# Viscoelastic and Dynamic Properties of Soft Liners and Tissue Conditioners

R. L. DURAN,* J. M. POWERS, and R. G. CRAIG

*School of Dentistry, The University of Michigan, Ann Arbor, Michigan 48109*

*The creep compliance and dynamic modulus of two tissue conditioners and five soft liners were determined after storage in water at 37 C. Under static conditions the tissue conditioners functioned like viscous liquids, whereas the soft liners were more elastic. In general, linear viscoelasticity was not observed. Under dynamic conditions, the materials were stiffer.*

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## Introduction.

The success of a complete denture depends on the fit of the denture, occlusion, esthetics, and other factors. A poorly fitting denture, irritation and other discomforts currently are treated by dentists with the use of tissue conditioners and soft liners.[1-3] It is desirable for tissue conditioners to adapt to the oral mucosa as it heals and also to absorb stresses during mastication. Soft liners must have limited flow over their life so as to minimize changes in occlusion and also to absorb stresses during function.

The viscoelastic behavior of soft liners and tissue conditioners has been determined by static methods that measure percent set, flow, and strain in compression,[4-6] but these tests usually involve only a single load. A creep test allows data to be collected during the duration of loading and over a range of loads. If the strain is divided by the stress caused by the applied load, the resulting creep compliance versus time curve can characterize both elastic and viscous properties of the material.[7] Evaluation of creep after the tissue conditioners and soft liners have been stored in water is necessary, because their properties have been observed to change.[8-9]

Clinically these materials also are subjected to periodic deformation that can be characterized by measurement of dynamic properties.[4] The dynamic modulus is the ratio of stress to strain applied for small cyclic deformations at a given frequency at a specific point on the stress-strain curve.[10]

The purpose of this study was to evaluate the viscoelastic characteristics under static and dynamic conditions of five soft liners and two tissue conditioners after storage in water by measurement of creep and dynamic modulus.

## Materials and methods.

Five resilient liners and two tissue conditioners were evaluated. Code, composition, batch number, and manufacturer of the products tested are listed in Table 1.

Four specimens for each product and condition were prepared according to A.D.A. Specification No. 19.[11] The materials were mixed according to manufacturer's instructions. The heat-cured materials (CSS, I, and SO) were cured overnight at 74 C. The silicone product (S) was allowed to cure for 24 hours in an environment of 100 percent humidity.

The samples for the creep test were formed in a cylindrical metal mold 19 mm high and 12.7 mm in diameter. The mold containing a material along with glass platens on each end was placed in a water bath at 37 C after two minutes from the

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TABLE 1
CODE, COMPOSITION, BATCH NUMBER, AND MANUFACTURER OF THE PRODUCTS TESTED

| Code | Product | Composition | | Batch No. | Manufacturer |
|---|---|---|---|---|---|
| Tissue Conditioners | | | | | |
| CC | Coe-Comfort | Powder: | Poly(ethyl methacrylate) | 110276 | Coe Laboratories, Inc. |
| | | Liquid: | Aromatic esters + ethanol (<10%) | 110276 | Chicago, Illinois |
| H | Hydrocast | Powder: | Poly(ethyl methacrylate) | 15777 | Kay-See Dental Mfg. |
| | | Liquid: | Aromatic esters + ethanol (>10%) | 15777 | Kansas City, Missouri |
| Resilient Liners | | | | | |
| CS | Coe Soft | Powder: | Poly(ethyl methacrylate) | 110276<br>020177 | Coe Laboratories, Inc. |
| | | Liquid: | Aromatic esters + ethanol | 110276<br>020177 | |
| CSS | Coe-Super Soft | Powder: | Acrylic co-polymer | 020177<br>100177 | Coe Laboratories, Inc. |
| | | Liquid: | Methyl Methacrylate + Plasticizer | 020177<br>100177 | |
| I | Impak | Powder: | Poly(ethyl methacrylate) | 050577 | Vernon-Benshoff, Inc. |
| | | Liquid: | Methyl methacrylate | 051677 | Albany, New York |
| S | Silastic | Paste: | Silicone (accelerated by moisture) | HH0367<br>HH0369 | Dow Corning Corp.<br>Midland, Michigan |
| SO | Soft-Oryl | Powder: | Poly(ethyl methacrylate) + Plasticizer | G621777<br>B050377 | Wm. Getz Dental Products<br>Chicago, Illinois |
| | | Liquid: | Methyl methacrylate | G621777<br>B050377 | |

beginning of the mix. The specimens were allowed to remain in the water bath the minimum time suggested by the manufacturer for leaving the material in the mouth. The loading apparatus used in this test is described in A.D.A. Specification No. 19[11] for testing strain in compression.

Creep was determined at two different loads: for CC, H, and CS, the loads were 0.80 N and 1.29 N; for I and S, the loads were 4.98 N and 9.95 N; and for CSS and SO, the loads were 5.29 N and 10.3 N. The specimens were tested at 10 minutes, 24 hours, 72 hours, and 3 months after the start of the mix. Recordings of deflections were made at the following times: 5, 15, 30, 45, and 60 seconds and 2, 3, 4, and 5 minutes. Values of creep compliance during loading were calculated as true strain divided by true stress. The creep compliance data were evaluated as a function of time between 30 and 300 seconds by analysis of variance[12] that included regression and co-variance models to study the effect of load and to determine values of the instantaneous elastic response ($J_o + J_R$) and the slope ($1/\eta$) as shown in Figure 1.

Values of the dynamic modulus (E) were determined for the tissue conditioners and soft liners after storage in water at 37 C for 10 minutes, 24 hours, 72 hours, and 3 months (except CC and H). Three pairs of cylindrical specimens (2.5 cm in length and 2.5 cm in diameter) were prepared according to manufacturer's instructions. A pair of samples was placed in a dynamic tester* at 37 C, subjected to an 8% static compression, and vibrated at different frequencies (v, $sec^{-1}$) and amplitudes. The mass (M, g) of the yoke of the vibrator was adjusted to obtain the maximum amplitude, and E was calculated by $E = 1.98 \times 10^{-6} Mv^2$ in $MN/m^2$. Data were analyzed by analysis of variance,[12] and means were compared by Tukey's interval.[13]

## Results.

The viscoelastic properties of the tissue conditioner were evaluated at two loads and three times of storage, whereas the soft liners were evaluated at two loads and four times of storage. Figure 2 is representative of a creep compliance curve for a tissue conditioner. The data obtained from the

*Vibrotester, Goodyear Tire and Rubber Co., Akron, OH.

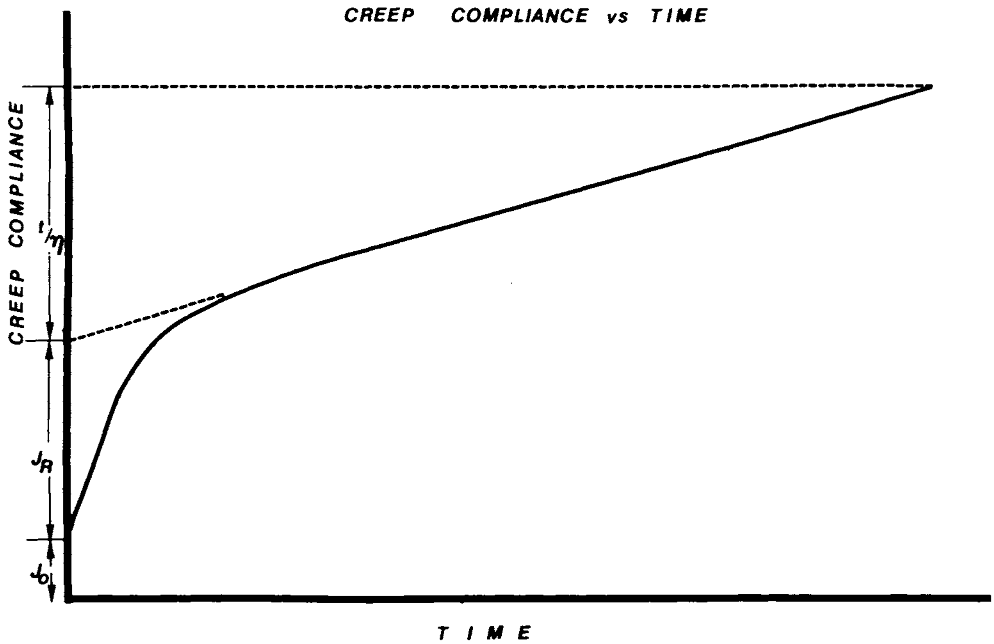


Fig. 1–Creep compliance versus time for a viscoelastic material.

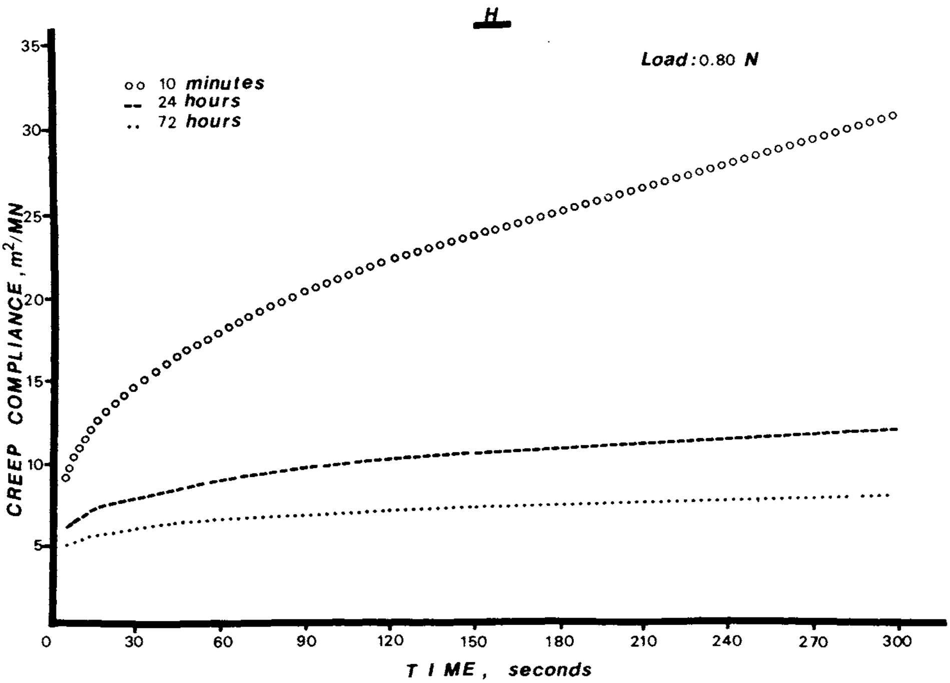


Fig. 2–Creep compliance versus time for H at different times of storage at 0.80 N.

analysis of variance were: the slope ($1/\eta$) of the regression line for the data at each load, the value of the correlation coefficient (r) for each regression, the level of significance attained for a test of the hypothesis that the slopes were equal, the intercept ($J_o + J_R$) of the regression for each load, and the level of significance attained for a test of the hypothesis that the regressions were equal. The aforementioned data are listed in Table 2 for the tissue conditioners and Table 3 for the soft liners.

For each of the tissue conditioners and soft liners tested, there was no significant difference between the slopes ($1/\eta$) determined for loads 1 and 2 at the 0.05 level of significance. The critical value of the correlation coefficient (r) above which the hypothesis that the slopes were equal to zero could be rejected was 0.297. There were

TABLE 2
DATA FROM ANALYSIS OF VARIANCE FOR TISSUE CONDITIONERS AFTER DIFFERENT TIMES OF STORAGE

| Code | Time of Storage | Slope, $m^2$/MN-sec | | Correlation Coefficient | | Level of Significance for Equal Slopes | Intercept, $m^2$/MN | | Level of Significance for Equal Regressions |
|---|---|---|---|---|---|---|---|---|---|
| | | Load 1 | Load 2 | Load 1 | Load 2 | | Load 1 | Load 2 | |
| CC | 10 min. | 0.137 | 0.137 | 0.947 | 0.987 | 0.82 | 20.2 | 18.2 | 0.046 |
| | 24 hr. | 0.046 | 0.047 | 0.885 | 0.966 | 0.78 | 10.6 | 11.5 | 0.014 |
| | 72 hr. | 0.026 | 0.026 | 0.910 | 0.981 | 0.71 | 9.60 | 8.24 | 0.000 |
| H | 10 min. | 0.058 | 0.052 | 0.921 | 0.979 | 0.18 | 14.4 | 13.3 | 0.000 |
| | 24 hr. | 0.015 | 0.014 | 0.978 | 0.880 | 0.31 | 7.99 | 7.01 | 0.000 |
| | 72 hr. | 0.008 | 0.008 | 0.957 | 0.851 | 0.85 | 5.96 | 5.00 | 0.000 |

TABLE 3
DATA FROM ANALYSIS OF VARIANCE FOR SOFT LINERS AFTER DIFFERENT TIMES OF STORAGE

| Code | Time of Storage | Slope, $m^2$/MN-sec | | Correlation Coefficient | | Level of Significance for Equal Slopes | Intercept, $m^2$/MN | | Level of Significance for Equal Regressions |
|---|---|---|---|---|---|---|---|---|---|
| | | Load 1 | Load 2 | Load 1 | Load 2 | | Load 1 | Load 2 | |
| CS | 10 min. | 0.0330 | 0.0320 | 0.933 | 0.896 | 0.74 | 9.03 | 8.51 | 0.058 |
| | 24 hr. | 0.0154 | 0.0130 | 0.945 | 0.896 | 0.07 | 5.40 | 6.00 | 0.026 |
| | 72 hr. | 0.0073 | 0.0083 | 0.835 | 0.925 | 0.24 | 3.48 | 3.97 | 0.000 |
| | 3 mo. | 0.0064 | 0.0053 | 0.595 | 0.602 | 0.53 | 3.86 | 4.28 | 0.202 |
| CSS | 10 min. | 0.0013 | 0.0015 | 0.700 | 0.871 | 0.39 | 1.75 | 1.71 | 0.638 |
| | 24 hr. | 0.0011 | 0.0013 | 0.633 | 0.843 | 0.28 | 1.64 | 1.57 | 0.174 |
| | 72 hr. | 0.0011 | 0.0013 | 0.736 | 0.937 | 0.26 | 1.49 | 1.43 | 0.062 |
| | 3 mo. | 0.0018 | 0.0020 | 0.726 | 0.847 | 0.61 | 1.20 | 1.04 | 0.000 |
| I | 10 min. | 0.0025 | 0.0020 | 0.837 | 0.909 | 0.10 | 0.82 | 0.54 | 0.000 |
| | 24 hr. | 0.0022 | 0.0020 | 0.731 | 0.872 | 0.50 | 0.76 | 0.45 | 0.000 |
| | 72 hr. | 0.0023 | 0.0021 | 0.764 | 0.956 | 0.62 | 0.74 | 0.49 | 0.000 |
| | 3 mo. | 0.0017 | 0.0019 | 0.825 | 0.881 | 0.60 | 0.32 | 0.32 | 0.741 |
| S | 10 min. | 0.000082 | 0.000050 | 0.190 | 0.028 | 0.91 | 1.39 | 1.12 | 0.000 |
| | 24 hr. | 0.000132 | 0.000058 | 0.117 | 0.028 | 0.84 | 1.44 | 1.21 | 0.000 |
| | 72 hr. | 0.000094 | 0.000064 | 0.051 | 0.081 | 0.92 | 1.50 | 1.38 | 0.000 |
| | 3 mo. | 0.000046 | 0.000054 | 0.025 | 0.052 | 0.98 | 1.48 | 1.20 | 0.000 |
| SO | 10 min. | 0.0027 | 0.0031 | 0.884 | 0.893 | 0.28 | 1.84 | 1.90 | 0.001 |
| | 24 hr. | 0.0017 | 0.0016 | 0.930 | 0.811 | 0.61 | 1.53 | 1.46 | 0.000 |
| | 72 hr. | 0.0013 | 0.0013 | 0.900 | 0.868 | 0.62 | 1.44 | 1.24 | 0.000 |
| | 3 mo. | 0.0014 | 0.0016 | 0.871 | 0.830 | 0.60 | 0.78 | 0.63 | 0.000 |

significant differences found between the regression curves for loads 1 and 2 when the hypothesis that the regressions were equal at the 0.05 level of significance was tested. There were significant differences between loads for CC, H, S, and SO at all times of storage, for I at 10 minutes and 24 and 72 hours, for CS at 24 and 72 hours, and for CSS at 3 months. Among CC, CS, and H, the slope decreased dramatically as the time of storage increased. The slope of I and SO also decreased, but the slope of CSS increased after storage for 3 months. The slope of S was not significantly different from zero at each time of storage. Among CC, CS, and H, the intercept decreased as the time of storage increased. The intercept of CSS, I, and SO also decreased, but that of S increased after storage for 3 months.

The flow of a viscoelastic material is described by the viscous portion ($t/\eta$) of the creep compliance curve and is determined by the viscosity ($\eta$) of the material. The values of the viscosity of the tissue conditioners and soft liners as calculated from the slope of the creep compliance curves at 10 minutes are listed in Table 4.

The stiffness of a viscoelastic material is described by the instantaneous and retarded elastic portions ($J_o + J_R$) of the creep compliance curve and can be expressed as an apparent elastic modulus [$1/(J_o + J_R)$] as listed in Table 4 for the tissue conditioners and soft liners.

Means of dynamic modulus (E) and standard deviations are presented in Table 5. Values of E increased as the time of storage increased, except CSS, I, and S for which no significant change occurred. The soft liner SO showed a dramatic increase in E during storage over 3 months, whereas CC, CS, and H showed small increases.

TABLE 4
VISCOSITY AND APPARENT ELASTIC MODULUS OF TISSUE CONDITIONERS AND SOFT LINERS AT 10 MINUTES AT LOAD 1

| Code | Viscosity ($\eta$), $10^7$ poise | Apparent Elastic Modulus [$1/(J_o + J_R)$] $MN/m^2$ |
|---|---|---|
| Tissue Conditioners | | |
| CC | 7.30 | 0.050 |
| H | 17.2 | 0.069 |
| Soft Liners | | |
| CS | 30.3 | 0.111 |
| CSS | 769 | 0.571 |
| I | 400 | 1.22 |
| S | -- | 0.719 |
| SO | 370 | 0.543 |

## Discussion.

The creep compliance curve of a linearly viscoelastic material is independent of load. Among the materials tested, only I at 3 months, CS at 10 minutes, and CSS at 10 minutes, 24 hours, and 72 hours were linearly viscoelastic. For the tissue conditioners and soft liners tested, the slope ($1/\eta$) of the creep compliance curve was independent of load; however, the intercept ($J_o + J_R$) was load dependent, excluding the aforementioned materials (I, CS, and CSS) and times. For most materials, the intercept decreased by 5 to 19 percent at the higher load (load 2). Soft liner I showed a decrease in the intercept of 34 to 41 percent at load 2. Soft liner CS showed an increase in the intercept of 11 to 14 percent at load 2.

The products CC, CS and H are ethanol-poly(methyl methacrylate) gels in which the ethanol can be leached during storage in water, whereas SO is a plasticized poly (methyl methacrylate) resin cured intraorally. The products CSS, I, and S are heat-cured in a flask and are probably polymerized more completely.

The low viscosity of the tissue conditioners compared to the soft liners can be explained by the gel structure of the tissue conditioners. As the ethanol is leached from the gel, the structure becomes stiffer and more resistant to flow. Clinically, the low initial viscosity of the tissue conditioners allows them to adapt to the oral mucosa as it heals from surgery or from abuse caused by an ill-fitting denture.

The flow of the soft liners was much lower than that of the tissue conditioners, with the exception of CS. The soft liner, CS, is a gel composed of ethanol and poly(methyl methacrylate) and behaved like a tissue conditioner. The silicone soft liner (S) behaved elastically throughout the 3-month storage. The flow of both I and SO decreased with storage, suggesting that plasticizer was leached out. The flow of CSS, however,

TABLE 5
DYNAMIC MODULUS FOR TISSUE CONDITIONERS AND SOFT LINERS AT DIFFERENT TIMES OF STORAGE

| Code | Dynamic Modulus, $MN/m^2$ | | | | | | | | Tukey's Interval |
|---|---|---|---|---|---|---|---|---|---|
| | 10 Min. | | 24 Hours | | 72 Hours | | 3 Months | | |
| Tissue Conditioners: | | | | | | | | | |
| CC | 5.48 | (0.12)* | 5.86 | (0.22) | 6.41 | (0.42) | -- | | 0.49 |
| H | 6.13 | (0.24) | 6.55 | (0.24) | 7.42 | (0.51) | -- | | 0.49 |
| Soft Liners: | | | | | | | | | |
| CS | 0.59 | (0.06) | 0.73 | (0.01) | 0.88 | (0.01) | 1.12 | (0.06) | 0.11 |
| CSS | 7.5 | (0.5) | 7.3 | (0.2) | 7.8 | (0.6) | 7.8 | (0.4) | NS† |
| I | 13.0 | (2.4) | 11.2 | (0.3) | 13.3 | (0.7) | 12.4 | (0.3) | NS |
| S | 2.45 | (0.15) | 2.46 | (0.00) | 2.59 | (0.06) | 2.60 | (0.02) | NS |
| SO | 0.88 | (0.03) | 1.09 | (0.09) | 3.79 | (0.28) | 9.19 | (0.29) | 0.54 |

*Mean values of three replications with standard deviations in parentheses.
†NS means no significant difference among times of storage at 0.05 level of significance.

increased with storage over 3 months, suggesting that perhaps absorption of water had occurred. Clinically, low flow of a soft liner probably would be desirable, so that changes in occlusion would be minimized over the life of the soft liner.

The stiffness of the ethanol-based gels (CC, CS, and H) was much lower than that of the soft liners that underwent polymerization. During storage all of the products tested, except S, became stiffer, although the change was most dramatic for the gels. The silicone soft liner (S) became slightly more flexible during storage, probably because of water absorption. The stiffest soft liner was product I. Clinically, the elastic behavior of the soft liners allows the liner to absorb the forces of mastication, thereby minimizing the force transmitted to sore areas of the mucosa. Of the products tested only the silicone rubber (S) did not become stiffer during the 3-month storage, indicating the difficulty in maintaining the "softness" of a soft liner.

Product H had larger values of dynamic modulus (E) at each time of storage than CC. After storage for 3 months, I, CSS, and SO had much higher values of E than S or CS. The tissue conditioners (CC and H) had values of E similar to CSS, a soft liner, and were stiffer than CS, S, and SO, but more flexible than I. Under cyclic loading the tissue conditioners were much stiffer than under static loading. The soft liners were also stiffer under cyclic than static loading, but to a lesser extent.

## Conclusions.

The tissue conditioners and soft liners generally were not linearly viscoelastic. The slope of the curve of creep compliance versus time was independent of load, but the intercept decreased by 5 to 19 percent at the higher load.

Under static loading the tissue conditioners functioned like viscous liquids, whereas the soft liners were more elastic. Under dynamic conditions the materials were stiffer.

Storage of the tissue conditioners and soft liners in water at 37 C caused an increase in the resistance of the material to flow and in the stiffness of the material measured under static conditions, with some exceptions. The creep compliance curves of two tissue conditioners and a soft liner composed of an ethanol-poly(methyl methacrylate) gel were affected more by storage than those of the soft liners that polymerized upon setting.

Under static loading the silicone soft liner was elastic and became slightly more flexible during storage. Under dynamic conditions there was no change in its flexibility.

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