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Influence of Body Posture and Gravitational Forces on Shear Wave Propagation in the Skin

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Key Words
Gravitational force · Shear wave propagation · Skin tensile line · Tensile strength

Abstract
The body posture and gravitational forces govern in part the intrinsic skin tensile strength because they influence the orientation of the dermal fibre networks. Our objective was to assess changes in shear wave propagation in the skin according to the body posture and orientation of the gravitational forces. The study was performed in 30 middle-aged women with a normal body mass index. The Reviscometer® was used to assess the mechanical wave propagation on the volar forearm in extension or flexion. Similar measurements were made on the supra-areolar region of the breast when the trunk was in the horizontal or vertical position. Four measurements were made in each of 4 directions at given angles with regard to the body axis. The device gave reproducible data. Shear wave propagation was influenced by the body posture. The intra-individual variability in shear wave velocity according to the directions of measurements increased when the tissues were in a relaxed position. Skin tensile anisotropy increased in a relaxed body posture. Shear wave propagation may be a convenient non-invasive tool to better identify the natural skin tension lines in the skin, thus refining the orientation of incision during cutaneous surgery.

By some aspects, the skin is a load-transmitting composite. It is subjected to the combined and variable effects of both intrinsic and extrinsic forces. The former are anisotropic for large strains. They depend on the arrangement, stiffness, elasticity and compliance of the fibre networks in the dermis [1] and are influenced by body posture. Indeed, they govern the orientation and patterns of Langer's lines and the relaxed skin tension lines [1, 2]. Langer's lines are defined by the orientation of forces that cause a circular puncture mark made with an awl in the skin of a cadaver to be distorted into a fusiform shape. The orientation of these Langer's lines is often different from those found in living subjects with joints positioned so that the skin is relaxed [2]. Hence, the relaxed skin tension lines refer to the orientation of the longest and straightest furrows produced by pinching the skin in a relaxed position.

Determining the orientation of tension lines is of importance in cutaneous surgery in order to avoid unsightly scars. In a previous study, we had shown that intrinsic forces imposed by limp position influenced some biometrological evaluations made in the plane of the skin surface, such as optical profilometry and axial sliding mobility [3]. Tensile strength evaluations made perpendicularly to the skin surface using the suction method appeared much less sensitive to these intrinsic forces [3, 4].

Numerous test procedures have been developed for determining mechanical properties of the skin. Each approach yields specific information [5]. In this study, we used a prototype device measuring the speed of propagation of an acoustic wave at the skin surface [6]. The shear wave propagation is inversely proportional to the stiffness and density of the tissues [6–13]. It should be theoretically influenced by the preferential orientation of the dermal fibre networks and therefore indicate the direction of tension lines.

The aim of the present study was to compare the directions of the shear wave propagation when modifying the body posture and orientation of the gravitational forces.

Volunteers and Method

A total of 30 healthy women aged from 36 to 49 years were enrolled in the study. All of them had a body mass index (weight/height^2) ranging from 19.3 to 22.9 (normal 18.7–23.8) which had been maintained almost constant over years.

Resonance running time measurements (RRTM) were made using the prototype Reviscometer® RVM 600 (C + K Electronic, Cologne, Germany). The probe of the device contained two stylus sensors distant 2 mm

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from each other. When placed onto the skin, one stylus transmitted acoustic shock waves and the other was the recipient. The time the waves needed to go from the transmitter to the recipient was the measured parameter expressed in arbitrary units.

Reproducibility of RRTM assessments using the Reviscometer was assessed in a preliminary study. Sixteen series of 16 measurements were performed on a silicone gel 2 mm thick. In addition, an in vivo assessment was made on human skin. In each subject, a series of 16 successive measurements was made in the same direction on the same site of the mid volar forearm. The in vitro and in vivo instrumental variability was derived from the calculation of the coefficient of variation following $CV = 10^2 \cdot SD \cdot mean^{-1}$.

For the main study, measures were taken on the volar forearm at 4 cm from the elbow and on the breast at 3 cm over the areola. On each of the test sites, a ring was lightly deposited onto the skin. The ring was marked with white dots placed at angles 0°/180°, 45°/225°, 90°/270° and 135°/315°. The probe was also marked at right angles to the alignment of the sensors. When placing the probe through the ring it was possible to take measurements in precise directions by adjusting the mark on the probe to one of the marks on the ring. In each subject, the angle 0°/180° on the ring was oriented along the forearm axis and vertically on the breast. Four measurements were averaged in each of the 4 directions, and the overall mean of the 16 measures (multidirectional RRTM) was also recorded.

Results are expressed as means ± SD with calculation of the coefficient CV. Comparisons were made using the paired two-tailed Student's t test. The Spearman correlation test was applied with calculation of the coefficient r. Significance was reached when p was lower than 0.05.

Results

As determined in the preliminary study, the instrumental variability was 1.2 ± 0.1% on the silicone gel and reached 11.3% on average (range: 6.7–13.6) on human skin in vivo.

In the main study, the mean multidirectional RRTM on the volar forearm were not significantly different according to the position of the limb (fig. 1). Data gained in flexion and extension of the limb were significantly correlated ($r = 0.60$, $p < 0.001$; fig. 2). The intra-individual variability in RRTM,

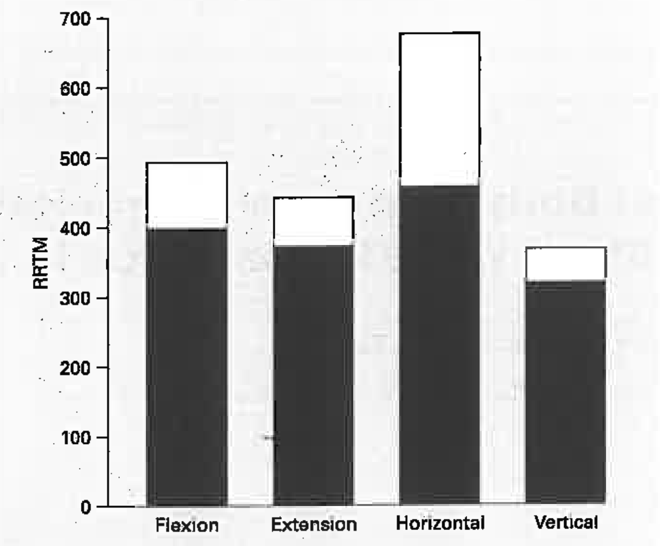

Fig. 1. Means (■) and SD (□) of RRTM (arbitrary units) on the forearm in flexion or extension and on the breast when the trunk is in a horizontal or vertical position.

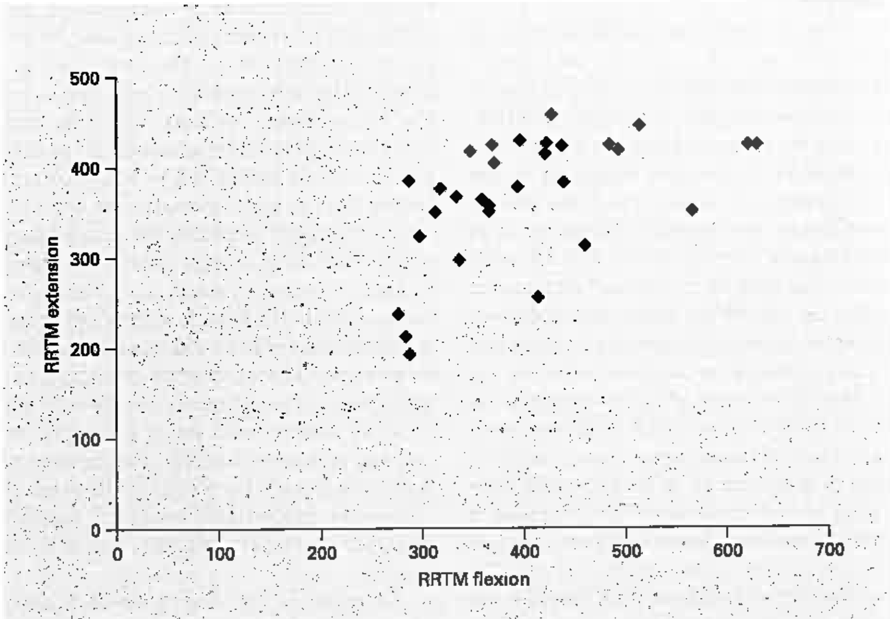

Fig. 2. Scatter plot of RRTM (arbitrary units) on the volar forearm in extension and flexion. Data are linearly correlated.

according to the directions of measurement, was significantly lower ($p < 0.05$) when the forearm was in extension (CV = 19%) than in flexion (CV = 24%). In an overall evaluation, the unidirectional RRTM was shorter in the limb axis direction and progressively increased toward a maximum at an orthogonal angle. Subtle interindividual differences were disclosed in the RRTM directions.

The multidirectional RRTM on the breast were significantly decreased ($p < 0.01$) when the trunk was vertically oriented compared to the horizontal position (fig. 1). No significant correlation (r = –0.41) was found between these figures (fig. 3). The intra-individual variability in RRTM according to the directions of measurements was significantly lower ($p < 0.01$) when the trunk was standing vertically (CV = 16%) rather than lying horizontally (CV = 48%). Anisotropy in the RRTM directions varied largely between women lying on their backs. In the sitting position, RRTM were always shorter in the vertical direction.

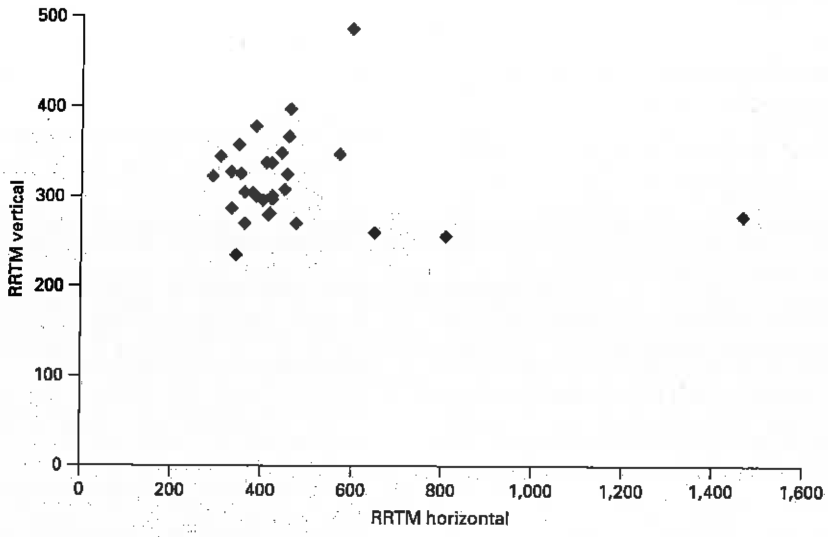

Fig. 3. Scatter plot of RRTM (arbitrary units) on the breast when the trunk is in vertical and horizontal positions. Data are not correlated.

Discussion

In the present study, the propagated signal was measured a small distance away from the emitting stylus. Indeed, the distance between the input disturbance and the pickup was varied, by some investigators, in the range of 1–5 mm in a direction normal to the disturbance. In the Reviscometer, the impulse of the wave propagation consists of a frequency spectrum. It has indeed been previously shown that a higher frequency above 2,000 Hz yielded experimental data more indicative of skin mechanical properties than a frequency lower than 1,000 Hz [12]. As assessed in the preliminary study, the reproducibility of Reviscometer data is quite high in vitro.

The present study was performed in a rather homogeneous group of subjects of the same gender within small ranges in age and body mass index. Such a selection was made in order to avoid interidividual variability as much as possible [6, 8, 10, 12]. Shear wave propagation is assumed to be influenced by the intrinsic skin tensile strength related to the density, elasticity and viscosity of the tissues [12].

Although the skin is known to be anisotropic for large strains [14], previous shear experiments indicated that for low strains the skin of young adults can be considered isotropic [6, 12]. Our data are at variance with such a contention. We indeed found moderate anisotropy in the shear wave velocity. Such a variability was more prominent when the skin was in a relaxed position. Skin extension with limb movement and gravitional forces tends to reduce the anisotropic aspects of the skin tensile strength.

While a one-dimensional RRTM analysis is attractive because of its simplicity, it can lead to significant errors when used to predict the overall visco-elastic properties of the skin [12]. The advantage of the device presently used is the easy determination of a multidirectional RRTM. It appeared that the forearm posture had little effect on the multidirectional RRTM, at least at a short distance from the elbow. In contrast, gravitational forces appeared to affect significantly the multidirectional RRTM in the skin of the breast.

The influence of intrinsic forces on the structures and physical properties of the skin have been measured and addressed in the literature only rarely. A previous study has shown that the limb position affected some biophysical parameters differently [3]. The surface topography and the axial sliding mobility of the dermis were strongly affected while mechanical properties evaluated by the suction method were little influenced by limb position.

The skin furrows found in young adults are organized in a rather biaxial isotropic pattern [15]. The parallelism between Langer's lines and the principal orientations of the primary lines is striking on the forearms. Thus the response of the skin to extrinsic stretching forces is linked to the orientation of the furrows. The present findings are therefore in line with previous works [3] and confirm the close interdependence of the shear wave velocity with the three-dimensional structure of the papillary dermis.

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