pH, Sebum Content and Stratum Corneum Hydration with Age and Gender in a Large Chinese Population. Skin Pharmacol Physiol. 2009;22(4):190–9.
38. Lynnerup N. Mummies. Am J Phys Anthropol. 2007;Suppl 45:162–90.
39. Yang B, Lai Q, Chen A, Ye L, Wang X, Lai Y, et al. Body Mass Index z Scores Correlate with Epidermal Function in Chinese Children. Diabetes Metab Syndr Obes Targets Ther. 2023;16:3393–401.
40. Zhu T, Yang S, Mauro TM, Man MQ. Association of Epidermal Biophysical Properties with Obesity and Its Implications. Skin Pharmacol Physiol. 2023;36(4):165–73.
41. Ye L, Lai Q, Wen S, Wang X, Yang B, Man MQ. Correlation of Body Mass Index with Epidermal Biophysical Properties Varies with Gender in Chinese. Skin Pharmacol Physiol. 2022;35(4):215–23.
42. Rodriguez AJ, Boonya-Ananta MT, Gonzalez M, Le VND, Fine J, Palacios C, et al. Skin optical properties in the obese and their relation to body mass index: a review. J Biomed Opt [Internet]. 2022 Mar 29 [cited 2024 Feb 12];27(03). Available from: https://www.spiedigitallibrary.org/journals/journal-of-biomedical-optics/volume-27/issue-03/030902/Skin-optical-properties-in-the-obese-and-their-relation-to/10.1117/1.JBO.27.3.030902.full
43. Mukherjee S, Mitra R, Maitra A, Gupta S, Kumaran S, Chakrabortty A, et al. Sebum and Hydration Levels in Specific Regions of Human Face Significantly Predict the Nature and Diversity of Facial Skin Microbiome. Sci Rep. 2016 Oct 27;6(1):36062.

44. Wertz PW. Stratum corneum Lipids and Water. Exog Dermatol. 2004;3(2):53–6.
45. Ishikawa J, Shimotoyodome Y, Ito S, Miyauchi Y, Fujimura T, Kitahara T, et al. Variations in the ceramide profile in different seasons and regions of the body contribute to stratum corneum functions. Arch Dermatol Res. 2013 Mar;305(2):151–62.
46. Verdier-Sévrain S, Bonté F. Skin hydration: a review on its molecular mechanisms. J Cosmet Dermatol. 2007 Jun;6(2):75–82.
47. Tagami H. Location-related differences in structure and function of the stratum corneum with special emphasis on those of the facial skin. Int J Cosmet Sci. 2008 Dec;30(6):413–34.
48. Egawa M, Kajikawa T. Changes in the depth profile of water in the stratum corneum treated with water. Skin Res Technol. 2009 May;15(2):242–9.
49. Man M -Q., Elias PM. Stratum corneum hydration regulates key epidermal function and serves as an indicator and contributor to other conditions. J Eur Acad Dermatol Venereol. 2019 Jan;33(1):15–6.
50. Björklund S. How water and osmolytes influence biophysical properties of stratum corneum.
51. Czekalla C, Schönborn KH, Lademann J, Meinke MC. Noninvasive Determination of Epidermal and Stratum Corneum Thickness in vivo Using Two-Photon Microscopy and Optical Coherence Tomography: Impact of Body Area, Age, and Gender. Skin Pharmacol Physiol. 2019;32(3):142–50.
52. Egawa M, Tagami H. Comparison of the depth profiles of water and water-binding substances in the stratum corneum determined in vivo by Raman spectroscopy between the cheek and volar forearm skin: effects of age, seasonal changes and artificial forced hydration. Br J Dermatol. 2008;158:251–60.
53. Yokoshiki S, Maeda M, Saijo Y. High resolution facial skin imaging with three-dimensional ultrasound microscope. In Honolulu, Hawaii, USA; 2017 [cited 2022 Dec 16]. p. 020015. Available from: http://asa.scitation.org/doi/abs/10.1121/2.0000748
54. van Grinsven T, Lafebre SJ, Kubat B, Klein WM. Postmortem changes in musculoskeletal and subcutaneous tissue. J Forensic Radiol Imaging. 2017 Sep;10:29–36.
55. Aufderheide A. Mechanisms of mummification. In: The scientific study of mummies. Cambridge: Cambridge University Press; 2003. p. 41–66.
56. Matsui T, Miyamoto K, Kubo A, Kawasaki H, Ebihara T, Hata K, et al. SASPase regulates stratum corneum hydration through profilaggrin-to-filaggrin processing. EMBO Mol Med. 2011 Jun;3(6):320–33.
57. Jungersted JM, Scheer H, Mempel M, Baurecht H, Cifuentes L, Høgh JK, et al. Stratum corneum lipids, skin barrier function and filaggrin mutations in patients with atopic eczema. Allergy. 2010 Jul;65(7):911–8.
58. Mlitz V, Latreille J, Gardinier S, Jdid R, Drouault Y, Hufnagl P, et al. Impact of filaggrin mutations on Raman spectra and biophysical properties of the stratum corneum in mild to moderate atopic dermatitis. J Eur Acad Dermatol Venereol JEADV. 2012 Aug;26(8):983–90.
59. Kato A, Hamada M, Maruyama T, Maruyama Y, Hishida A. Pruritus and hydration state of stratum corneum in hemodialysis patients. Am J Nephrol. 2000 Dec;20(6):437–42.
60. Sakai S, Kikuchi K, Satoh J, Tagami H, Inoue S. Functional properties of the stratum corneum in patients with diabetes mellitus: similarities to senile xerosis. Br J Dermatol. 2005 Aug;153(2):319–23.
61. Camilion JV, Khanna S, Anasseri S, Laney C, Mayrovitz HN. Physiological, Pathological, and Circadian Factors Impacting Skin Hydration. Cureus [Internet]. 2022 Aug 4 [cited 2024 Nov 16]; Available from: https://www.cureus.com/articles/98088-physiological-pathological-and-circadian-factors-impacting-skin-hydration
62. Maarouf M, Maarouf CL, Yosipovitch G, Shi VY. The impact of stress on epidermal barrier function: an evidence-based review. Br J Dermatol. 2019 Dec;181(6):1129–37.

63. Kathryn L. Hatch, Harriet H. Prato, S. Haig Zeronian, Howard I. Maibach. In Vivo Cutaneous and Perceived Comfort Response to Fabric: Part VI: The Effect of Moist Fabrics on Stratum Corneum Hydration. Text Res J. 1997;67(12):926–31.

64. Bruce A. Cameron, Donna M. Brown, Merry Jo Dallas, Brenda Brandt. Effect of Natural and Synthetic Fibers and Film and Moisture Content on Stratum Corneum Hydration in an Occlusive System. Text Res J. 1997;67(8):585–92.

65. Querido D. Preliminary study of the effect of acute antemortem haemorrhage on postmortem abdominal impedance in rats. Forensic Sci Int. 2002 Jul;127(3):218–24.

1. Appendices

Appendix I. Correlation between subject traits & parameters (n = 30).

SCH site	Age	BMI
Forehead*	R = -0.12974 (p = 0.4944)	R = 0.37493 (p = 0.0412)
Nose**	R_S = 0.27470 (p = 0.1418)	R_S = -0.27751 (p = 0.1376)
Cheekbone*	R = -0.21573 (p = 0.2522)	R = 0.06570 (p = 0.7301)
Cheek*	R = -0.22328 (p = 0.2356)	R = 0.14712 (p = 0.4379)
Sternum*	R = -0.33230 (p = 0.0728)	R = 0.13387 (p = 0.4806)
Pectoral r.*	R = 0.00223 (p = 0.9907)	R = -0.37622 (p = 0.0405)
Umbilicus*	R = 0.14420 (p = 0.4471)	R = 0.11877 (p = 0.5319)
Latus*	R = -0.35584 (p = 0.0536)	R = 0.20515 (p = 0.2768)
Arm (anterior)**	R_S = 0.37763 (p = 0.0397)	R_S = -0.36831 (p = 0.0452)
Index**	R_S = 0.06883 (p = 0.7178)	R_S = -0.46974 (p = 0.0088)
Thigh (anterior)**	R_S = 0.36244 (p = 0.0490)	R_S = -0.46039 (p = 0.0105)
Leg (anterior)**	R_S = 0.10559 (p = 0.5787)	R_S = -0.03694 (p = 0.8463)
Dorsum**	R_S = 0.04700 (p = 0.8052)	R_S = 0.01157 (p = 0.9516)
Scapula**	R_S = 0.00200 (p = 0.9916)	R_S = -0.11437 (p = 0.5473)
Lumbus**	R_S = -0.03520 (p = 0.8535)	R_S = 0.29862 (p = 0.1090)
Paralumbar r.**	R_S = 0.09022 (p = 0.6354)	R_S = -0.04918 (p = 0.7964)
Arm (posterior)**	R_S = -0.03988 (p = 0.8342)	R_S = 0.01313 (p = 0.9451)
Thigh (posterior)**	R_S = 0.07909 (p = 0.6778)	R_S = -0.01135 (p = 0.9525)
Leg (posterior)**	R_S = 0.23524 (p = 0.2108)	R_S = -0.11838 (p = 0.5333)
Umbilicus/Lumbus*	R = 0.09802 (p = 0.6063)	R = 0.07505 (p = 0.6935)
Umbilicus/Forehead*	R = 0.23202 (p = 0.2173)	R = -0.26193 (p = 0.1620)
Umbilicus/Index**	R_S = -0.05970 (p = 0.7540)	R_S = 0.40454 (p = 0.0266)

* Parametric correlation of Pearson

** Nonparametric correlation of Spearman

Abbreviations : BMI = Body Mass Index ; Pectoral r. = Pectoral region ; Paralumbar r. = Paralumbar region.

Appendix II. Association between biological sex and studied parameters.

SCH Site	Sex	N	Mean (±SD) or median (IQR)	p
Forehead	Total	30	33.52 (±13.41)	0.43
	Female	10	30.73 (±10.21)	
	Male	20	34.91 (±14.80)	
Nose	Total	30	24.92 (20.37–37.77)	0.76
	Female	10	24.90 (21.30–43.96)	
	Male	20	25.15 (20.37–37.14)	
Cheekbone	Total	30	55.61 (±14.02)	0.81
	Female	10	56.51 (±10.55)	
	Male	20	55.16 (±15.70)	
Cheek	Total	30	35.23 (±14.00)	0.84
	Female	10	35.97 (±15.18)	
	Male	20	34.86 (±13.77)	
Sternum	Total	30	47.55 (±10.53)	0.96
	Female	10	47.70 (±14.26)	
	Male	20	47.47 (±8.54)	
Pectoral region	Total	30	40.93 (±10.78)	0.67
	Female	10	39.73 (±14.43)	
	Male	20	41.53 (±8.81)	
Umbilicus	Total	30	30.96 (±7.06)	0.48
	Female	10	29.64 (±7.47)	
	Male	20	31.62 (±6.94)	
Latus	Total	30	31.58 (±8.13)	0.99
	Female	10	31.55 (±10.06)	
	Male	20	31.59 (±7.27)	
Arm (anterior)	Total	30	35.64 (31.80–40.73)	0.31
	Female	10	33.02 (27.63–38.99)	
	Male	20	36.65 (31.92–41.02)	
Index	Total	30	34.69 (29.93–42.77)	0.13
	Female	10	41.72 (33.40–44.98)	
	Male	20	32.32 (27.68–37.56)	
Thigh (anterior)	Total	30	30.92 (27.27–35.90)	0.60
	Female	10	29.94 (26.43–38.31)	
	Male	20	31.23 (28.80–35.83)	

Appendix II Continued.

Leg (anterior)	Total	30	28.58 (25.79–34.50)	0.27
	Female	10	26.88 (22.91–33.10)	
	Male	20	29.28 (27.47–34.65)	
Dorsum	Total	30	46.89 (37.14–54.72)	0.06
	Female	10	38.08 (35.13–47.20)	
	Male	20	48.29 (45.90–57.76)	
Scapula	Total	30	39.85 (36.17–44.26)	0.60
	Female	10	39.52 (35.13–42.00)	
	Male	20	40.52 (37.52–45.37)	
Lumbus	Total	30	36.10 (31.57–43.50)	0.76
	Female	10	33.45 (30.86–47.67)	
	Male	20	37.47 (32.99–43.44)	
Paralumbar region	Total	30	36.30 (29.08–39.33)	1.00
	Female	10	33.72 (26.48–42.83)	
	Male	20	36.48 (29.09–38.82)	
Arm (posterior)	Total	30	31.38 (28.20–37.00)	0.89
	Female	10	33.72 (27.10–37.93)	
	Male	20	30.94 (28.66–36.04)	
Thigh (posterior)	Total	30	31.02 (28.00–33.39)	0.15
	Female	10	31.24 (30.02–38.95)	
	Male	20	30.42 (26.15–32.97)	
Leg (posterior)	Total	30	32.72 (26.93–36.93)	0.93
	Female	10	33.23 (25.93–35.43)	
	Male	20	31.13 (27.19–37.02)	
Umbilicus/Lumbus	Total	30	0.84 (±0.24)	0.69
	Female	10	0.82 (±0.33)	
	Male	20	0.86 (±0.18)	
Umbilicus/Index	Total	30	0.87 (0.55–1.15)	0.20
	Female	10	0.70 (0.53–0.94)	
	Male	20	0.99 (0.58–1.21)	
Umbilicus/Forehead	Total	30	1.07 (±0.46)	0.95
	Female	10	1.08 (±0.48)	
	Male	20	1.06 (±0.46)	

Appendix III - Association between studied parameters and cause of death

SCH Site	Cause of death	N	Mean (±SD) or median (IQR)	p
Forehead	Total	30	33.52 (±13.41)	0.19
	Heart Failure	12	37.94 (±13.16)	
	Cancer	4	24.10 (±9.04)	
	Infection	4	26.46 (±8.72)	
	Stroke	4	30.82 (±11.86)	
	Internal Bleeding	3	29.24 (±22.60)	
	Other	3	45.66 (±6.27)	
Nose	Total	30	24.92 (20.37–37.77)	0.73
	Heart Failure	12	25.15 (18.38–37.14)	
	Cancer	4	28.42 (20.72–41.37)	
	Infection	4	24.15 (21.80–36.00)	
	Stroke	4	29.52 (23.02–46.92)	
	Internal Bleeding	3	20.37 (13.60–29.63)	
	Other	3	42.29 (19.29–60.98)	
Cheekbone	Total	30	55.61 (±14.02)	0.52
	Heart Failure	12	55.50 (±14.68)	
	Cancer	4	51.20 (±9.79)	
	Infection	4	57.16 (±6.79)	
	Stroke	4	56.06 (±20.88)	
	Internal Bleeding	3	46.16 (±18.67)	
	Other	3	68.71 (±3.59)	
Cheek	Total	30	35.23 (±14.00)	0.11
	Heart Failure	12	38.33 (±13.58)	
	Cancer	4	19.21 (±13.91)	
	Infection	4	34.51 (±9.72)	
	Stroke	4	31.18 (±15.22)	
	Internal Bleeding	3	38.22 (±14.15)	
	Other	3	47.59 (±0.57)	
Sternum	Total	30	47.55 (±10.53)	0.82
	Heart Failure	12	47.15 (±11.09)	
	Cancer	4	52.48 (±6.20)	
	Infection	4	51.34 (±16.89)	
	Stroke	4	42.78 (±8.93)	

Appendix III Continued.

SCH Site	Cause of death	N	Mean (±SD) or median (IQR)	p
	Internal Bleeding	3	45.53 (±5.46)	
	Other	3	45.90 (±12.77)	
Pectoral region	Total	30	40.93 (±10.78)	0.30
	Heart Failure	12	38.86 (±9.54)	
	Cancer	4	36.42 (±5.98)	
	Infection	4	47.34 (±20.25)	
	Stroke	4	44.28 (±5.18)	
	Internal Bleeding	3	49.43 (±4.93)	
	Other	3	33.73 (±9.72)	
Umbilicus	Total	30	30.96 (±7.06)	0.62
	Heart Failure	12	29.33 (±8.40)	
	Cancer	4	29.74 (±4.57)	
	Infection	4	36.42 (±5.53)	
	Stroke	4	31.35 (±6.90)	
	Internal Bleeding	3	33.36 (±6.24)	
	Other	3	28.90 (±7.29)	
Latus	Total	30	31.58 (±8.13)	0.71
	Heart Failure	12	31.49 (±5.76)	
	Cancer	4	28.01 (±11.31)	
	Infection	4	36.56 (±13.23)	
	Stroke	4	28.87 (±2.35)	
	Internal Bleeding	3	34.50 (±12.09)	
	Other	3	30.72 (±7.94)	
Arm (anterior)	Total	30	35.64 (31.80–40.73)	0.88
	Heart Failure	12	35.40 (29.44–42.17)	
	Cancer	4	36.30 (29.17–44.93)	
	Infection	4	44.02 (32.11–59.73)	
	Stroke	4	33.80 (33.02–35.24)	
	Internal Bleeding	3	36.83 (35.03–37.23)	
	Other	3	32.76 (31.97–36.24)	
Index	Total	30	34.69 (29.93–42.77)	0.39
	Heart Failure	12	37.07 (32.04–51.20)	
	Cancer	4	33.75 (26.50–40.88)	

Appendix III Continued.

SCH Site	Cause of death	N	Mean (±SD) or median (IQR)	p
	Infection	4	38.41 (25.71–47.20)	
	Stroke	4	32.94 (30.35–37.67)	
	Internal Bleeding	3	29.93 (13.90–30.97)	
	Other	3	37.45 (23.31–44.98)	
Thigh (anterior)	Total	30	30.92 (27.27–35.90)	0.49
	Heart Failure	12	32.54 (28.94–37.11)	
	Cancer	4	32.20 (23.24–37.05)	
	Infection	4	37.07 (30.97–49.00)	
	Stroke	4	29.10 (25.60–32.43)	
	Internal Bleeding	3	29.03 (24.23–29.80)	
	Other	3	29.24 (24.86–38.23)	
Leg (anterior)	Total	30	28.58 (25.79–34.50)	0.45
	Heart Failure	12	28.51 (25.29–34.29)	
	Cancer	4	33.37 (28.58–38.40)	
	Infection	4	31.28 (27.65–55.70)	
	Stroke	4	26.47 (22.44–31.08)	
	Internal Bleeding	3	24.53 (18.10–34.80)	
	Other	3	27.27 (25.79–37.74)	
Dorsum	Total	30	46.89 (37.14–54.72)	0.45
	Heart Failure	12	50.20 (38.06–61.22)	
	Cancer	4	43.12 (37.53–47.50)	
	Infection	4	46.60 (34.40–79.34)	
	Stroke	4	38.27 (30.39–48.05)	
	Internal Bleeding	3	52.57 (46.97–77.87)	
	Other	3	48.38 (37.14–54.72)	
Scapula	Total	30	39.85 (36.17–44.26)	0.34
	Heart Failure	12	41.87 (34.97–47.90)	
	Cancer	4	35.64 (33.67–37.65)	
	Infection	4	40.95 (37.97–71.94)	
	Stroke	4	39.52 (35.05–40.90)	
	Internal Bleeding	3	42.57 (39.00–53.50)	
	Other	3	42.00 (38.31–44.26)	
Lumbus	Total	30	36.10 (31.57–43.50)	0.55

Appendix III Continued.

SCH Site	Cause of death	N	Mean (±SD) or median (IQR)	p
	Heart Failure	12	38.80 (28.73–46.97)	
	Cancer	4	36.76 (32.59–38.69)	
	Infection	4	39.25 (33.34–78.50)	
	Stroke	4	32.99 (31.10–42.47)	
	Internal Bleeding	3	43.37 (36.63–47.17)	
	Other	3	31.90 (23.18–35.39)	
Paralumbar region	Total	30	36.30 (29.08–39.33)	0.14
	Heart Failure	12	34.32 (27.24–37.94)	
	Cancer	4	34.65 (30.97–37.90)	
	Infection	4	40.86 (35.71–70.05)	
	Stroke	4	40.53 (31.75–42.28)	
	Internal Bleeding	3	38.93 (37.40–41.57)	
	Other	3	29.08 (24.44–29.10)	
Arm (posterior)	Total	30	31.38 (28.20–37.00)	0.99
	Heart Failure	12	31.17 (27.84–35.99)	
	Cancer	4	33.64 (29.09–39.36)	
	Infection	4	32.52 (26.39–41.60)	
	Stroke	4	30.87 (29.09–40.90)	
	Internal Bleeding	3	32.33 (30.07–37.00)	
	Other	3	31.18 (29.11–35.86)	
Thigh (posterior)	Total	30	31.02 (28.00–33.39)	0.21
	Heart Failure	12	30.65 (24.64–33.96)	
	Cancer	4	30.29 (27.37–32.83)	
	Infection	4	43.98 (32.45–56.24)	
	Stroke	4	26.64 (24.82–31.52)	
	Internal Bleeding	3	32.83 (30.87–32.87)	
	Other	3	29.97 (29.48–30.02)	
Leg (posterior)	Total	30	32.72 (26.93–36.93)	0.34
	Heart Failure	12	33.23 (27.25–36.86)	
	Cancer	4	31.63 (28.85–35.59)	
	Infection	4	40.92 (28.33–50.37)	
	Stroke	4	24.05 (20.52–30.55)	
	Internal Bleeding	3	36.93 (27.10–37.10)	
	Other	3	27.27 (21.21–35.34)	

Appendix III Continued.

SCH Site	Cause of death	N	Mean (±SD) or median (IQR)	p
Umbilicus/Lumbus	Total	30	0.84 (±0.24)	0.95
	Heart Failure	12	0.81 (±0.24)	
	Cancer	4	0.84 (±0.16)	
	Infection	4	0.88 (±0.45)	
	Stroke	4	0.88 (±0.27)	
	Internal Bleeding	3	0.78 (±0.05)	
	Other	3	0.95 (±0.06)	
Umbilicus/Index	Total	30	0.87 (0.55–1.15)	0.35
	Heart Failure	12	0.56 (0.49–1.00)	
	Cancer	4	0.99 (0.71–1.21)	
	Infection	4	1.01 (0.75–1.69)	
	Stroke	4	0.91 (0.76–1.10)	
	Internal Bleeding	3	1.17 (0.86–2.78)	
	Other	3	0.65 (0.57–1.55)	
Umbilicus/Forehead	Total	30	1.07 (±0.46)	0.014
	Heart Failure	12	0.83 (±0.27)	
	Cancer	4	1.31 (±0.34)	
	Infection	4	1.45 (±0.40)	
	Stroke	4	1.14 (±0.51)	
	Internal Bleeding	3	1.49 (±0.68)	
	Other	3	0.65 (±0.21)	

Appendix IV. Ratio analysis (n = 30).

Variable	Mean (±SD) or median (IQR)	p
Umbilicus/Lumbus	0.84 (±0.24)	0.0012
Umbilicus/Index	0.9 (0.6–1.2)	0.18
Umbilicus/Forehead	1.07 (±0.46)	0.42