Excessive Weight Favours Skin Physiology – Up to a Point: Another Expression of the Obesity Paradox

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Keywords

Obesity · Body mass index · Epidermal barrier · Skin biomechanics · In vivo skin physiology

Abstract

Background/Aims: Recently classified as an epidemic by the WHO, obesity (as well as the state of being overweight) clearly affects significant populations across all ages. The relationship between obesity and some diseases (e.g. cardiovascular ones) is known, although many paradoxes remain to be explained. Very little information is available, however, regarding its impact on skin physiology and skin disease. This study aims to examine the influence of excessive weight on epidermal hydration and transepidermal water loss, key variables of skin water balance and skin biomechanics. **Methods:** A convenience sample of 89 healthy female volunteers was selected and divided into 4 groups, according to their BMI (body mass index), as normal (control), overweight, obese (I and II), and morbid. Skin physiology was quantitatively assessed in all individuals in 4 anatomical areas using non-invasive biometrical analysis by reference instrumentation. Descriptive and comparative statistics were

applied, adopting a confidence level of 95%. **Results:** A non-linear alteration for all variables was detected as a function of BMI. **Conclusion:** Results suggest that excessive weight might favour skin performance within certain limits, reflecting a particular adaptation of the skin to the weight gain and body contour.

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Introduction

According to recent studies, obesity affects more and more populations around the globe. Recent numbers in the USA as well as in Europe [1–3] refer one third of adults being affected, justifying the recent WHO classification as an alarming threat considering the current rising prevalence.

The relationship of obesity as an independent risk factor for diabetes, hypertension, dyslipidaemia, cardiovascular disease and even cancer has been extensively studied and described [4–6], and many controversial, even paradoxical (the so-called obesity paradox), findings remain to be fully understood (see below) [5, 6]. However,

a dermatological link with current skin problems associated with this disease like xerosis, pruritus, rash, vesiculae, striae, or with more specific conditions such as acanthosis nigricans, is still unclear [6–8]. Most of these are tangible comorbidities since the impact of overweight over the normal skin physiology has not been thoroughly studied.

Xerosis is common in obese patients, and a few studies have identified a relationship between obesity and skin hydration changes, principally involving an increased transepidermal water loss (TEWL), the most popular indicator of the skin's "barrier" function, as well as some modifications of sweat gland activity [7, 9–11]. The cutaneous "barrier" function is a key issue in normal skin physiology and is directly related to the particular structure of human epidermis (corneocytes, lipids and extracellular cement), to the tissue's cellular cohesion, and to the mechanical behaviour of the skin, the so-called envelope function. An increase in TEWL might, therefore, be related with reduced integrity and consequently to a decrease in the skin barrier function, which might affect stratum corneum hydration.

A very few studies have focused on TEWL and the body mass index (BMI). A high TEWL was associated with BMI in obese patients (BMI between 30 and 39.9), but these patients often suffer from profuse sweating, and this most likely confuses results [7, 11]. The overweight state (BMI between 25 and 29.9) was also related to a decrease in TEWL, suggesting a lower permeability of the skin to evaporative water loss in these subjects [10].

With respect to mechanical properties and overweight, relevant information is even more insufficient, although of current research interest. In fact, we are now more aware than ever of the effects of obesity on the lower extremity biomechanics in relation to stasis, dermatitis, ulceration, and vascular insufficiency [12–14]. Recently, obesity has been related with the elevated tissue loads which explain pressure ulcers and determine more complex deep tissue injuries [13]. New knowledge is needed to better understand the multiple controversies and contradictions involving biomechanical adaptation of skin in weight loss provided by cosmetic intervention (abdominoplastia) or other strategies and procedures evoking massive weight reduction [13–15].

In the present study we look further into these special relationships between excessive body weight and cutaneous physiology focusing on skin water balance and skin biomechanics as a function of BMI in vivo, in different anatomical sites, and compare it with normal weight individuals' skin.

Materials and Methods

A convenience sample of 89 female volunteers, healthy, except for the weight specifications, and aged between 19 and 46 years (mean $\pm$ SD 32 ± 7), was selected and divided into 4 groups according to the WHO criteria for the classification of the BMI, calculated by the Quetelet formula $BMI = \text{weight}/\text{height}^2$, as follows [16, 17]:

- Group I, the group of normal weight individuals, corresponding to a BMI between 19.9 and 24.9, used as control
- Group II, the overweight individuals, corresponding to a BMI between 25 and 29.9
- Group III, the class I and II obese individuals, corresponding to a BMI between 30 and 39.9
- Group IV, morbidly obese individuals, corresponding to a BMI above 40

Volunteers were included after informed written consent, in accordance with previously established selection criteria, fully compliant with all ethical standards set by the Declaration of Helsinki and respective amendments [18], and previously submitted to the institutional ethical commission. Strict non-inclusion/exclusion criteria were being pregnant or nursing, any skin disorder or skin changes in the measurement areas, systemic disease, and ongoing topical and/or systemic medication.

All studies were developed under proper medical supervision. Obese patients were selected from the surgery consultation at the Department of Plastic Surgery of S. José Hospital (Lisbon, Portugal).

After selection and before measurements, the volunteers were left in the laboratory for approximately 20 min to adapt their skin to environmental conditions. Evaluations were performed under controlled temperature and humidity conditions ($21 \pm 1^\circ\text{C}$, $45 \pm 5\%$), in the absence of heat sources and forced convection, in accordance with previously published recommendations [19, 20]. Skin water balance was quantitatively assessed in terms of the barrier function, by TEWL, and skin hydration in 3 different anatomical areas – the face (measuring the forehead and the zygomatic areas, since the particular distribution of secretory glands in these areas promotes different physiological behaviours), the breast, and the abdominal region. TEWL was obtained by the Tewameter TM300 (CK Electronics GmbH, Germany) expressed in grams per square metre per hour. The measurement system is based on Fick's law of diffusion and allows determination of the amount of water vapour that continuously diffuses to the stratum corneum, widely used as the indicator of the human epidermal barrier function. The epidermal hydration was obtained by the Moisture Meter SC (Delphin Technology, Finland) system, measuring the skin's capacitance by assessing the surface water dielectric constant through which the stratum corneum hydration (expressed in arbitrary units) is registered [21, 22].

Skin biomechanics were quantitatively assessed with the Cutometer[®] MPA 580, and the Reviscometer[®] RVM 600 systems (CK Electronics GmbH, Germany). The Cutometer[®] was adjusted to an elementary charge cycle at a constant pressure of 400 mbar, held for 3 s and then released, followed by a relaxation period of about 3 s. A probe of 8 mm was used to obtain these descriptors – maximum skin distension (U_f), maximum recoverable strain after completion of the deformation period (U_a), both expressed in millimetres, and U_a/U_f "total elasticity," U_r/U_e "net elasticity" also known as "pure elastic index," and U_v/U_e , the "viscoelasticity" or "viscoelastic-elastic elongation ratio" [18]. In the

Fig. 1. Graphic illustration of the skin water balance-related variables TEWL (**a**) and epidermal hydration (**b**) mean values registered in these 4 anatomical areas as a function of BMI. A trend line is drawn to show this paradoxical tendency here identified, through which the patient's epidermal water balance seems to improve with some overweight (see text).

Table 1. Descriptive and comparative statistics of TEWL and epidermal capacitance mean values normalized for each individual's BMI obtained from all patients in 4 different anatomical sites

Anatomical site	n	TEWL, g/m ² /h			Epidermal hydration, AU		
		mean	SD	<i>p</i>	mean	SD	<i>p</i>
Zygomatic				0.000			0.004
Normal weight	42	11.653	4.456		48.905	21.343	
Overweight	15	8.094	2.960		56.200	21.197	
Obese class I and II	17	8.382	2.218		63.059	15.073	
Morbidly obese	15	16.333	7.569		45.067	19.594	
Forehead				0.000			0.017
Normal weight	42	9.710	3.159		50.095	18.227	
Overweight	15	8.162	2.448		57.333	20.756	
Obese class I and II	17	8.071	1.974		64.824	16.637	
Morbidly obese	15	15.320	4.644		46.467	16.269	
Breast				0.000			0.000
Normal weight	42	7.336	10.837		45.667	21.714	
Overweight	15	8.011	6.175		65.533	13.768	
Obese class I and II	17	10.341	5.620		71.765	20.330	
Morbidly obese	15	15.920	9.162		69.600	25.595	
Abdomen				0.000			0.001
Normal weight	42	6.463	2.665		32.167	20.688	
Overweight	15	3.799	1.543		44.000	12.427	
Obese class I and II	17	5.312	3.500		41.000	13.010	
Morbidly obese	15	7.980	2.963		26.067	8.439	

Groups were defined according to the WHO references (see text). * *p* < 0.05, refers to the comparison among groups.

Fig. 2. a–d Graphic illustration of the mean values of the main biomechanical descriptors, registered in these 4 anatomical areas as a function of BMI. Again the trend line is drawn to illustrate the tendency of the variables here identified, suggesting that morbid obesity seems to favour the skin's biomechanical performance (see text).

case of the Reviscometer®, the resonance running time (RRT) was recorded at angles 0°, 45°, 90°, and 135°, expressed as the multidirectional mean RRT in arbitrary units [21, 23].

The statistical analysis (descriptive and inferential) was performed using SPSS (v. 20.0, Microsoft, USA). Comparison between variables resulted from non-parametric tests – the Mann-Whitney test for 2 independent samples and the Kruskal-Wallis test for more than 2 independent samples. A variance analysis among groups was also made by using the Tukey HSD test. The level of significance for inferential purposes was $\alpha = 0.05$.

Results

Results from different anatomical areas are presented by BMI with a stratification of groups (a trend line was added in Fig. 1 and 2 to illustrate this evolution tendency

determined by the BMI). All values were age adjusted to avoid this confounding factor. Each variable mean value was divided, in each group, by the respective BMI.

Higher TEWL values are detected in normal weight and morbidly obese individuals when compared with overweight and class I and II obese subjects (Table 1). This morbidly obese group presented the highest values, and this trend line was present in all anatomical areas. A tendency to lower values of TEWL in overweight and obese class I and II individuals was evident or clearly observed, while higher values were noted at the extremities (normal weight and morbidly obese), graphically apparent with this “U” shape. Regarding the epidermal hydration (Table 1; Fig. 1), overweight and class I and II obese individuals showed higher epidermal hydration values when compared with normal and morbidly obese indi-

Table 2. Descriptive and comparative statistics of biomechanical descriptors normalized for each individual's BMI obtained from all patients in 4 different anatomical sites

Anatomical site	<i>n</i>	Ua, mm			Uf, mm			Ur/Ue			Uv/Ue		
		mean	SD	<i>p</i>	mean	SD	<i>p</i>	mean	SD	<i>p</i>	mean	SD	<i>p</i>
Zygomatic area				0.000			0.000			0.000			0.000
Normal weight	42	0.538	0.260		1.080	0.861		0.475	0.355		0.296	0.235	
Overweight	15	0.350	0.131		1.979	0.868		0.112	0.120		0.080	0.025	
Obese class I and II	17	0.341	0.183		2.415	3.030		0.088	0.037		0.076	0.017	
Morbidly obese	15	0.393	0.143		0.769	0.572		0.528	0.326		0.500	0.308	
Forehead				0.000			0.000			0.000			0.000
Normal weight	42	0.442	0.269		0.693	0.960		0.667	0.405		0.522	0.434	
Overweight	15	0.180	0.132		1.639	1.104		0.084	0.108		0.078	0.106	
Obese class I and II	17	0.138	0.042		2.093	2.341		0.044	0.011		0.037	0.010	
Morbidly obese	15	0.322	0.196		0.487	0.765		0.732	0.334		0.639	0.292	
Breast				0.000			0.000			0.000			0.000
Normal weight	42	0.633	0.282		0.807	1.026		0.948	0.466		0.560	0.300	
Overweight	15	0.289	0.149		1.665	0.736		0.145	0.221		0.083	0.045	
Obese class I and II	17	0.280	0.118		2.182	2.848		0.089	0.030		0.072	0.027	
Morbidly obese	15	0.489	0.234		0.620	0.832		1.077	0.471		0.725	0.331	
Abdomen				0.000			0.000			0.000			0.000
Normal weight	42	0.978	0.405		1.296	1.427		0.817	0.399		0.359	0.249	
Overweight	15	0.446	0.239		1.970	1.123		0.189	0.240		0.091	0.029	
Obese class I and II	17	0.320	0.122		2.088	2.827		0.111	0.047		0.063	0.025	
Morbidly obese	15	0.368	0.120		0.454	0.444		1.240	0.614		0.795	0.545	

Uf, maximum skin distension; Ua, maximum recoverable strain after completion of the deformation period; Ur/Ue, net elasticity; Uv/Ue, viscoelasticity. The total elasticity ratio Ua/Uf, represented in figure 2, was directly calculated from this table. Groups are defined according to the WHO references (see text). * $p < 0.05$, refers to the comparison among groups.

viduals. The graphic representation, with an “inverted U” shape, shows higher epidermal hydration values for overweight and obese individuals, while lower values were registered in normal and morbidly obese individuals.

For the biomechanical variables, the Cutometer quotient descriptors Ua/Uf (or “total elasticity”), Ur/Ue (“net elasticity”) and Uv/Ue (“viscoelasticity”) were chosen, as they have been reported as being better suited to illustrate these characteristics [22–24]. A clear reduction of Ua, the skin's capacity to recover and to return to the original resting conformation after the stress period, was noted in the overweight and obese populations, except for the morbid patients, while Uf, the maximum extensibility obtained during the stress period, was clearly higher in the overweight and class 1 and 2 obese populations (Table 2; Fig. 2). Ur/Ue and Uv/Ue show the same distinction between the different groups. Figure 2 clearly shows these tendencies in which a similar normal elasticity (total and viscoelasticity) was only found for the morbidly obese. Finally, the RRT, Reviscometer's main variable which relates the acoustic propagation time with biomechanics,

has shown a tendency similar to the epidermal hydration (Table 2; Fig. 2). The RRT might be calculated in different directions (from 0 to 360°) and has been suggested to provide an approach to anisotropy by the quotient $RRT_{\max}/RRT_{\min}$ ratio [8, 21]. We compared these ratios from different orientations (0°, 45°, 90°, and 135° as the mean multidirectional RRT), in all anatomical regions and found non-significant, highly variable results (data not shown).

Discussion

The increase in obesity, especially affecting women, was the most expressive revelation in the last national health enquiry [3]. Likely related, women represented more than 80% of the nutrition and surgery consultation at the S. José Hospital where the obese patients were selected. These facts partially explain why our study only included women. However, from the functional point of view, and apart from the expected differences in struc-

ture, the influence of sex on skin physiology is still an issue. Water-related variables (e.g. TEWL and capacitance) are reported not to differ significantly between genders [25, 26]. Other variables, such as the sebum secretion rate and the transcutaneous oxygen partial pressure, seem to be clearly determined by sex (sebum secretion rate higher in males and transcutaneous oxygen partial pressure higher in females), that is the specific neuroendocrine structure-determined environment [27, 28]. Even so, a recent study suggested that gender had no significant impact on the levels of the residual skin surface components known as the epidermal “acid mantle” [29]. Also related, differences between genders have been extensively reported for biomechanical descriptors, as have differences involving ageing, since, reportedly, skin elasticity decreases more intensively in women after the menopause [26, 30, 31]. Recent data suggest that epidermal entrance echo and dermis thickness decrease with age and that the decrease in skin thickness per decade is more significant in men than in women [32]. Therefore, gender was regarded as a source of variability that could be managed by including only women in the present study.

Although a strong connection between morbid obesity and various skin alterations and disease is known, only a few studies were dedicated to the impact of overweight on skin physiology. Not rarely, experimental conditions and conclusions are controversial, and the comparison of results becomes an impossible goal. Additionally, most of the published human *in vivo* studies compared obese individuals with normal weight references, ignoring other classes of excessive weight subjects.

The increase in TEWL with BMI has been reported by simply comparing normal weight and obese individuals. One study found a decrease in TEWL in the forearm volar surface of obese children [10]. An inverse correlation between the U_a/U_f and sagging was described in obese individuals [24]. Stronger mechanical characteristics were found in samples of abdominal skin removed from massive weight loss patients [15]. Another study, in mice, reported a progressive reduction of U_a with weight gain and a reduction of the net elasticity when animals had previously been subjected to a high-fat diet [33].

Recently we have proposed an experimental approach to study the functional changes taking place in obesity *in vivo* [34], and this provided the basis for the first set of comparable results relating changes in epidermal water balance and skin biomechanics under these conditions [35]. The present study is the first approaching the epidermal water “barrier” and the envelope functions, basic indicators of *in vivo* skin physiology, in a population in-

cluding overweight, class I, II and morbidly obese individuals (as defined by the BMI) and confirms that the weight gain determines a distinct adaptation of skin physiology. Regarding the epidermal barrier function, overweight and obesity classes I and II individuals show lower TEWL values than normal weight and morbidly obese subjects (Table 1; Fig. 1). Furthermore, it is known that morbidly obese patients often mention dry skin as one of the most common complaints, and this frequently correlates with lower epidermal hydration, as reported previously [7, 8]. Nevertheless, we noted that individuals with BMI between 25 and 39.9 exhibited higher levels of epidermal hydration in all anatomical areas, which contrasts with the lowest values found in the morbidly obese group (Table 1). This occurrence might affect skin biomechanics, once the influence of hydration on skin mechanical properties has been referred for a long time [8, 20, 34, 36].

Cutometer descriptors were higher in both normal and morbidly obese patient groups in all anatomical areas, while overweight and class I and II obese patients demonstrated significant decreases in the same descriptors when compared with normal subjects. A decrease in these parameters seems to suggest a better biomechanical behaviour even in the presence of lower hydration levels [34, 36]. The multidirectional mean RRT has been reported to be sensitive to discriminate between different skin conditions, although some doubts remain regarding its significance. The higher the RRT, that is, the longer the waves need to propagate, the less elastic the skin [23, 31]. Some studies, however, related the decrease in RRT with photo-aged skin [37, 38] and to a dry skin/dehydrated skin condition [39]. In our study, we found a pattern that approximately follows the epidermal hydration, supporting the view that interpretation of *in vivo* multidirectional mean RRT should always take the epidermal hydration status into consideration [23].

These results suggest that the increased weight and the consequent adaption to a new body contour evoke an irregular evolution of skin physiology, illustrated by the “U” or “ $\cap$ ” curve shapes in Figures 1 and 2. The expected variable increase/decrease corresponding to the weight gain gives place to a non-linear change in which, and paradoxically, some weight gain actually seems to benefit these properties. We are aware that obesity is a complex state, demanding extensive epidemiological analysis and pathophysiological explanation. Some weight gain has been shown to improve the survival of patients with cardiovascular disease (hypertension, heart failure, coronary disease, peripheral vascular disease) and also of patients

with chronic renal failure, advanced neoplasia, acquired immune deficiency syndrome, or (simply) elderly subjects, evoking what is known as the “obesity paradox” [5, 6, 40, 41]. Several explanations have been proposed including that a higher BMI implies higher subcutaneous mass, including muscle, and this may explain a better physiological performance due to lower systemic vascular resistance, lower humoral pressure and sympathetic activities, resulting even in some protective effects [40, 41]. Seemingly, our study shows that the weight gain apparently improves the barrier in a first stage (class I) that, by the chronic exposure to the disease progression, gives place to a different set point, where a higher water loss encompasses epidermal dryness. The weight gain seems to compromise all biomechanical indexes, in particular for the overweight and obese (class I and II) individuals, when compared to normal in all anatomical areas. In the morbidly obese group, however, all biomechanical indexes are close to normal.

While we acknowledge that our sample dimension is reduced, in particular for morbid patients, our results display consistent data homogeneity and strong coherent comparisons. Additionally, the sample stratification was based on the WHO BMI classes, and it is known that BMI over 30 have higher specificity and low sensitivity, which can contribute to the relevant bias. Of particular value, we believe, is that our study population was all “healthy” (with the critical exception of excessive weight) in the way that comorbidities were absent, as well as regular medication. Stratified groups with those characteristics might reveal different characteristics. Other markers such as the

waist circumference or the body fat percentage were not tested within this study, and the exposure time, that is, the number of years volunteers were classified as obese was not considered. Further studies are required to better understand these impacts. Notwithstanding any physiological benefits seen, one must always keep in mind that obesity is a serious risk factor determining a wide variety of clinical conditions.

Conclusion

Our results contribute to complement the “obesity paradox” regarding skin physiology. In the same way that some weight gain seems to improve the pathophysiology of various patient groups, including elderly individuals, it also appears to improve cutaneous performance.

Statement of Ethics

Volunteers were included after informed written consent, in accordance with previously established selection criteria, fully compliant with all ethical standards set by the Declaration of Helsinki and respective amendments [18], and previously submitted to the institutional ethical commission.

Disclosure Statement

The authors declare that there is no financial or personal relationship that can be understood as representing a potential conflict of interest.

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