Surface Evaluation of Living Skin (SELS) parameter correlation analysis using data taken from astronauts working under extreme conditions of microgravity

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Abstract
Background: In space, due to fluid shift a 45% decrease in the skin topography parameter volume (mm³) was seen using the VisioScan® camera. Simultaneously, the parameters roughness, scaling, and wrinkles changed dramatically as well. Thus, the present study has the objective to understand the relationship between the SELS parameters under extreme conditions and their application by addressing scientific-dermatological questions.

Material and Methods: SELS measurements were performed on the volar forearms of six astronauts. The Pearson correlation coefficient was used to determine the association between the variables.

Results: A significant correlation was found between the skin topography parameter volume and the skin parameters roughness, scaling, and wrinkles. A closer look at each astronaut revealed a significant correlation for all astronauts for the parameters volume and roughness and for more than 65% of the astronauts for the parameters volume and scaling and volume and wrinkles. However, no correlation could be found between the parameters skin hydration and roughness and scaling, respectively.

Conclusion: Only the parameter skin volume leads to meaningful data under microgravity. Physiological changes observed by fluid shift are comparable to the skin condition edema on earth. Based on the obtained data, we can conclude that the formulas for the SELS parameters roughness, scaling, and wrinkles for this special skin condition need to be reviewed.

KEYWORDS
edema, fluid shift astronauts, ISS, long-duration stay, SELS parameters

1 | INTRODUCTION

Characterizing the condition of the skin surface structure is a central aim for the evaluation of numerous cosmetic applications as well as for dermatological research. A non-optical measurement for the skin profile is carried out by the VisioScan® camera, developed by Tronnier et al.¹ The camera captures high-resolution, non-glossy pictures of the skin surface. For this purpose, the head contains two special metal-halogenide lights (UV range) that illuminate a 15 × 17 mm measuring area of the skin uniformly. The spectrum and density of the lamps have been chosen in such a way that only the skin surface, without reflections of deeper layers, is monitored. A CCD camera, built into the measuring head, records a picture of the skin, which is then transferred as a gray-value bitmap file to the
storage device. The processing and evaluation of the images is done with the SELS software (Surface Evaluation of Living Skin), inter alia with respect to the skin parameters roughness, scaling, wrinkles and volume. In detail, the parameter roughness shows the depth profile made up of the ratio of all pixels smaller than the color threshold value from the setup of the program and the sum of the zero runs. The parameter scaling shows the level of dryness of the stratum corneum, and all pixels larger than the threshold value from the setup of the program are recorded and put in proportion to the total number of pixels. The parameter wrinkles is made up of the ratio of horizontal and vertical "wrinkles" and the total number of wrinkles; the parameter volume shows single deeper wrinkles in the skin. It considers the area and the profile and represents the volume of fluid needed to fill the surface up to the mean height of the profile.

Thanks to its easy and simple handling, the VisioScan® camera has also been used for skin physiological measurements in space. Living in space has a huge impact on the body. One of the effects of microgravity is the so-called "puffy face syndrome." Here, an increased volume of fluid travels toward the upper regions of the body, making them look swollen. In a previous study, a total of six astronauts measured their skin topography during spaceflight. Results of this study showed an impressive reduction of approx. 45% of the parameter volume due to the fluid shift. However, it was remarkable that also the parameters roughness, scaling and wrinkles changed dramatically. Although an improved skin hydration and skin barrier function were found in orbit compared to pre-flight (before flight to space station), these differences seemed to be questionable. Thus, the aim of the study at hand was to analyze the correlation between the SELS parameter volume and the parameters roughness, scaling and wrinkles under extreme conditions and to question the application of the VisioScan® camera by scientific-dermatological questions.

2 | METHODS

The detailed study protocol is described elsewhere. Two pre-flight measurements in the last 10 months before flight with at least two months between the two sessions. In-orbit measurements were planned around FD15, FD30, FD60, FD120, FD150 and one close to return. If time permits, additional measurements around FD45 and FD90 have been added. Post-flight activities were performed with the following schedule: Return (R+ 3-10, R+ 30 ± 5 and R+ 150-180.

2.3 | Hardware

The hardware that is used is a spaceflight-modified VisioScan® VC89 COTS hardware based on the manufacturer, Courage & Khazaka electronic GmbH, Germany. The same hardware is used in-flight as well as for ground testing before and after flight. Due to intrinsic hardware variations of the VisioScan® VC89 camera, the exposure time was individually adjusted in order to compare the pre-flight (before flight to space station)/post-flight (after landing) with in-flight (onboard the space station) measurements.

2.4 | Surface Evaluation of Living Skin (SELS) measurements

The examination/investigation phases were pre-, in- and post-flight.

The skin surface profile was measured by means of SELS (Surface Evaluation of Living Skin, VisioScan® VC98 camera). All measurements were conducted on the same skin area (volar inside of the forearm) and at the same time of day. Pre- and post-flight measurements are based on the mean value of three consecutive measurements, whereas in-flight, the measurements are based on the mean value of two images. Thus, a total of 164 VisioScan® images were taken pre-, in- and post-flight of six astronauts in the Skin B project.

2.5 | Experiment schedule

There were two pre-flight measurements in the last 10 months before flight with at least two months between the two sessions. In-orbit measurements were planned around FD15, FD30, FD60, FD120, FD150 and one close to return. If time permits, additional measurements around FD45 and FD90 have been added. Post-flight activities were performed with the following schedule: Return (R+) 3-10, R+ 30 ± 5 and R+ 150-180.

2.6 | Statistical analysis

The Pearson correlation coefficient (r) was computed using SAS®, release 9.3 (SAS Institute Inc, Cary, NC, USA) on a Microsoft® Windows® 7 Professional platform to determine the linear association between the variables. Correlation coefficient (r) values were obtained in accordance with the following combined variables:

1. Between volume and roughness.
2. Between volume and scaling.
3. Between volume and wrinkles.
4. Between skin hydration and roughness.
5. Between skin hydration and scaling.

The results obtained by these calculations were interpreted according to the degree of correlation (positive or negative) and taking into consideration the absolute value and the significance (P < .01 or P < .05)
based on the two-sided t test. Calculations are based on n = 6 subjects considering repeated measurements.

Graphic display is provided by scatter plots showing either the parameter versus time point or two parameters on the axes, and presenting different subjects with different symbols.

3 | RESULTS

3.1 | Correlation between the parameters volume and roughness

The pre- and post-flight values were similar (mean difference -0.19, not relevant) with a mean roughness of 1.17 AU (95% CI: 1.01-1.32) and 1.36 AU (95% CI: 1.21-1.50), respectively. The mean in-flight roughness was significantly decreased to a mean roughness of 0.55 AU (95% CI: 0.49-0.62, P < .0001; Figure 1A).

Pearson’s rho as descriptive statistics for correlation (r) and the level of significance (P) as computed are presented in Table 1, and corresponding scatter plots of significant (two-tailed) correlations are depicted in Figure 1B.

Pearson’s correlation revealed a statistically significant positive correlation between the SELS parameters volume and roughness in all test subjects as follows: TS1 (r = .72211, P < .0001), TS2 (r = .82916, P < .0001), TS3 (r = .69495, P < .0001), TS4 (r = .74936, P < .0001), TS5 (r = .67103, P < .0001) and TS6 (r = .79464, P < .0001).
In addition, a statistically significant positive correlation was also noticed between the parameters volume and roughness for all test subjects \( r = .50414, P < .0001 \).

### 3.2 Correlation between the parameters volume and scaling

The pre- and post-flight values were similar (mean difference 0.35, not relevant) with mean values of 1.42 AU (95% CI: 1.34-1.50) and 1.07 AU (95% CI: 0.95-1.18), respectively. The mean in-flight scaling was significantly decreased to a mean scaling of 0.52 AU (95% CI: 0.47 - 0.56, \( P < .0001 \); Figure 2A).

#### TABLE 1 Comparative description of correlation coefficient (\( r \)) between the SELS parameters volume and roughness

| Test subject | Pearson’s correlation coefficients \( r \) (positive) | \( P \)-value |
|--------------|---------------------------------------------------|--------------|
| Total        | .50414                                            | <.0001       |
| 1            | .72211                                            | <.0001       |
| 2            | .82916                                            | <.0001       |
| 3            | .69495                                            | <.0001       |
| 4            | .74936                                            | <.0001       |
| 5            | .67103                                            | <.0001       |
| 6            | .79464                                            | <.0001       |

#### FIGURE 2

A, Effect of long-term stay on ISS on the SELS parameter scaling. Six astronauts were analyzed, each identified by a symbol, and the mean value for each time point is indicated by a red bar. B, Scatter plot of correlation pattern for the SELS parameters volume and scaling. Every single measurement is indicated by a symbol, whereas each astronaut is identified by a defined symbol.
Similar to the Pearson correlation between the SELS parameters volume and roughness, a statistically significant positive correlation was also observed between the SELS parameters volume and scaling for the following test subjects: TS1 (\( r = .85013, P < .0001 \)), TS3 (\( r = .88752, P < .0001 \)), TS4 (\( r = .70089, P = .0002 \)), TS5 (\( r = .93140, P < .0001 \)) and TS6 (\( r = .94761, P < .0001 \)). However, one test subject (TS2) showed a positive correlation, which, however, was not statistically significant (\( r = .29447, P = .1210 \); Table 2).

Furthermore, a statistically significant positive correlation was also noticed between the parameters volume and scaling for all test subjects (\( r = .77421, P < .0001 \); Figure 2B).

### Table 2
Comparative description of correlation coefficient (\( r \)) between the SELS parameters volume and scaling

| Test subject | Pearson's correlation coefficients | \( P \)-value |
|--------------|-----------------------------------|---------------|
| Total        | .77421 (positive)                 | <.0001        |
| 1            | .85013 (positive)                 | <.0001        |
| 2            | .29447 (positive)                 | .1210         |
| 3            | .88752 (positive)                 | <.0001        |
| 4            | .70089 (positive)                 | .0002         |
| 5            | .93140 (positive)                 | <.0001        |
| 6            | .94761 (positive)                 | <.0001        |

![Figure 3A](image1.png)  
*A, Effect of long-term stay on ISS on the SELS parameter skin wrinkles. Six astronauts were analyzed, each identified by a symbol, and the mean value for each time point is indicated by a red bar.*

![Figure 3B](image2.png)  
*B, Scatter plot of correlation pattern for the SELS parameters volume and wrinkles. Every single measurement is indicated by a symbol, whereas each astronaut is identified by a defined symbol.*
TABLE 3 Comparative description of correlation coefficient (r) between the SELS parameters volume and wrinkles

| Test subject | Pearson’s correlation coefficients | P-value |
|--------------|-----------------------------------|---------|
| Total        | -0.57024 (negative)               | <.0001  |
| 1            | -0.16964 (negative)               | .3976   |
| 2            | -0.66740 (negative)               | <.0001  |
| 3            | -0.82454 (negative)               | <.0001  |
| 4            | -0.21673 (negative)               | .3206   |
| 5            | -0.81260 (negative)               | <.0001  |
| 6            | -0.70371 (negative)               | <.0001  |

3.3 | Correlation between the parameters volume and wrinkles

The pre- and post-flight values were similar (mean difference -1.72, not relevant) with a mean value of 22.22 AU (95% CI: 21.31 - 23.13) and 23.94 AU (95% CI: 23.13 - 24.75), respectively. The mean in-flight value was significantly increased to a mean value of 27.61 AU (95% CI: 26.83 - 28.39, P < .0001; Figure 3A).

Here, Pearson’s correlation revealed a statistically significant negative correlation between the SELS parameters volume and wrinkles in four out of six test subjects: TS2 (r = -.66740, P < .0001), TS3 (r = -.82454, P < .0001), TS5 (r = -.81260, P < .0001) and TS6 (r = -.70371, P < .0001). Two further test subjects also showed a negative correlation, which, however, was not statistically significant: TS1 (r = -.16964, P = .3976) and TS4 (r = -.21673, P = .3206; Table 3).

In addition, a statistically significant negative correlation was also noticed between the parameters volume and wrinkles for all test subjects (r = -0.57024, P < .0001; Figure 3B).

3.4 | Correlation between the SELS parameters roughness/scaling and skin hydration

It has already been described that throughout the stay onboard the ISS, the in-flight skin hydration was significantly increased statistically by 4.32 AU on average (P = .0019).2

To exclude any influence of the skin hydration on the SELS parameters, a Pearson correlation coefficient (r) was also calculated between the parameters skin hydration and roughness and skin hydration and scaling (Table 4).

Here, no correlation could be found, neither between roughness and skin hydration nor between scaling and skin hydration.

4 | DISCUSSION

Living and working on ISS takes place in a near-weightless environment, the so-called microgravity. Microgravity means $1 \times 10^{-6} g$, whereas 1 g is equal to the force of gravity on the Earth's surface. When thinking of weightlessness, we usually think of astronauts and objects that seem to float as well as of water that tends to remain in space as spherical droplets.

However, weightlessness compromises the whole biological network, for instance, the osseous and muscular supporting system or the cardiovascular and vestibular system. But one of the most obvious responses to the microgravity environment is the redistribution of fluid and tissue of the body. A substantial volume of fluid moves from the legs headward upon entry into orbit and results in the well-known swollen face called puffy face. After some time, the body reaches a homeostatic distribution that remains throughout the stay on ISS. It was described that the leg volumes of Skylab astronauts decreased by 1000 mL within 4-6 hours, whereas arms did not exhibit significant changes in volume.3,4 Based on these data, we did not expect any dramatic impact on the SELS parameter volume when planning the Skin B experiment. Even though dramatic changes were not described for arm volumes in former studies, it has been recognized by the VisioScan® camera for the first time in the present study. Impressive pictures of a smooth and plumped-up skin were obtained.2 To our surprise, the other SELS parameters roughness, scaling and wrinkles changed significantly in a similar way as well.2 And, in fact, in this data analysis, we could find that there is a statistically significant correlation between the parameters volume and roughness, volume and scaling, and volume and wrinkles for all test subjects.

In this context, the question arises of why in contrast to numerous studies performed on earth, the SELS values do not provide useful results under extreme conditions? Firstly, it should be mentioned that the SELS method is a globally recognized and proven method for the evaluation of the surface of living skin. These include evaluation of reliability and validity of the SELS method versus Primos measurements.5,6 In addition, the SELS method has been used in a correlation study between skin roughness and age7 and numerous supplementation and skin care studies.8-13 However, to answer the question, it is necessary to take a closer look at the fluid shift phenomenon. The fluid of the human body can be divided into the intracellular and extracellular fluids. The intracellular fluids are also known as cytosol, whereas...
the extracellular fluids can be divided further into three compartments: the interstitial compartment (fluid outside blood vessels), intravascular compartment (blood plasma and lymph) and transcellular fluid in the joints, the brain, the spinal cord, etc. As already mentioned, a headward body fluid shift occurs under microgravity exposure. Here, fluid volume moves into the interstitial space and leads to symptoms such as the swollen and puffy face. These physiological changes are comparable to edema, an abnormal accumulation of interstitial spaces of tissue, although the pathophysiological background is different. It can therefore be assumed that the SELS software is certainly able to reflect the water accumulation under the skin based on the parameter volume. In contrast, for the other SELS parameters the values should be seen in a critical light in regard to this dermatological skin condition. The images of the camera are still meaningful, but to obtain reliable data, the used formulae will need to be reviewed.

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