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Change in Skin Physiological Parameters in Space – Report on and Results of the First Study on Man

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Key Words
In vivo assessment · Skin physiology · Skin care · Space research

Abstract
Astronauts often show skin reactions in space. Systematic tests, e.g. with noninvasive skin physiological test methods, have not yet been done. In an interdisciplinary cooperation, a test series with skin physiological measurements was carried out before, during and after a long-term mission in the International Space Station. The hydration of the stratum corneum (Corneometer), transepidermal water loss (Tewameter), and the surface structure of the skin (SkinVisiometer) were measured. In order to record cutaneous states, the suction elasticity was measured (Cutometer), and an ultrasound measurement with 20 MHz (DermaScan) was also made. In addition, one measuring field of the two inner forearms was treated with a skin care emulsion. There were indications of a delayed epidermal proliferation of the cells, which would correspond to the clinical symptoms. Hydration and TEWL values are improved by respective skin care. On the cutaneous level, the elasticity measurements and the ultrasound picture showed results which correspond to a significant loss of elasticity of the skin. Further examinations are necessary to validate these preliminary results.

Introduction

Time spent in space, e.g. in the International Space Station (ISS), leads to a series of pathophysiological changes in the astronauts, which most probably are mainly due to the lack of gravity. In terrestrial training programs and so-called parabolic flights they cannot be sufficiently simulated.

Among the subjective complaints, especially after a longer stay in space, the skin-related ones play an important role together with the complaints connected to the circulation and, impairments of balance. Apart from itching and dryness of the skin (which is possibly also partly due to the special skin care carried out in the ISS), a thinning of the skin and increased sensitivity combined with delayed healing of wounds and partly also an increased tendency to infections of the skin have been reported.

This is why in a pilot study applying noninvasive dermatological test methods before, during and after a long-term mission of an astronaut, single measuring parameters of the skin have been recorded and at the same time possibly positive effects of skin care were examined.

For this purpose, a test program was developed which had to be coordinated with the European Space Agency (ESA) with regard to content and time schedule. The measuring devices to be used for the tests in the ISS had

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to be miniaturized by the manufacturer and subsequently tested as to their suitability for space travel as well as their permissibility. The same went for the selected skin care emulsion.

Methods

Planning and Implementation of the Tests

Due to weight constraints the number of measuring devices to be used had to be limited. Also as far as the time strain resulting from the measurements was concerned, limits had to be considered. Thus, the following methods/devices were chosen for the measurements on the skin surface and epidermis: (1) Corneometer® for the determination of hydration of the stratum corneum; (2) Tewameter® to measure transepidermal water loss (TEWL), and (3) SkinVisiometer® to measure the surface structure of the skin (Courage & Khazaka, Cologne, Germany).

The tests predominantly concerning the cutis were carried out by means of: (4) determination of skin elasticity with the Cutometer® (Courage & Khazaka), and (5) measurement of the ultrastructure of the skin with 20-MHz ultrasound (DermaScan®, Cortex Technology, Denmark). The latter two tests could only be performed before and after the mission.

All measurements were carried out on different skin areas previously determined on both inner forearms of 1 test subject (astronaut). Before and after the mission measurements were carried out by the staff of the Institute for Experimental Dermatology at the Astronaut Centre, Cologne. The measurements in the ISS were done by the test subject, who was briefed. At the same time, the measuring areas on the right forearm were treated with a skin care emulsion daily.

The test program was scheduled in such a way that shortly before and after the mission two terrestrial measurements were carried out, and interim measurements took place during the stay in the ISS. Due to space technological reasons, however, preflight measurements had to be carried out quite some time before the mission, and the measurements in the ISS only comprised a part of the stay, because the measuring devices were taken to the ISS with the next supply shuttle (table 1).

Results

Epidermal Measurements

Measuring the Hydration of the Stratum Corneum (Corneometer MSC 100)

The results of skin physiological measurements of the epidermis are known to depend to a large extent on the conditions of the respective environment and skin adaptation to these conditions. While these measuring conditions in the ISS were more or less stable throughout the measuring period (table 2), the environmental conditions for the measurements before and after the mission – the astronaut stayed in Florida, Cologne, and Moscow, respectively – had an extreme influence on the results, as can be seen from the Corneometer values (table 3). This is why for the analysis of the results, mean values were calculated and those were then (in individual depictions) compared to the mean values of the ISS measurements.

Table 1. Data of the skin measurements

Measurements	ISS	HY	TEWL	SELS	ELAST	US
L –332 days		x	x	x	x	x
L –120 days		x	x	x	x	x
	Launch					
L +90 days		x	x	x		
L +104 days		x	x	x		
L +118 days		x	x	x		
L +132 days		x	x	x		
L +146 days		x	x	x		
L +159 days		x	x	x		
	Return					
R +31 days		x	x	x	x	x
R +62 days		x	x	x	x	x

ISS = Stay in the space station; HY = hydration (Corneometer); TEWL = transepidermal water loss (Tewameter); SELS = surface evaluation of living skin (SkinVisiometer); ELAST = Cutometer; US = ultrasound B-scan (DermaScan C); L = launch; R = return.

Table 2. Conditions for skin physiological measurements in space

Date	Temperature, °C	Relative humidity, mm Hg	Location of measurements (ISS)
L +90 days	25	10	Pris module
L +104 days	24	10	service module
L +118 days	24	9	service module
L +132 days	25	10	service module
L +146 days	26	10	service module
L +159 days	25	10	service module

Table 3. Hydration measurements (Corneometer MSC 100, a.u.) before and after the mission (inside of the forearm, n = 3)

L –332 days		L –120 days		R +31 days		R +62 days	
right	left	right	left	right	left	right	left
47.3	41.0	32.7	36.0	35.7	38.7	34.0	32.3

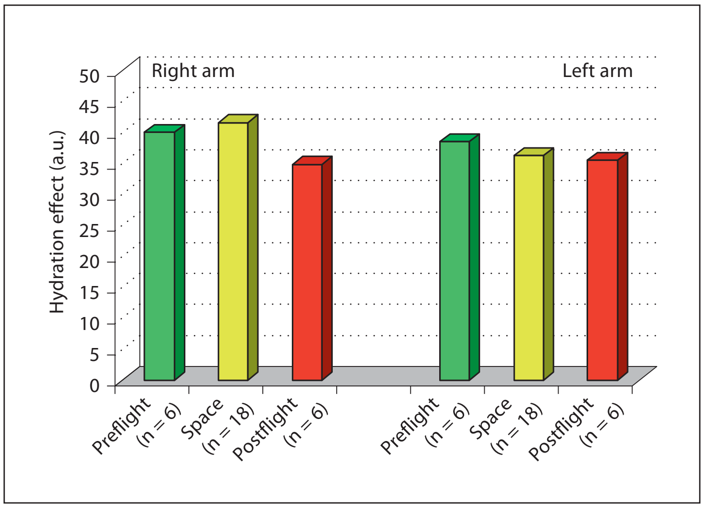

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Fig. 1. Skin physiological measurements: hydration effect (Corneometer MSC 100, mean values).

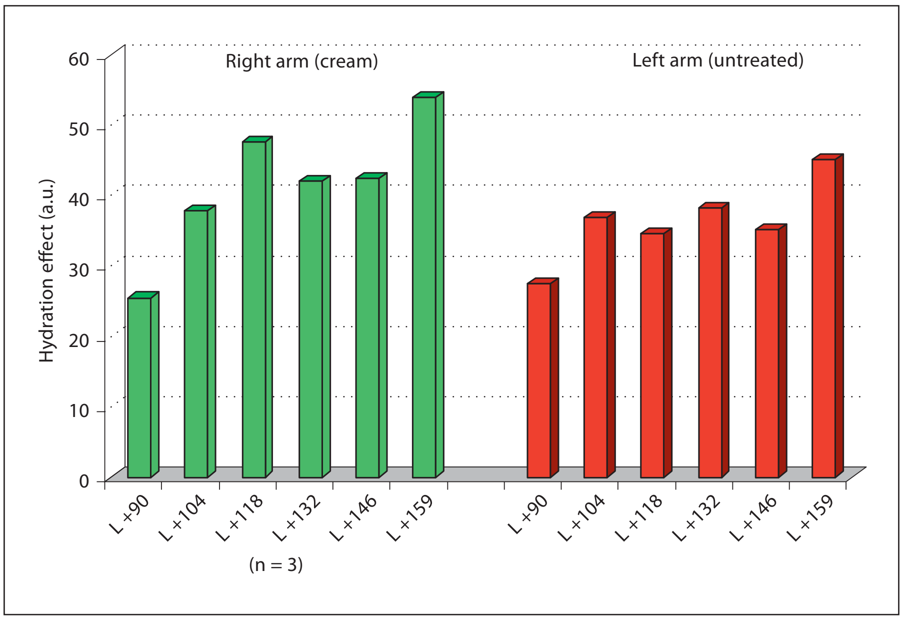

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Fig. 2. Skin physiological measurements in space: hydration effect (Corneometer MSC 100). L = Launch.

Comparison of the mean values of the hydration measurements before, during and after the mission showed that there were only minor differences between the sides (right > left). However, there is a clear hydration effect of the applied skin care emulsion (fig. 1).

When it comes to the individual values for the measurements in space, both measuring fields on the forearm show an increase in the Corneometer values over time, although the prevailing conditions (table 2) remained unchanged. In addition, there was no clear connection to the TEWL values (see below).

An increase in hydration values of this kind is also found in the aging skin. This phenomenon is, however, not a real hydration increase of the aged skin, which is dry, but it is due to a change in measuring area (i.e. the dielectric of the condenser) in favor of epidermis parts containing more water due to a thinning of the stratum corneum (fig. 2).

Measuring TEWL (Tewameter MSC 100)

With the measurement of TEWL the capacity of the epidermal barrier can be assessed quantitatively. Low values, which occur in the case of dermatitis atopica or other dermatoses, indicate a barrier disorder.

With this method, the mean values also show the stabilizing effect of the skin care treatment carried out dur-

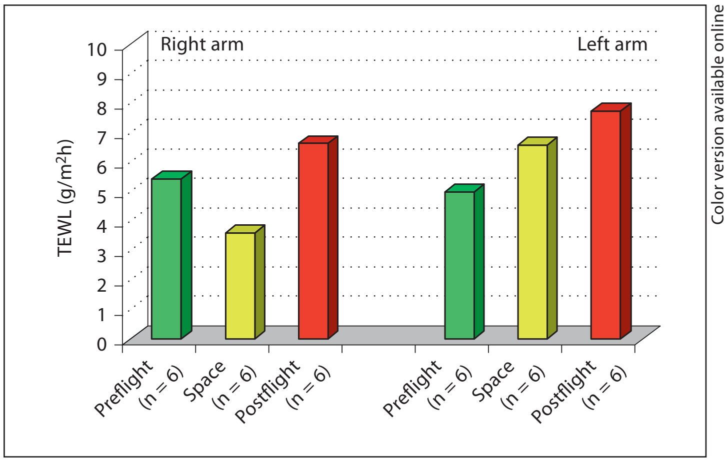


Fig. 3. Skin physiological measurements: TEWL (Tewameter MSC 100).

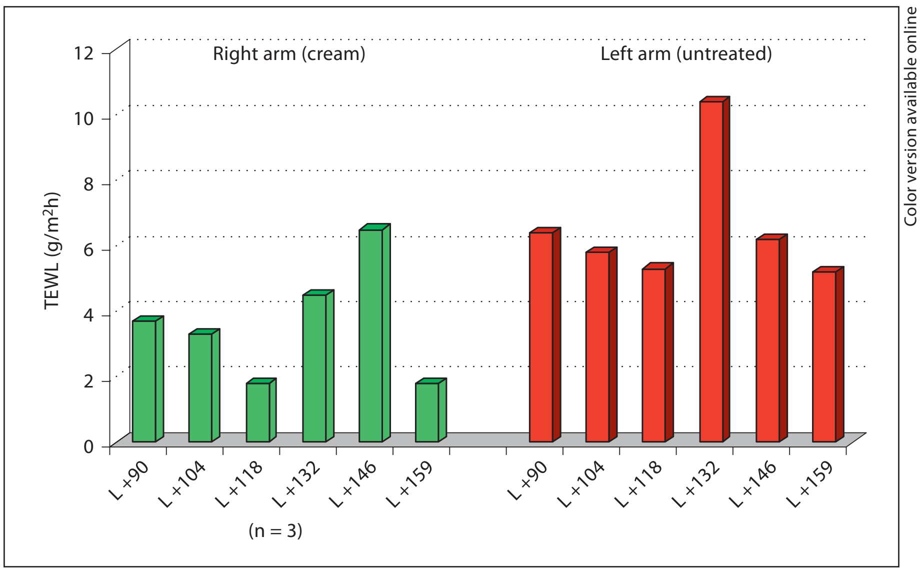


Fig. 4. Skin physiological measurements in space: TEWL (TEWL MSC 100). L = Launch.

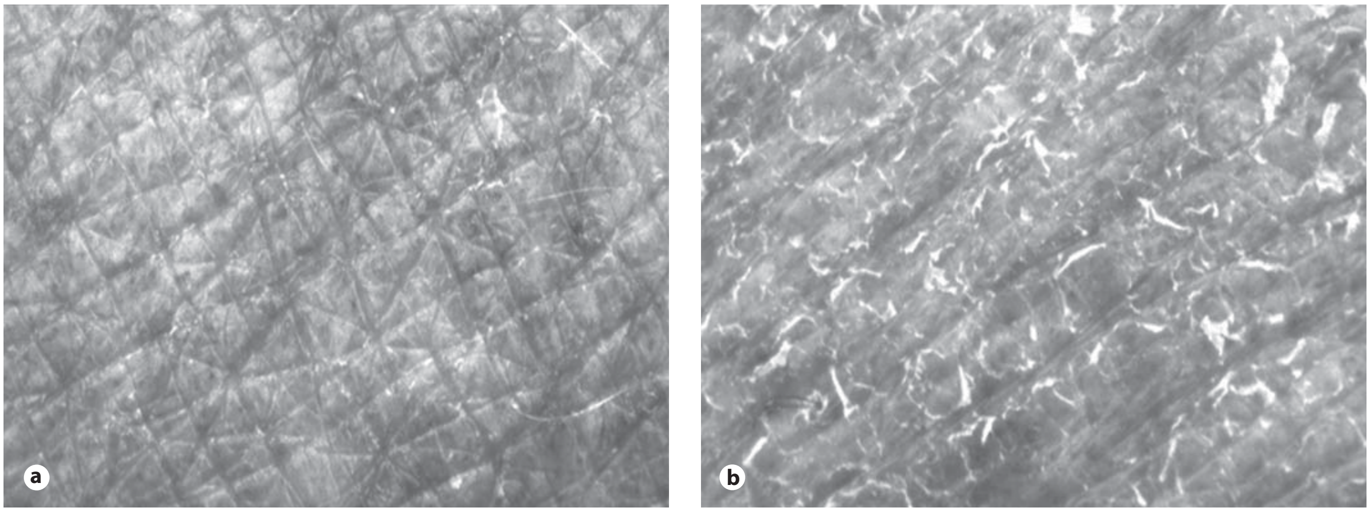
ing the mission (fig. 3). Furthermore, there is a continuous increase in TEWL values in the untreated measuring field. Whether this tendency is really relevant seems questionable in view of the different conditions for the terrestrial measurements. The individual values determined during the mission show some variation, probably related to the measurement, but no tendency to increase (fig. 4).

Measuring the Surface Structure of the Skin (Surface Evaluation of Living Skin, SELS, SkinVisiometer Version 7/2000, S. Challois-M. Vergeau)

With this method, the skin surface structure is recorded with a CCD camera under controlled lighting and its surface parameters [roughness, scaling, smoothness (volume), and wrinkling] are determined via lightness values and the order of the pixels [1]. Constant short-wave lighting and the analysis of the recorded skin field adjusted to it are decisive for the evaluation of skin surface parameters.

As a result of the different climatic conditions the test person's skin was subjected to, there was a certain variation in the individual parameters (e.g. as a result of strong scaling) in the terrestrial measurements before the mission (fig. 5).

When the photographs of the skin before and after the mission were compared, coarser skin surface fields were noticed (fig. 6). Such an increased coarsening of the skin fields is also found in aging skin (fig. 7), probably as a result of a slowed-down turnover of epidermal cells from the basal layer to the stratum corneum. These findings correlate with the measuring results of the Corneometer, which indicated decreased thickness of the stratum cor-



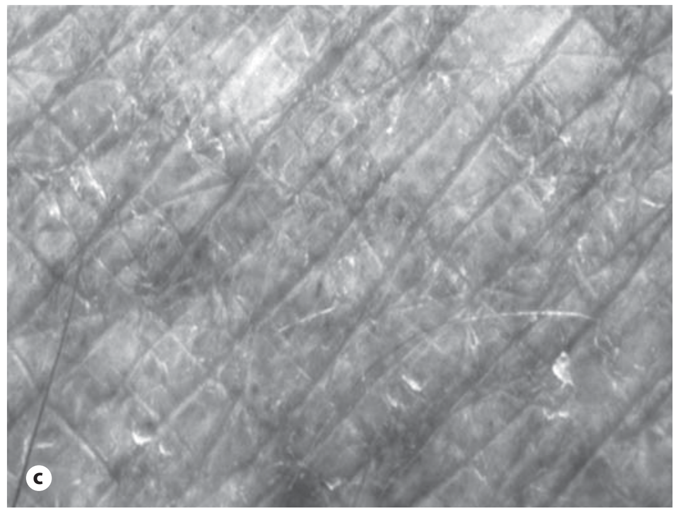


Fig. 5. Skin physiological measurements: skin surface structure (forearm, SkinVisiometer). **a** SELS before the mission (normal skin). **b** SELS before the mission (strong development of scales). **c** SELS after the mission (coarser skin surface fields).

neum, and they also explain the dermatological complaints of astronauts mentioned earlier.

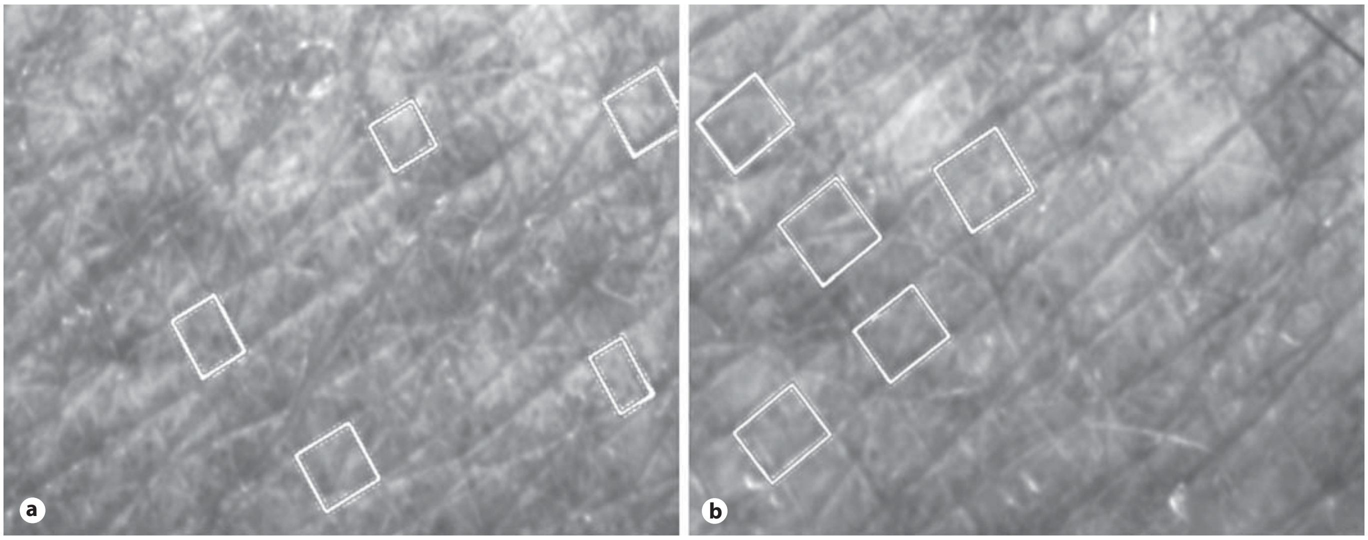
Unfortunately, the Visiometer measurements in space were registered with a deviating recording mode so that a direct quantitative comparison with the terrestrial measurements is not possible (fig. 8). However, when it comes to the determination of the roughness values, skin treated with the emulsion during the mission is evidently smoother. The untreated measuring field shows a tendency toward an increase in roughness over the same period of time (fig. 9).

Measuring Skin Elasticity (Cutometer SEM 575 Version 9.0.2.0)

For space technological reasons these measurements, which were, above all, aimed at identifying possible influences at the level of the cutis (elasticity and 20-MHz ultrasound), could only be carried out terrestrially before and after the completion of the mission.

During measurements, the skin is sucked into the measuring probe by means of below-atmospheric pressure. Here, the impression depth is recorded by an optical measuring system without contact. It is possible to carry out measurements at constant below-atmospheric pressure and also at linearly decreasing below-atmospheric pressure.

Prior to each measurement, maximum pressure, measuring time, the time of pressure rise and fall as well as the number of measuring cycles are set. After the measurement, the respective measuring curve in a coordinate system appears on the monitor. It shows the impression depth of the skin into the measuring probe during action



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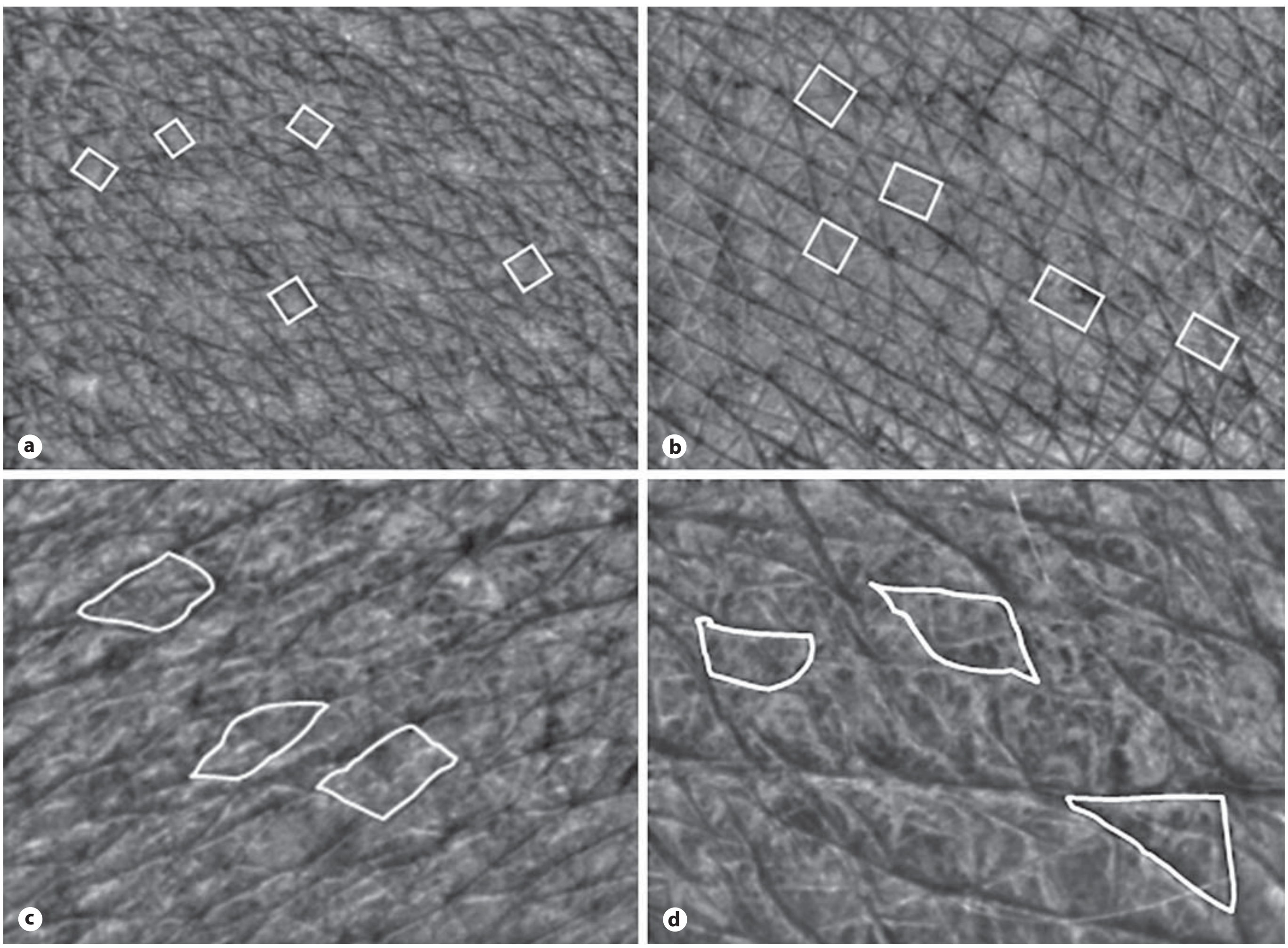

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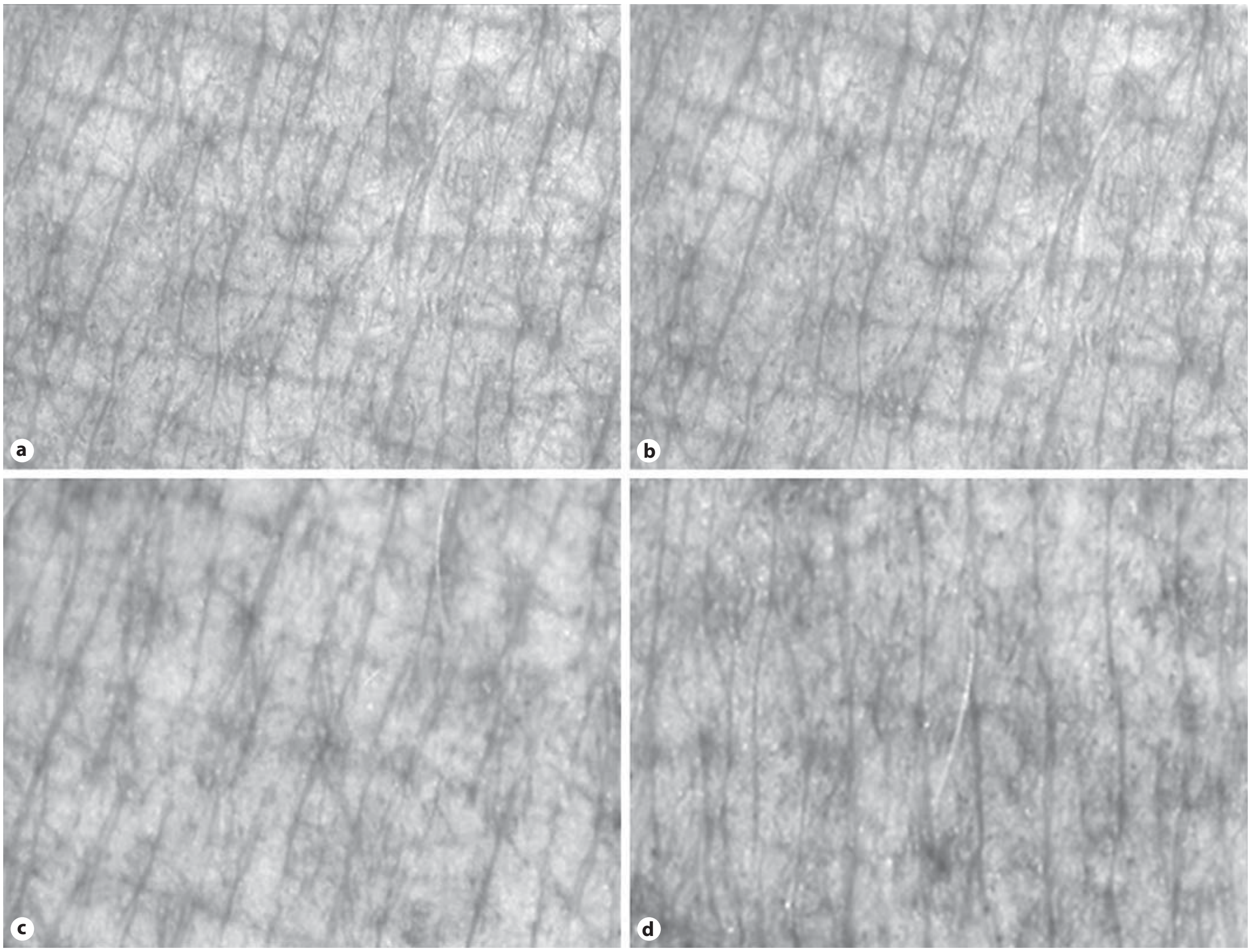
Fig. 6. Skin physiological measurements in space: skin surface structure (forearm, SkinVisiometer). **a** Before the mission. **b** After the mission.
Fig. 7. Age-related changes in skin surface fields (SkinVisiometer). **a** 10 years. **b** 20 years. **c** 50 years. **d** 65 years.



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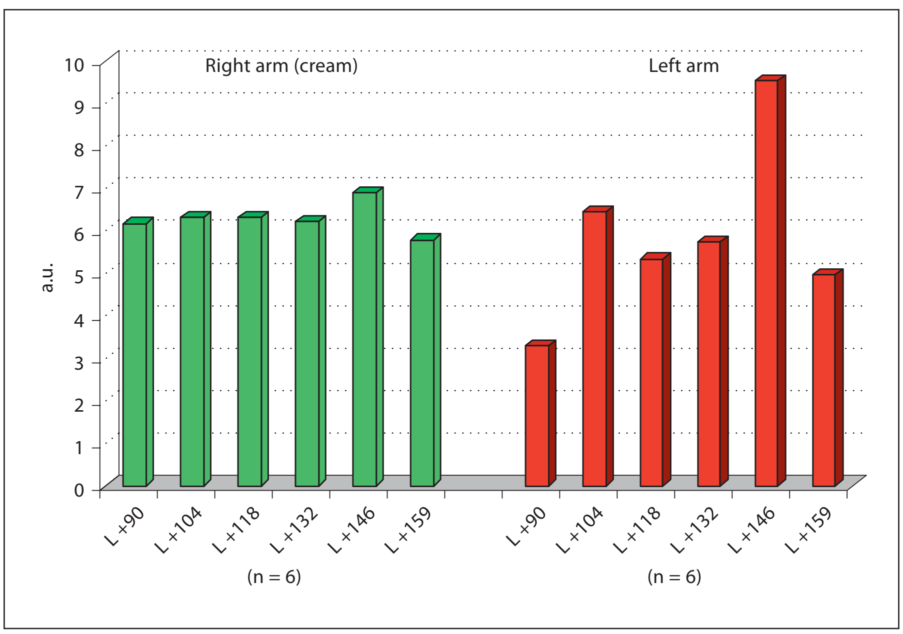

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Fig. 8. Skin physiological measurements in space: skin surface structure (forearm, SkinVisiometer).

Fig. 9. Skin physiological measurements in space (VisioScan, SE_r – roughness). L = Launch.

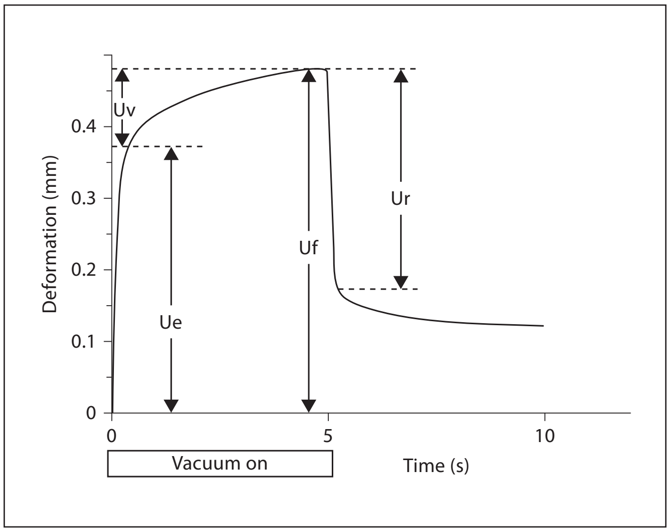

Fig. 10. Example of an elasticity curve.

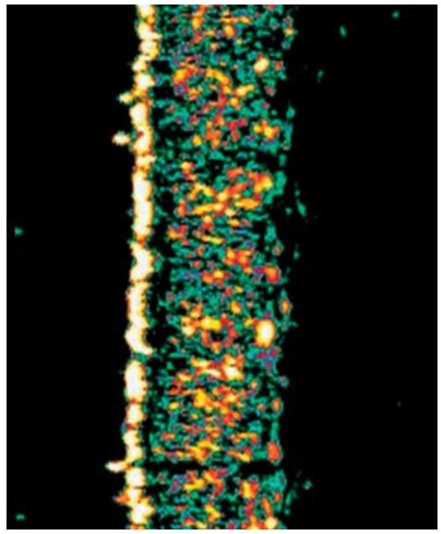

Fig. 11. Preflight skin physiological measurements: ultrasound images, L –120 days.

Table 4. Elasticity parameters

	Name	Calculation	Changes with age
Total stretching of the skin	R_0	–	↑
Viscoelasticity (sucking-in phase)	R_6	Uv/Ue	↑
Biological elasticity (relaxation phase)	R_7	Uv/Uf	↓
Elastic properties	R_5	Ur/Ue	↓

Table 5. Changes in elasticity due to the mission (Cutometer SEM 575 9.0.2.0)

	Preflight (n = 8)	Postflight (n = 8)
R_0	0.240.0	0.265.8
R_6	0.175.0	0.266.3
R_7	0.487.0	0.522.5
R_5	0.583.3	0.854.0

time and its regression afterwards. The characteristic pixels are approached with the cursor and the individual data are recorded.

For the determination of suction elasticity, the skin is sucked into a standardized probe by means of a fixed level of negative pressure. During this suction process and the subsequent release after the negative pressure is no longer there, a typical elasticity curve develops (fig. 10).

The total stretching/dilation of the skin (R_0) as well as the viscoelastic properties in the initial suction phase (R_6) (Uv/Ue) and the relaxation phase R_7 (Ur/Uf) are termed biological elasticity. The combination of the two parts of curve R_5 (Ur/Ue) characterizes the elastic properties of the skin [2] (table 4). After the stay in the ISS, all elasticity parameters increased (table 5), different to normal ageing of the skin, which indicates a clear loss of elasticity of the cutis.

Morphology of the Cutis

Ultrasound B-Scan 20 MHz (DermaScan CV3, Version 1.6.5.0, Cortex Technology, Denmark)

The loss of skin elasticity after the stay in space is confirmed by changes in the ultrasound picture of the skin. While before the mission only slight subepidermal photo-aging was visible as a low-echo zone (fig. 11), after the mission there were large low-echo zones in the entire cutis (fig. 12). In other places there were inversions of subcutaneous adipose tissue into the basal cutis as they occur in case of the so-called cellulite in women (fig. 13). These low-echo zones are obviously not the result of an inclusion of liquid in the sense of edema – in that case one would expect decreased values for R_0 and increased values for R_6 – but are caused by a rarification of the fiber structure in the cutis.

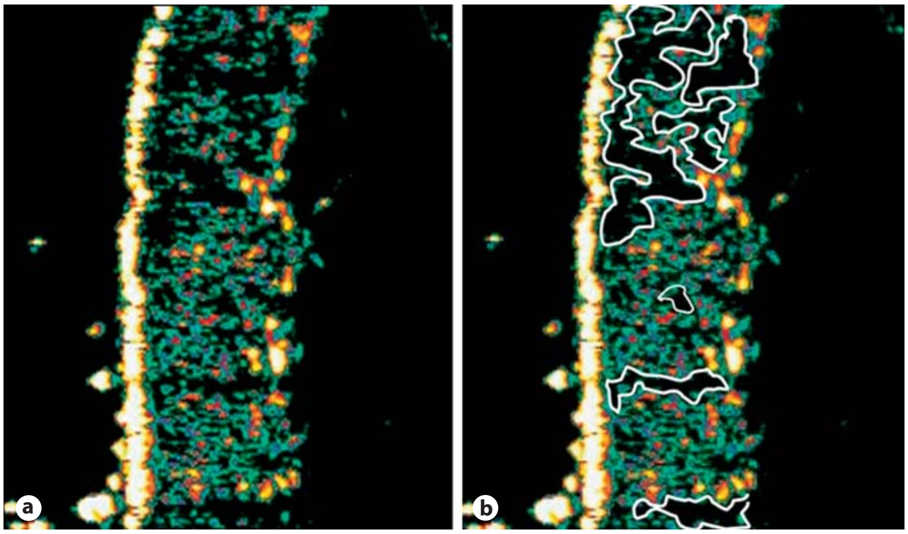

Fig. 12. Postflight skin physiological measurements: ultrasound images, R +31 days.

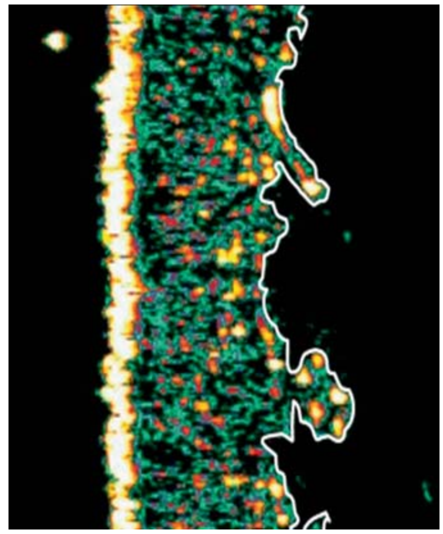

Fig. 13. Postflight skin physiological measurements: ultrasound images, R +62 days.

Discussion

Clinically relevant side effects on the skin of astronauts in space play almost as important a role as do the side effects connected to blood vessels.

To date, there are no systematic studies on the effects of a stay in space on the human skin [3], and skin changes during a long-term mission in particular. Ultrasound measurements were only carried out during a short-term mission, i.e. under the influence of vessel alteration [4].

Numerous further examinations deal with the influence of weightlessness on the vascular system [5–7]. Of course, skin physiological measurements are also influenced by an adjustment of vascular parameters to weightlessness. Within about 3–5 days, however, the liquid shift (blood and tissue liquid) is completed. The adjustment of salt and blood composition takes about 4 weeks. The measurements in the ISS presented here were carried out after a longer period of time.

One should also mention the extensive tests – partly done on animals – which deal with the regression of muscles and bones due to inactivity and in which therapeutic recommendations are given to a certain extent [8–11].

These changes, whose effects, as we know, only become relevant after the return to earth, could also be used for comparisons between skin and bone changes in space. Comparative tests between cutis measurements and bone density in case of osteoporosis seem to support this idea.

The skin physiological test series during a long-term mission in space, which now has been completed – run by ESA under the name SkinCare project, could be started after a planning time of only 18 months. During this time the measuring devices were miniaturized and tested for their suitability for use in space. The skin care emulsion also had to be selected and packaged in a way suitable for space travel. The entire measuring program had to be developed and coordinated with the space travel agency ESA. Furthermore, the measurements had to be practiced with the astronaut who was to be the test subject.

The successful completion of the program showed that it was well planned. Changes in the time schedule of the mission, which had a negative influence on the measuring times and which led to an insufficient acclimatization for the terrestrial measurements, were caused by the space travel planning and internal rescheduling. The fact that the Visiometer readings in the ISS could not be analyzed was due to a mistake in the analyzing system. For all these reasons, but also because the measurements were carried out on only one person, the whole test program does, of course, not fulfill the requirements of a comprehensive validation. This is why only those values which clearly deviated from the comparative or reference values, respectively, were presented. However, their evaluation is made with the greatest caution and the relevance of the findings needs to be confirmed by further series of measurements.

Table 6. Medical incidents in shuttle program from postflight medical debrief, STS-26-STS-74 (1988–1995)

Condition	Frequency	Percent
Facial fullness	226	81.0
Headache	212	76.0
Sinus congestion	173	62.0
Dry skin, irritation, rash	110	39.4

Table 7. Ingredients of the skin-protection cream

- Aqua
- Glycerin (moisturizer)
- Caprylic/capric triglyceride (cosmetic oil)
- Urea (moisturizer)
- Sodium polyacrylate (stabilizer)
- Hydrogenated polydecene (cosmetic oil)
- Trideceth-6 (emulsifier)
- Creatine (increases barrier function of skin)
- Phenoxyethanol (preservative)
- Trisodium dicarboxymethyl alaninate (complexing agent)

The epidermal measurements provided evidence of a thinning of the stratum corneum and a prolonged molting time of the cells from the stratum basale toward the stratum corneum. These results (table 6) correlate with the reports of the astronauts about the state of the skin during their stay in space. A one-sided treatment with a skin care emulsion during the mission (table 7) led to an improvement in the hydration of the stratum corneum as well as an improvement in the barrier function of the epidermis.

Elasticity measurements and especially the ultrasound images of the skin showed signs of a rarification of the cutaneous fiber system. The observed low-echo zones were not due to liquid inclusion in the sense of an edema, which was shown by comparative elasticity tests. The changes in elasticity values (R_0 and R_6) that are typically seen in an edema do not exist. Atrophy due to inactivity, as it occurs in paraplegia, shows clearly smaller and more defined low-echo areas.

At present, one can only speculate about the causes for the epidermal and cutaneous changes, which only in the broadest sense correspond to age-related changes.

Further tests, above all with more test subjects, using optimized test conditions and additional measuring methods (e.g. for the determination of capillary blood flow and oxygen saturation of hemoglobin) are necessary. This way, the side effects on the skin related to a long-term stay in space can certainly be minimized and possibly general medical risks can be recorded via skin physiological parameters. This goes, above all, for the causes of the skin changes, e.g. the influence of weightlessness, which can thus be determined.

Acknowledgments

The successful performance of this test series was only possible through an interdisciplinary collaboration. Our thanks go to our partners in this cooperation: Jean Cornier and Michael Massow, ISS Lab Ruhr GmbH, Dortmund, Germany. The team at the European Astronaut Centre, Cologne, Germany. The project implementation manager and the mission integration team at the European Space Agency, ESTEC, Noordwijk, The Netherlands. Gabriel Khazaka, Courage & Khazaka Electronic GmbH, Cologne, Germany. Ralf von Heise-Rotenburg and his co-workers, Kayser-Threde GmbH, Munich, Germany. Annette zur Mühlen, Evonik, Business Unit, Care Specialities, Stockhausen GmbH, Krefeld, Germany.

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