# THE MECHANICAL PROPERTIES OF THE PALMAR APONEUROSIS AND THEIR SIGNIFICANCE FOR THE PATHOGENESIS OF DUPUYTREN'S CONTRACTURE

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**Normal tendons and palmar aponeuroses from patients with carpal tunnel syndrome and tissues of the palmar aponeuroses from patients with Dupuytren's contracture were subjected to biomechanical tests. Several parameters characterizing the viscoelastic load response of the tissues were investigated. The tissues from patients with Dupuytren's contracture were classified according to their macroscopic and histological appearance into apparently normal palmar aponeuroses, thickened fibre bundles and contracture bands. There were biomechanical differences between the normal palmar aponeuroses and the apparently normal palmar aponeuroses indicating that biomechanical changes occur before thickening of fibres or cellular proliferation can be observed. Significant biomechanical changes occurred between apparently normal palmar aponeuroses and thickened fibre bundles.**

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The biomechanical properties of tendons and skin are well known and display the following features. The load–strain curve is usually divided into three portions, (1) the "toe-region" characterized by an increasing stiffness (slope of the load–strain relationship), (2) the linear load–strain region and (3) the failure region with decreasing stiffness followed by rupture (Fung, 1981). At low strain levels the collagen fibres are not straight but wavy (Kastelic et al. 1980; Viidik, 1979). As observed in the study of Millesi (1965), this wavy arrangement may be explained by the interaction of the collagen fibres with the elastin. If a tissue with a parallel arrangement of collagen fibres is strained to more than 3% the wavy arrangement of the collagen fibres is straightened (Viidik, 1979). This part of the stress–strain curve corresponds to the toe region. Within the linear region of the load–strain relationship, the collagen fibres themselves are elongated (Mosler et al, 1985; Viidik, 1979). Connective tissues display viscoelastic behaviour within both the "toe-region" and the linear region (Cohen et al, 1978; Dehoff, 1978; Dunn and Silver, 1983). If a certain strain is applied to the tissue, the load response is composed of an elastic (time independent) and a viscous fraction (time dependent). A plastic load component occurs at strain levels at the beginning of the failure region (Fung, 1981).

Biomechanical studies of the palmar fascia are few. The aim of the present study was to investigate the biomechanical behaviour of tissues from different groups of patients with Dupuytren's disease and to compare them with those of normal palmar aponeurosis (NPA) and to normal tendons (NT) from patients without Dupuytren's disease. It was our working hypothesis that if structural changes in the fibre bundles precede the cellular proliferation, alterations in biomechanical behaviour must occur before the cellular proliferation develops.

## MATERIALS AND METHODS

### Specimens

The specimens were harvested during operations on patients with or without Dupuytren's disease. They were classified according to their macroscopic clinical appearance during surgery. One part was used for biomechanical tests. Corresponding parts were subjected to histological and biochemical studies.

*Normal tendon (NT).* Segments of the palmaris longus tendon were excised during surgery from patients with carpal tunnel syndrome.

*Normal palmar aponeurosis (NPA).* In patients treated for carpal tunnel syndrome by open operation, a segment of the palmar aponeurosis overlying the index and long finger rays was excised.

*In patients with Dupuytren's disease* in whom we performed a complete fasciectomy, the total palmar aponeurosis (Fig 1) was harvested. On the radial side, usually corresponding to the index finger ray, but sometimes corresponding to the long finger ray, a segment of palmar aponeurosis which fulfilled the criteria of normal palmar aponeurosis (ANPA) was also obtained. Other segments could be classified as thickened fibre bundles (THFB). The cords or contracture bands (CB) were also classified by macroscopic inspection. During surgery it was not possible to distinguish between the initial phase of the cellular proliferation, the peak of the cellular proliferation, the involution, and the residual scar-like stage. However, after histological examination we could classify the CB group into its histological subclasses. According to preliminary studies, these subgroups were not different biomechanically, and are therefore treated as one group in this paper.

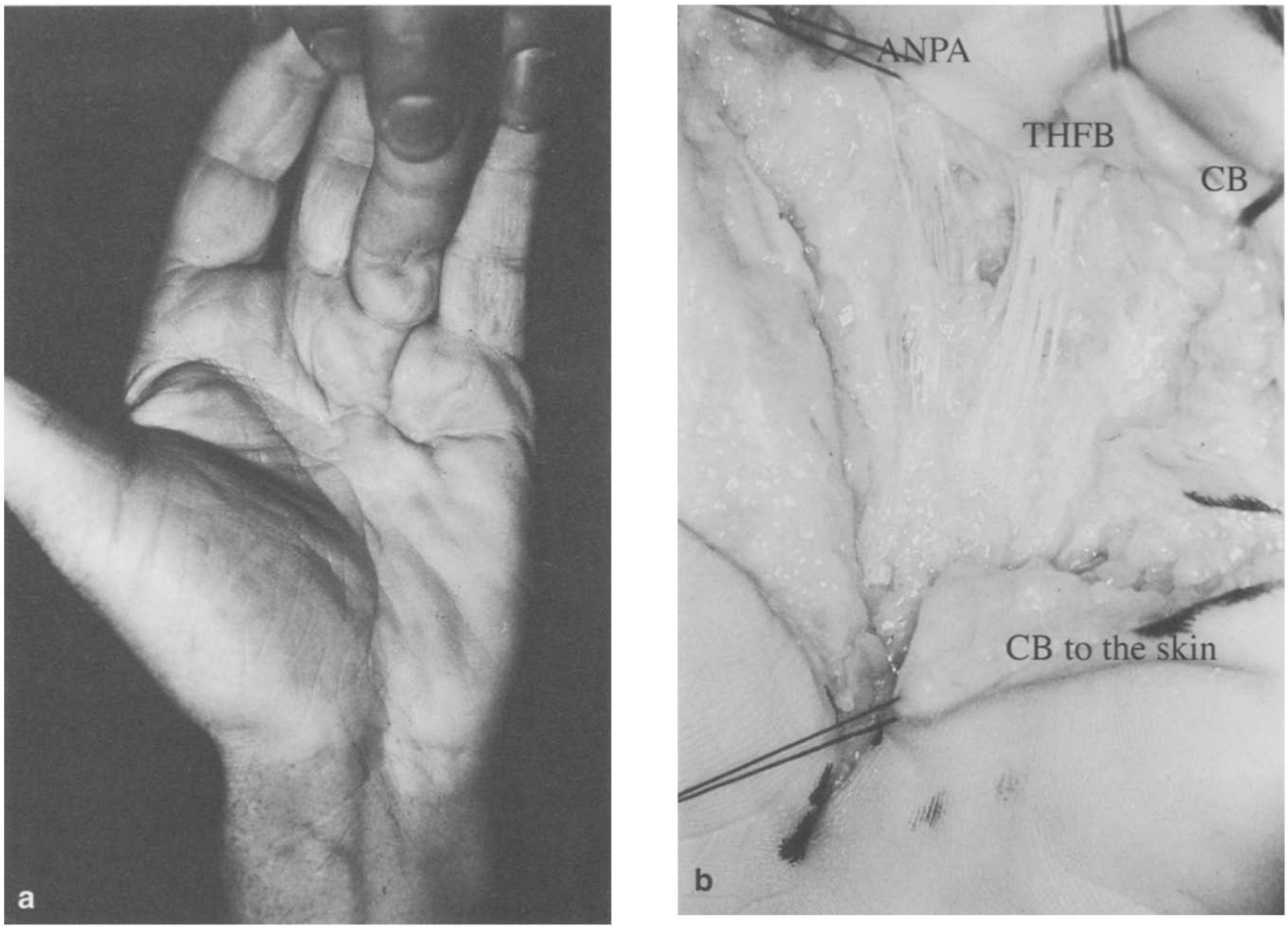


Fig 1 (a) A patient with marked Dupuytren's contracture of the ring finger. Another contracture band merges into the skin causing a 'funnel-like' retraction. The index and middle fingers are not contracted. (b) The palmar aponeurosis of this hand is exposed by a Y-shaped incision. One can easily distinguish the normal looking, transparent fibre bundles to the index finger (ANPA), the thickened, opaque fibre bundles to the middle finger (THFB), the contracture bands (CB) to the ring finger and the contracture band to the skin over the little finger ray (CB to the skin).

## Mechanical tests

A tensile testing apparatus for uniaxial biomechanical tests was designed and manufactured in our laboratory (Reihsner et al, 1991). The diameter of the specimens ranged from 1 to 5 mm. The cross-sectional areas of the samples showed an inhomogeneous distribution over the length. Therefore, we expressed our results in terms of forces. We used cross-sectional independent parameters for a comparison of biomechanical behaviour of specimens with different diameters. Excised specimens were stored in phosphate buffered saline (at 4°C) until biomechanical analysis. No preconditioning was performed. As shown later in the results section, the specimens exhibited a highly viscoelastic behaviour, so results obtained during a particular test might have been affected by preceding strain applications. In order to avoid these effects, we used different sets of specimens for the evaluation of the following groups of biomechanical parameters: group 1 for quantitation of hysteresis loop and residual strain; group 2 for recovery time interval; group 3 for the determination of the relaxation and inverse relaxation; and group 4 for retardation and inverse retardation. The number of specimens subjected to different biomechanical tests are given in Tables 1 to 4. The tests were carried out at successive strain levels. The time interval between two tests was higher than the recovery time. The biomechanical parameters that we studied are now described.

*Residual strain.* The specimens were loaded until a strain level of 2.5%, 5% or 10% was achieved and then unloaded. The residual strain (remaining elongation) was recorded immediately after complete removal of load. Fig 2a shows a typical load–strain graph. The residual strain ($\varepsilon^r$) is defined as the intersection of the load–strain graph (obtained during unloading) with the strain-axis.

**Table 1—Residual strain and hysteresis loop of different tissues as a function of strain level (NT normal tendon, NPA normal palmar aponeuroses, ANPA apparently normal palmar aponeuroses, THFB thickened fibre bundles and CB contracture bands)**

| *Strain level (%)* | *NT n=15* | *NPA n=23* | *ANPA n=15* | *THFB n=15* | *CB n=16* |
|---|---|---|---|---|---|
| | | | *Residual strain ($10^{-3}$)* | | |
| 2.5 | 0.3 (0.05)[a] | 0.6 (0.1)[b] | 2.5 (0.4)[c] | 5.0 (0.2)[d] | 6.3 (0.4) |
| 5.0 | 0.5 (0.1)[a] | 1.0 (0.2)[b] | 2.4 (0.2)[c] | 14.6 (0.6) | 14.6 (0.6) |
| 10.0 | 0.8 (0.1)[a] | 2.6 (0.1)[b] | 4.0 (0.3)[c] | 30.1 (1.5) | 30.5 (1.2) |
| | | | *Hysteresis loop (%)* | | |
| 2.5 | 7.0 (0.2)[a] | 5.0 (0.1)[b] | 16.0 (2.0) | 21.0 (2.0) | 19.0 (3.0) |
| 5.0 | 9.5 (0.3)[a] | 5.0 (0.2)[b] | 18.0 (1.0)[c] | 24.0 (2.0) | 21.0 (4.0) |
| 10.0 | 12.0 (0.5)[a] | 8.2 (1.3)[b] | 21.0 (2.0) | 25.0 (3.0) | 30.0 (2.0) |

Results are expressed as mean (SEM). Significance of differences between average values: a=$P$<0.05 between NT and ANPA, b=$P$<0.05 between ANPA and NPA, c=$P$<0.05 between NPA and THFB, and d=$P$<0.05 between THFB and CB.

**Table 2—Recovery time of different tissues as a function of strain level (NT normal tendon, NPA normal palmar aponeuroses, ANPA apparently normal palmar aponeuroses, THFB thickened fibre bundles and CB contracture bands)**

| *Strain level (%)* | *NT n=8* | *NPA n=12* | *ANPA n=8* | *THFB n=6* | *CB n=19* |
|---|---|---|---|---|---|
| | | | *Recovery time interval (mm)* | | |
| 2.5 | 5.0 (0.2) | 6.7 (0.8) | 8.3 (1.7)[c] | 30.0 (5.0)[d] | 178 (27) |
| 5.0 | 7.0 (1.4) | 10.0 (1.4) | 13.3 (1.7)[c] | 45.0 (15)[d] | 175 (42) |
| 10.0 | 11.6 (0.7) | 13.4 (1.5) | 18.1 (1.6)[c] | 45.5 (4.9)[d] | 210 (9.3) |

Results are expressed as mean (SEM). Significance of differences between average values: c=$P$ <0.05 between NPA and THFB, and d=$P$ < 0.05 between THFB and CB.

*Hysteresis loop.* The hysteresis loop (area between the loading and unloading curves) was expressed as fraction of strain energy (area beneath the loading curve). This ratio (normalized hysteresis loop) represents the percentage of energy loss during the test (Fig 2a).

*Recovery time.* If a specimen is loaded immediately after the unloading phase of the first test the load-strain relationship is shifted to higher strains at a certain load. This shift diminishes as the time interval between consecutive tests increases (5, 10, 15, 30, 60, 120, 180 min). Curve 2 (Fig 2a) indicates the load–strain behaviour of a test performed immediately after the first test (curve 1). If the time interval between the load applications is increased, the curve shifts to the original graph (curve 3), until curve 1 is reproduced (recovery time interval). The time interval necessary to restore the biomechanical quality of a tissue completely is defined as recovery time.

*Relaxation.* Load relaxation tests were performed at strain levels of 2.5%, 5% and 10%. The time constant of the relaxation process is defined as the inverse of the steepness at the initial load (initial slope). The viscous fraction was calculated as the ratio of the difference between initial and final load by initial load. A typical load relaxation graph is shown in Fig 2b.

*Inverse relaxation.* The inverse relaxation graphs were recorded at strain levels of 2.5%, 5% and 7.5% after partial unloading from 5%, 7.5% and 10%. During the inverse relaxation test the load increases with time (Fig 2b).

*Retardation.* The specimens were loaded until strain levels of 2.5%, 5% and 10% were achieved (initial values of strain). The loads corresponding to these strain levels were then kept constant and strain was recorded as a function of time. The characteristic increase of strain with time is shown in Fig. 2c.

*Inverse retardation.* The initial strain levels of the inverse retardation tests were 2.5%, 5% and 7.5% after partial unloading from the final values of strain achieved during the retardation tests starting from 5%, 7.5% and 10%. The time constants and viscous fractions were defined in an analogous way to the relaxation tests.

**Table 3—Stress-relaxation behaviour of different tissues as a function of strain level (NT normal tendon, NPA normal palmar aponeuroses, ANPA apparently normal palmar aponeuroses, THFB thickened fibre bundles and CB contracture bands)**

| *Strain level (%)* | *NT n=10* | *NPA n=14* | *ANPA n=8* | *THFB n=7* | *CB n=11* |
|---|---|---|---|---|---|
| | | | *Relaxation: time constant (sec)* | | |
| 2.5 | 5.9 (0.6) | 6.1 (1.0)[b] | 40 (16) | 43 (10)[d] | 196 (42) |
| 5.0 | 45 (11) | 70 (23) | 82 (17) | 52 (7.9)[d] | 156 (24) |
| 10.0 | 34 (5.9) | 39 (6.1) | 95 (26) | 97 (20) | 154 (38) |
| | | | *Relaxation: viscous fraction (%)* | | |
| 2.5 | 2.4 (1.2) | 6.1 (1.4) | 7.2 (1.4)[c] | 15.4 (1.8)[d] | 23.7 (3.1) |
| 5.0 | 3.1 (1.4)[a] | 7.5 (1.3) | 9.0 (1.4)[c] | 21.9 (2.5) | 28.3 (4.6) |
| 10.0 | 3.0 (1.3)[a] | 7.8 (1.5) | 11.2 (2.1)[c] | 24.2 (3.7) | 30.9 (5.0) |
| | | | *Inverse relaxation: time constant (sec)* | | |
| 2.5 | 4.2 (1.0) | 6.3 (1.7)[b] | 12.0 (2.0) | 15.0 (1.4) | 19.0 (5.0) |
| 5.0 | 32.0 (3.3) | 35.0 (2.7)[b] | 19.0 (2.3) | 25.0 (3.1) | 33.0 (7.7) |
| 10.0 | 56.0 (6.7) | 56.0 (4.6)[b] | 24.0 (3.5) | 31.0 (7.8) | 50.0 (9.3) |
| | | | *Inverse relaxation: viscous fraction (%)* | | |
| 2.5 | 0.03 (0.01) | 0.62 (0.4)[b] | 2.4 (0.5) | 6.2 (2.1) | 12.9 (4.1) |
| 5.0 | 5.1 (2.2) | 5.7 (1.2) | 4.3 (1.1)[c] | 18.4 (3.7) | 26.9 (9.8) |
| 10.0 | 8.2 (2.8) | 8.4 (1.2) | 6.3 (1.3)[c] | 17.3 (3.8) | 46.5 (20.7) |

Results are expressed as mean (SEM). Significance of differences between average values: a=$P < 0.05$ between NT and ANPA, b=$P < 0.05$ between ANPA and NPA, c=$P < 0.05$ between NPA and THFB, and d=$P < 0.05$ between THFB and CB.

**Table 4—Retardation (creep) behaviour of different tissues as a function of strain level (NT normal tendon, NPA normal palmar aponeuroses, ANPA apparently normal palmar aponeuroses, THFB thickened fibre bundles and CB contracture bands)**

| *Strain level (%)* | *NT n=12* | *NPA n=16* | *ANPA n=7* | *THFB n=7* | *CB n=14* |
|---|---|---|---|---|---|
| | | | *Retardation: time constant (sec)* | | |
| 2.5 | 5.5 (0.6) | 7.9 (0.9) | 11.0 (1.2)[c] | 15.0 (1.3)[d] | 45.0 (8.2) |
| 5.0 | 37.0 (7.1) | 44.0 (8.7) | 43.0 (7.9) | 53.0 (9.2) | 77.0 (14.1) |
| 10.0 | 58.0 (3.5) | 47.0 (3.8)[b] | 80.0 (6.9) | 80.0 (5.4) | 77.0 (8.3) |
| | | | *Retardation: viscous fraction (%)* | | |
| 2.5 | 11.3 (2.7) | 8.8 (1.5)[b] | 14.5 (2.1)[c] | 25.7 (4.0) | 39.1 (7.2) |
| 5.0 | 12.6 (3.0) | 10.5 (1.2) | 15.2 (3.4) | 28.9 (6.0) | 42.2 (8.0) |
| 10.0 | 14.1 (2.5) | 15.4 (2.8) | 16.7 (3.2)[c] | 31.5 (5.1) | 44.8 (7.2) |
| | | | *Inverse retardation: time constant (sec)* | | |
| 2.5 | 217 (35) | 156 (22)[b] | 230 (13)[c] | 502 (44)[d] | 1040 (190) |
| 5.0 | 380 (23) | 395 (18) | 405 (34)[c] | 586 (41)[d] | 1280 (120) |
| 10.0 | 390 (15) | 428 (29) | 497 (31)[c] | 643 (46)[d] | 1450 (155) |
| | | | *Inverse retardation: viscous fraction (%)* | | |
| 2.5 | 6.4 (1.2) | 3.3 (0.9)[b] | 8.9 (1.5)[c] | 23.0 (2.1)[d] | 44.0 (2.9) |
| 5.0 | 6.9 (0.9) | 7.8 (1.2)[b] | 15.9 (1.7)[c] | 29.1 (1.0)[d] | 45.8 (4.7) |
| 10.0 | 9.0 (1.8) | 15.2 (2.4) | 19.1 (2.7)[c] | 31.8 (3.5)[d] | 47.7 (4.1) |

Results are expressed as mean (SEM). Significance of differences between average values: a=$P < 0.05$ between NT and ANPA, b=$P < 0.05$ between ANPA and NPA, c=$P < 0.05$ between NPA and THFB, and d=$P < 0.05$ between THFB and CB.

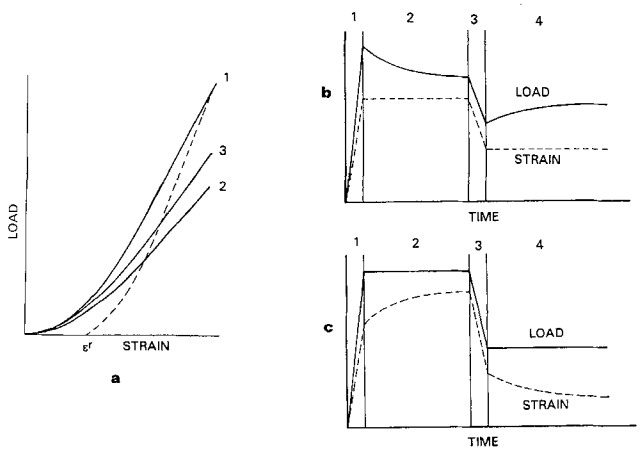


Fig 2 (a) The load-strain behaviour of palmar aponeuroses obtained during the loading (curve 1) and the unloading phases (curve 1, dashed line). If the time interval between consecutive tests is increased the load-strain curve approximates to the result of the first test. (b) Relaxation (region 2, full line: load vs. time) and inverse relaxation phases (region 4, full line). The dashed line indicates the corresponding relationship of strain vs. time. (c) A retardation test (region 2, dashed line: strain vs. time) and an inverse retardation phase (region 4, dashed line). The relationship of load vs. time is indicated by the full line.

During the inverse retardation test the strain decreases with time, i.e. there is a contraction of the sample (Fig 2c).

### Statistical analysis

We used the Kruskal–Wallis and Mann–Whitney tests. $P<0.05$ was considered statistically significant.

## RESULTS

### Residual strain

The residual strain increased with increasing strain level ($\varepsilon^*$). NT displayed the lowest residual strain at all levels of $\varepsilon^*$. The differences were most pronounced between NPA and ANPA at the "physiological strain level" ($\varepsilon^*=2.5\%$). It was interesting to note that the residual strain of NPA at $\varepsilon^*=10\%$ corresponded to the residual strain of ANPA at the physiological level $\varepsilon^*=2.5\%$. The residual strain of ANPA at $\varepsilon^*=10\%$ was lower than that of THFB at $\varepsilon^*=2.5\%$. There were marked differences between the residual strain of ANPA and THFB at $\varepsilon^*=5\%$ and $\varepsilon^*=10\%$. The changes of the residual strain were characteristic of the initial phase of DC (Table 1).

### Hysteresis loop

The normalized hysteresis loop (% of the input of strain energy) also increased with increasing $\varepsilon^*$. NPA showed the lowest hysteresis loop at all levels of $\varepsilon^*$. It was significantly lower than the values of NT. Differences were most pronounced between NPA and ANPA especially at the physiological level ($\varepsilon^*=2.5\%$). There was not much difference between ANPA, THFB, and CB. The increase of the hysteresis loop was characteristic for all phases of DC (Table 1).

### Recovery time

The recovery time increased with increasing strain level $\varepsilon^*$. There was a significant difference between ANPA and THFB. This difference was dramatically increased between THFB and CB. Recovery time seemed to increase markedly with the development of a contracture (Table 2).

### Relaxation test

For the viscous fraction the lowest values were found in NT. There was no difference between NPA and ANPA, and a marked difference between ANPA and THFB, and THFB and CB. Evidently, the viscous fraction correlated with the morphological manifestation of DC. The main differences in time constant were limited to the physiological level, $\varepsilon^*=2.5\%$. There was a significant difference between THFB and CB and an even more pronounced one between NPA and ANPA (Table 3).

### Inverse relaxation test

The increase in the viscous fraction was most pronounced between NT and NPA. There was no difference between the time constants of NT and NPA, a marked difference between NPA and ANPA, and a small but steady increase from ANPA via THFB to CB (Table 3).

### Retardation test

At the physiological levels ($\varepsilon^*=2.5\%$) there was a small but steady increase in the time constant from NT via NPA, ANPA to THFB, but the rise was extremely pronounced between THFB and CB. Apparently, it correlated with the manifestation of a contracture. We observed a steep increase in the viscous fraction between ANPA and THFB, and between THFB and CB. It coincided with the appearance of morphological changes (Table 4).

### Inverse retardation test

At the physiological level ($\varepsilon^*=2.5\%$) a marked increase in time constants was found between ANPA and THFB and even more so between THFB and CB. It seemed to be a characteristic for the occurrence of morphological changes and especially the appearance of a contracture. The viscous fraction of the inverse retardation test displayed similar characteristics. For both parameters it is

interesting to note that the values of NPA at ε*=2.5% were lower than the ones of NT (Table 4).

## DISCUSSION

In general, the biomechanical parameters of the tissues studied showed a characteristic increase in their values with increasing strain levels. Thus, a comparison of the biomechanical behaviour of the tissues has to be referred to the same strain level (ε*). Since the wavy arrangement of the collagen fibres is straightened out at about 3% strain (Viidik, 1979) the lowest strain level was set at 2.5% (within the toe region).

NT and NPA are not the same from the biomechanical point of view. The residual strain and the viscous stress component (relaxation and inverse relaxation) of NT are lower in comparison with NPA. The hysteresis loop of NT is larger, especially at the strain levels of ε*=5% and ε*=10%. From these differences we may conclude that the arrangement of collagen fibres in NT is optimal for transmitting or resisting forces. The NPA, in contrast, is more extensible and seems to be designed to store strain energy.

For the tissues of patients with DC, an increase of all biomechanical parameters from ANPA via THFB to CB is apparent even at the strain level of 2.5%. The biomechanical parameters expressed as fractions of the corresponding values found in CB show characteristic differences (Fig 3). The hysteresis loop of THFB displays the same biomechanical changes as CB and that of ANPA is very close to CB. The hysteresis loops of NT and NPA are similar to each other, but are far smaller compared with CB. In contrast, the recovery times of NT, NPA, ANPA and THFB are markedly lower than those of CB.

Comparing the specimens of ANPA (as a group) with NPA there was a significant increase in the residual strain and the hysteresis loop. At the strain level of 2.5%, the residual strain in the specimens of the ANPA-group was already as high as that in the specimens of NPA at a 10% strain level. This observation is illustrated by Fig 4.

Looking at the residual strains of ANPA, 11 specimens out of 33 are also in the range of NPA, but the rest show a much higher residual elongation. From this observation, it seems that the apparently uninvolved palmar aponeurosis from some patients with DC is also biomechanically normal. However other specimens of ANPA already show a pathologically increased residual elongation and even before macroscopic changes occur. The frequency distributions of the residual strains is shown in Fig 5. The width of the distribution ranges from 0 to 0.18% for the NPA (Fig 5a). From the distribution of residual strains of ANPA (Fig 5b) one may conclude that some specimens behave like NPA while others show elevated values of residual strain. The average values of THFB (the frequency distribution is shown in Fig 5c) and CB (Fig 5d) are very close to one another and about 2.5 times higher than that found in ANPA. We

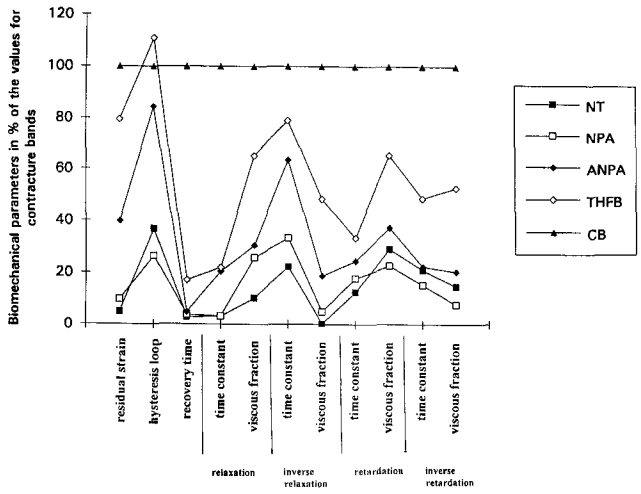


Fig 3 The biomechanical behaviour of the different tissue classes (NT normal tendon, NPA normal palmar aponeurosis, ANPA apparently normal palmar aponeurosis, THFB thickened fibre bundles, and CB contracture bands) observed at a strain level of 2.5% expressed as fraction of the respective values found in CB.

may hypothesize that the increased residual strain and the increased hysteresis loop of a certain percentage of specimens of ANPA originate from changes in the

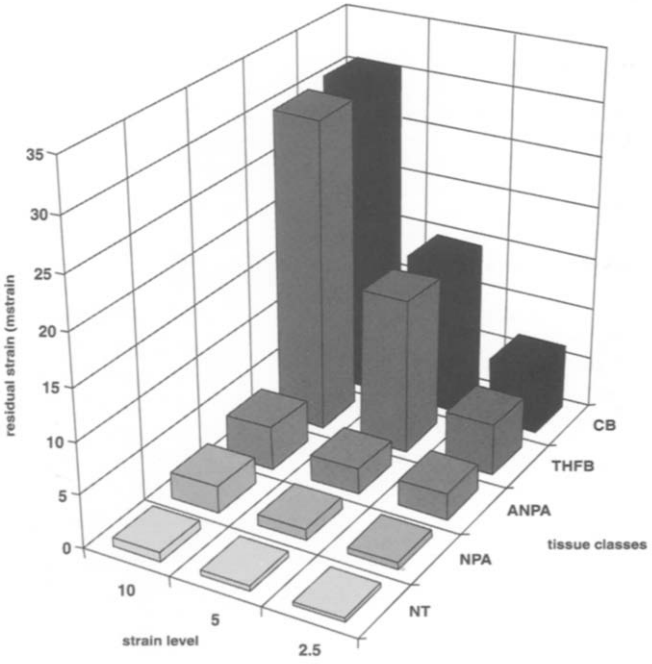


Fig 4 Residual strain as a function of the tissue classes and the strain level from which the unloading procedure was started. The residual strains for NPA obtained at the 10% strain level fell within those of ANPA obtained at 2.5% indicating certain structural rearrangements before thickening of fibre bundles and cellular proliferation could be detected.

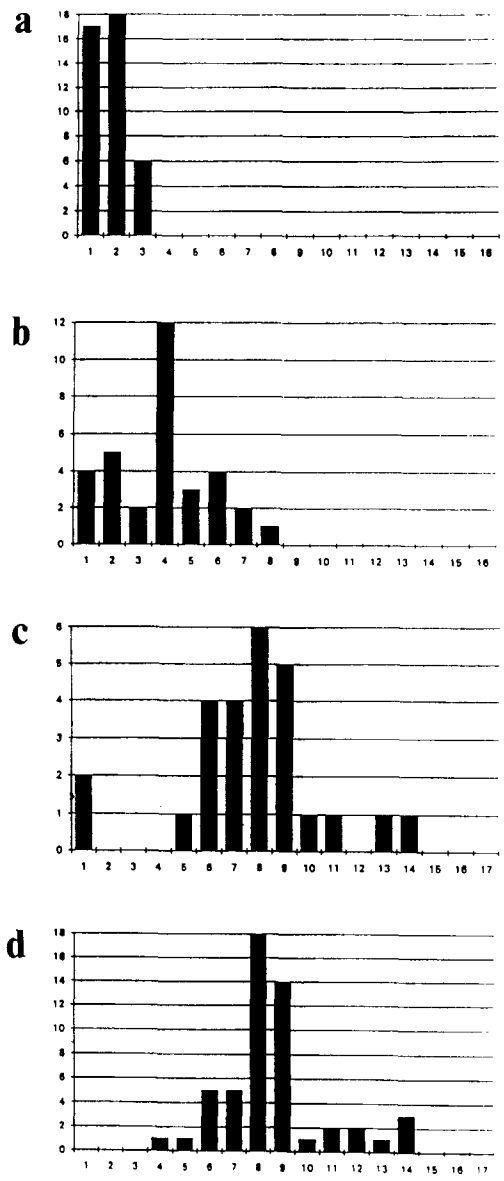


Fig 5 Frequency distribution of residual strain after unloading from a strain level of 15% as a function of tissue classes. The distributions are given for (a) ANPA, (b) NPA, (c) THFB and (d) CB.

elastin network in the early stage of DC (Millesi, 1965; Pasquali-Ronchetti et al, 1993). In our previous study (Reihsner et al, 1991) on the biomechanical role of elastin fibres in NPA, we found a significant increase of the residual strain and the hysteresis loop after enzymatic removal of elastin. Histological studies show a change in morphology and distribution of elastic fibres in some specimens of ANPA. As a consequence, the energy storing function of the elastin network is reduced. This presumption is supported by our actual finding of a significant decrease in the elastic stress component, as found by the relaxation and retardation tests.

The specimens classified as THFB demonstrate a significant increase in the recovery time. In comparison with ANPA, there is also a further increase in the residual strain, the relaxation and inverse relaxation behaviour, the retardation behaviour and the viscous fraction of the inverse retardation phase. Specimens classified as THFB have completely lost the wavy course of the fibres. This means that the fibres have lost the capacity to absorb sudden changes of stresses as do intact collagen-elastin compounds during the straightening of the wavy course. These fibre bundles are immediately exposed to stress peaks. Due to increased collagen production and the fusion of fibres to form major units, the diameter is increased and this leads to an increased transverse contraction. By transverse contraction we refer to the phenomenon whereby elongation of a viscoelastic tissue produces a narrowing of the tissue in the transverse direction, most pronounced in the middle of the specimen. It does not mean an active contraction, as the term is used in medicine, in contrast to "contracture". The notion of "transverse contraction' is well established in physics, and is expressed as the ratio of strain in a transverse direction by strain in a longitudinal direction (Poisson's ratio $\nu$) during the application of load in longitudinal direction. In quantifying this parameter using palmar aponeurosis from patients with DC, we found the following values: ANPA, $\nu$=0.02; THFB, $\nu$=0.38; and CB, $\nu$=0.46. Elongation is no longer achieved by structural changes in the fibre arrangement, but rather by elongation of the thick fibre at the expense of the diameter.

CB show the same pattern of viscoelastic properties as THFB, but they are much more pronounced. It is accompanied by a sharp increase in the time constants of relaxation and retardation. The most characteristic alteration in biomechanical behaviour of CB is the enormous increase in the recovery time. In NPA the recovery time is 10 minutes. With CB we have measured recovery times up to 7 hours. As a second stress-strain test during the recovery time leads to a characteristic change of the stress-strain curve, this means that a patient with a recovery time of more than 7 hours might start the next day's work before the tissue in the palmar aponeurosis has recovered. We do not yet understand what effect this has in the development of a contracture, but we think it may be of relevance.

The results of our study may be summarized as follows:

- Biomechanical changes occur *before* cellular proliferation, generally regarded as the onset of DC, commences.
- Even in the part of the specimens defined as ANPA, characteristic changes in the biomechanical behaviour can be detected.
- There are typical changes in the biomechanical

behaviour for the defined classes of Dupuytren's tissue.

- The changes in the biomechanical parameters of ANPA seems to be linked to structural changes of the elastin network.
- The changes of the biomechanical parameters of THFB and CB can be interpreted as a shifting from an elastic to a more viscoelastic behaviour.
- The sharp increase of the mechanical recovery time in CB goes along with the occurrence of contracture.

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