CHAPTER V

DISCUSSION

The discussion was represented as follow;

Part I: Elastic limit of orthodontic elastomeric chains

1.1 Force-displacement curves of three-loop and four-loop of three forms of orthodontic elastomeric chains, and

1.2 Generated force, displacement and percent elongation at elastic limit of three-loop and four-loop of three forms of orthodontic elastomeric chains.

Part II: Force decay of orthodontic elastomeric chains in the simulated tooth movement condition

2.1 Remaining force and percent remaining force of three forms of orthodontic elastomeric chains in each time period, and

2.2 Force degradation of three forms of orthodontic elastomeric chains in each time interval.

PART I: ELASTIC LIMIT OF ORTHODONTIC ELASTOMERIC CHAINS

Three-loop and four-loop closed, open and wide space of orthodontic elastomeric chains, Ormco® Grey Power Chain Generation II, were tested their tension. While the basis material of them were the same, so the independent variables were the form and number of loops of elastomeric chains.

1.1 Force-displacement curves of three-loop and four-loop of three forms of orthodontic elastomeric chains

Force production by elastomeric chains were based upon the force values produced in series of tensile tests. It was the purpose of this investigation to determine and compare the force production from the continuous force-displacement curves, which were generated by closed, open and wide space orthodontic elastomeric chains.

The characteristic of the tracing of force-displacement curves in tension test related to their molecular structures. The exact nature of the tensile responses of polymeric material depend upon the chemical structure of the polymer, conditions of sample preparation, molecular-weight distribution, crystallinity, and the extent of any crosslink or branching (Fried, 1995).

Orthodontic elastomeric chains were proceeded from elastomers, which are intermediate in character between amorphous and crystalline polymers. Elastic properties result when a polymer is largely amorphous with only weak forces between molecular chains. On elongation, the amorphous region stretch; the molecular chains become nearly parallel, producing a semicrystalline state (Harper, 1975).

The force-displacement curves of six groups of orthodontic elastomeric chains (Figure 4.2 - 4.7) were slightly different, but the overall patterns were relatively similar, especially the same forms (closed space, open space and wide space forms). The patterns of force-diplacement curves of closed space groups (C_3 and C_4) were almost the same, but there were slightly different from the open and the wide groups. Similary to O_3-O_4 and W_3-W_4 groups, the patterns of curves were very alike in the same forms, but had slightly differences to the others. Although the form of all samples (loop-form) were different from the standard dumbell shape or uniform cross-sectional area (ASTM D 412), but the force-displacement curves were also similiar to the typical tension curve of polymeric materials.

Three parts of the force-displacement curve of elastomeric chain were illustrated clearly. In initial part, the tracing was almost linear with slightly curve at the beginning. This nonlinear portion was resulted from the broken of the secondary bond, Van der Waals forces. Along linear portion of the plot was reflected principally in the uncoiling of long molecular chains (Nikolai, 1985). When elastomeric chains were applied force, the soft flexible segments of polyurethane block structure (Figure 2.3) were extended (Morton-Jone and Ellis, 1986).

In the middle part, the tracing was slightly declined with high frequency traced line up to the elastic limit point. The elastomeric chains exhibited viscoelastic behavior that was intermediate phase between perfectly viscous and elastic behavior. According to De Gonava (1985), under elastic limit point the orthodontic elastomeric chains underwent chain stretching and uncoiling, which leaded to elastic behavior that was quick and reversible.

The final part of the curve was over the elastic limit point. The tracing was thin with low frequency traced line. It was low decline at the beginning and re-steep in the end, but it was not as steep as the initial part. The low decline of curve showed that the continued extension of elastomeric chains produced with a low increased force and permanent deformation occured. When the forces between chains were weak, the chains were free to slip by one another (Harper, 1975). The chain slippage leaded to viscous behavior that was slow and irreversible (De Gonava, 1985). The latter steep curve was due to the material stiffness increased as primary bond, covalent bond, began to be stretched with continued increasing of the load. Thus, the slope of the curve grew and rupture eventually occured (Nikolai, 1985). The maximum load of this investigation was only 10 newtons, so all elastomeric chains were not broken.

According to Nikolai (1985), the internal force distributions under tension of the elastomeric chains arised from the external load application, the imposition of an activating deformation and maintainance of a constrained configuration. The loading of one site created internal forces in the whole of the structure. These internal forces not only exist throughout the lengths of the sample, but they were also distributed over the entirety of the cross-sections. The intensity of internal force, stress, was defined by load per unit area. Thus, the larger the cross-sectional area, the lesser the intensity of internal force.

Under tension state, not only the cross-sectional area at the loop and the solid bar of elastomeric chains were not the same, but also the internal stress. The solid bar area had more concentrated stress because it had lesser cross-sectional area than the loop area. The force-displacement curve of each sample was obtained from the average intensity of the internal force of the loop and solid bar. Furthermore, the geometric configuration of the elastomeric chains were changed after force application. The loop area was distortion and the solid bar was elongation in constrained state. Both areas had lesser cross-sectional area under continue loading, so the stress was also continuously increased with time.

1.2 Generated force, displacement and percent elongation at elastic limit of three-loop and four-loop of three forms of orthodontic elastomeric chains

1.2.1 Generated force at elastic limit of three-loop and four-loop of three forms of orthodontic elastomeric chains

The generated forces at elastic limit in the same number of loops were the greatest in closed form and were the least in wide form. There were highly significant differences by form ($p < 0.001$), and only different between wide form to the closed and open forms (Table 4.2, 4.3). No generated force between closed and open groups were significant differences. The length of a solid bar was the different part among three forms of elastomeric chains. Since the solid bar area had less mass of material, a single row of chain mass, than the loop area, so that the solid bar was a weak point of elastomeric chains. The closed form had no solid bar between loops, so the overall length of the sample was only loop area, which had double amount of chain mass. The geometric configuration of closed form (without solid bar) and open form (0.5-millimeter solid bar) were slightly different, but they were clearly different to the wide form, 1.5-millimeter solid bar, which was the longest length (about three times or more). Thus, the wide form produced weaker and lesser force than the closed and the open forms. Although there were no significantly different on generated force between the closed and the open forms, but the least elastic strength generated from the longest solid bar.

In the same forms, the generated force from the three-loop groups were slightly greater than the four-loop groups (Table 4.1), but there was no significantly different ($p < 0.05$) as shown in Table 4.2. This was similar to the reported by Rock (1985), He evaluated force at transition points from force-extension curves of two-loop, three-loop, and four-loop groups of orthodontic elastomeric chains from several manufactures by tension testing with constant crosshead speed. The great majority of the results showed that the exerted force at this point dropped as the number of loops increased.

The geometric configuration of elastomeric chain had more effected on elastic strength than the number of loops. Hence, an elastomeric chain with long solid bars gave less force than the chain without or with short solid bars.

1.2.2 Displacement and percent elongation at elastic limit of three-loop and four-loop of three forms of orthodontic elastomeric chains

At elastic limit, the wide form had the greatest displacement values and the closed form had the least in both three-loop and four-loop groups. In the same forms, all four-loop groups had greater displacement values than three-loop groups (Table 4.1). However, each group of elastomeric chains had different initial lengths as if in the same number of loops, so the displacement at elastic limit tended to be differed and it could not be distinctly comparable.

It is necessary to converse the initial length in each group to one hundred percent, so the percent elongation was calculated. In either three-loop or four-loop groups, the open form had the greatest percent elongation and the closed form had the least. In the same forms, three-loop groups had higher values of percent elongation than four-loop groups (Table 4.1).

The initial lengths of all six groups were different, even in the same number of loops. The greastest values of displacement were the wide form (W_3, W_4), but the greatest percent elongation were the open form (O_3, O_4). The four-loop groups had higher displacement values than three-loop groups, but the percent elongation values were on the contrary.

According to Nikolai (1985), the accurate determination of the coordinates of the elastic limit of the module was difficult because of the time-dependent nature of the mechanical behavior of the material. In addition, the rate of loading during the test influenced mechanical-property values to some extent; for example, environmental condition, particularly temperature in the test locality, many affected values, as may specimen-storage time and conditions prior to testing.

From Part I, all of elastomeric chains were tested in same controlled environment, so they could be compared among three forms of elastomeric chains. Thus, the amount of generated force, displacement and percent elongation at elastic limit in this investigation were only specific for this condition, but the trends of these results were also advantage for the clinical application. The closed form of elastomeric chains generated high force at elastic limit although it could stretch at the least percent elongation. However, its geometric configuration was lend itself for adjusting the number of loops.

PART II: FORCE DECAY OF ORTHODONTIC ELASTOMERIC CHAINS IN THE SIMULATED TOOTH MOVEMENT CONDITION

2.1 Remaining force and percent remaining force of three forms of orthodontic elastomeric chains in each period

Three groups of elastomeric chain (C_4, O_3 and W_3) were initially stretched at 22.5 millimeters, and the initial forces were required at range of 300 grams to 400 grams. Lu et al. (1993) suggested that the initial forces for moving canines were neither larger than 400 grams nor less than 150 grams. From Table 4.6, the initial forces of C_4 (373.06 grams) and O_3 (375.09 grams) groups were nearly the same, but there was lesser in W_3 group (318.15 grams). Since the forms and number of loops of elastomeric chains were different, so the initial force of each group was not the same. The remaining forces in all periods were transfered to percent for comparable, and the initial force of all three groups were one hundred percent.

The patterns of percent remaining force of all three forms during six weeks (Figure 4.8) showed that they were continuously dropped with dramatically decreased on the first day as the studies of Bishara and Andreasen (1970), Hershey and Reynolds (1975), Ash and Nikolai (1978). Throughout six weeks, the percent remaining force of closed form in each period was the greatest and the least was the open form. It should be noted that the amounts of initial force and percent elongation at initial stretched conditions of these three groups were not the same.

The remaining forces of orthodontic elastomeric chains from Table 4.6 remained only 60-70% on the first day, and gradually reduced through all six weeks. The values of the remaining force were varied in various studies that were depended on the different in basis material, the experimental condition such as temperature, humidity, pH value and also the storage aging time of the samples. However, the behavior characteristic of elastomeric chains in several researches were relatively similar.

The initial forces of the closed and the open forms were almost the same, but it was less in the wide form. The remaining force at the sixth week was the greatest in the closed form and there was the least in the wide form. On the other hand, the percent remaining force after six weeks was also the greatest in the closed form (47.21%), but the least was the open form (27.51%). The remaining forces at the sixth week were 153.94 grams, 103.15 grams and 94.21 grams in closed, open and wide space respectively that seemed to be inadequate force for canine retraction because the optimum force for bodily movement for a large tooth such as canine was 150-250 grams (Storey and Smith, 1952; Reitan, 1957; Gianelly and Goldman, 1971; Nikolai, 1975; Quinn and Yoshikawa, 1985). Furthermore, Andresen and Zwanziger (1980) suggested that the factor of friction should be mentioned relative in sliding an edgewise bracket over an archwire.

From the results of this experiment, if the minimum effective force for canine retraction was 150 grams, the remaining force with simulated tooth movement 0.5 millimeters per week after six weeks of closed space (153.94 grams) was slightly greater than the minimum effective force. While the remaining force of the open and the wide forms were greater than minimum effective force in the third and the second week respectively. These meant that the closed, open and wide space forms exhibited enough force level for canine retraction within six, three and two weeks respectively, and it might be shorter time with friction comcerning. Thus, the clinicians should make a proper time appointment to patients.

The percent remaining force among three forms of elastomeric chains showed significant differences to each other in each time period (Table 4.7). In the same forms, the percent remaining forces were also significantly different to each other among each time period (Table 4.8 - 4.11). The percent remaining force in all three groups were decreased with time. The factors that effected to them in each time period were elastic relaxation and reduction of chain extension. In the first week, the chain extension was constant at 22.5

millimeters, so the remaining force was mostly depended on elastic relaxation, which related to time. Thereafter the end of the first week, the chain extensions were decreased with simulated tooth movement, 0.5 millimeters per week. Thus, the remaining forces after the first week to the sixth week were effected from both elastic relaxation and reduction of chain extension. The remaining force among three forms of elastomeric chains in each time period showed statistically significant differences ($p< 0.01$).

The initial forces of all groups (C_4, O_3, W_3) were greater than their generated forces at elastic limit (Table 4.1, 4.5) especially the open form. The open form had the least percent remaining force in all periods because it was stretched with the greatest percent elongation, so permanent deformation occured. However, the remaining forces of open form were still higher than the wide form. Thus, the remaining force depended on not only elastic relaxation and reduction of chain extension, but also the amount of initial force.

Table 5.1 Generated force of C_4, O_3 and W_3 groups at initial extension, 22.5 millimeters (Estimated from their force-displacement curves)

Group	Org. length (mm.)	Init. extension (mm.)	Displacement (mm.)	Approx. force (gm.)
C_4	9.73	22.5	12.77	460
O_3	8.34	22.5	14.16	490
W_3	10.34	22.5	12.16	380

The amounts of initial force of C_4, O_3 and W_3 groups (373.06, 375.09 and 318.15 grams respectively) in Part II (Table 4.5) were lower than the generated force at 22.5 millimeters stretched that were estimated from the force-displacement curves of C_4, O_3 and W_3 group in Part I (Figure 4.3, 4.4 and 4.6), which were approximated 460, 490 and 380 grams respectively (Table 5.1). The factor that effected the amount of force was the speed of extension because the strain rate in Part II was faster than the strain rate in Part I, 200% per minute.

The initial force production was sensitive to the strain rate (Fried, 1995). In this investigation, the strain rate in Part I was favorable for establishing optimal force-displacement curves, but the initial stretching of elastomeric chain in Part II was close-by the clinical application.

Similarly to Kovatch et al. (1976) who concluded that the typical elastomeric behavior, which resulted in load-extension curves, depended on the rate of extension as well as the amount of extension. The specimens with faster deformation speed were initially stronger and stopped at a cross-over region, but subsequently they fell off much more rapidly. The cross-over region of several strain rate was approximate the elastic limit point, so at this point was not depend on the speed of stretching.

Hence, the elastomeric chains with slowly stretched remained the greater force than fast stretched elastomeric chains. Thus, when the clinicians used elastomeric chains for canine retraction, they should slowly stretch it for obtaining the greater generated force and remaining the high force for a longer period.

2.2 Force degradation of three forms of orthodontic elastomeric chains in each time interval

The force degradation of all samples exhibited a very rapid loss of force over the first day and a slow rate of force thereafter. These results were similar to the studies of Bishara and Andreasen (1970), Ash and Nikolai (1978), Brantley et al. (1979), von Fraunhofer et al. (1992) and Storie et al. (1994). The total amounts of force degradation in this investigation with simulated tooth movement, 0.5 millimeters per week, after six weeks of closed, open and wide space were 58.73%, 72.49% and 70.38% respectively (Table 4.12). They were different from the previous studies because of the different in basis material, the experimental condition and their storage aging time.

After the first time interval, the pattems of percent force decay were swining every week especially the wide form (Table 4.12 and Figure 4.9). The long solid bar of wide form might induce the deviation of force decay. The increasing force decay in 1^{st}-2^{nd}week may be due to the reduction of chain extension, which started after the first week. Moreover, the technic error in force measurement was also effected because each sample could be measured only once in each period. If the digital force gauge was used, the force measurement would be more accurate.

The percent force decay rate of all three forms of elastomeric chains showed significant differences ($p < 0.01$) only on the first day to the other time intervals. The differences among the remained time intervals after one day were not significant ($p > 0.05$) as shown in Table 4.15 - 4.18. The force degradation in the first week was due to only force relaxation of elastomeric chain, but thereafter the reduction of chain extension, 0.5 millimeters per week, was incorporated. Therefore, the percent force decay rates of all three forms of elastomeric chains were the greatest on the first day and then they were continuously decreased almost the same rate throughout 6-week period (Figure 4.10).

According to Nikolai (1985), the activated elastic modules often maintained much of their initial stretch for a substantial length of time. When they were maintained in a stretched configuration, the tension lost over time because of the relatively weak of secondary bonding in amorphous materials. In general, the magnitude of loss force depended on their basis material, the magnitude of the initial force relative to the geometric configuration of the elastomers, and the length of time the activation was maintained.

The results from Table 4.12 expressed that the force decay in the open form was the greastest. In open form, O_3 group, was initially stretched 169.78% (Table 4.5), which was much over its percent elongation at elastic limit, 78.41% (Table 4.1). Then, the permanent deformation were occured, and the elastic recovery were decreased. Although the percent elongation at elastic limit of wide form (70.48%) was greater than the closed form (61.86%), but in part II the closed form was initially stretched 131.24% that was greater than the wide form

(117.60%). Thus, the permanent deformation was greater in the closed form than wide form. Though the wide form seemed to be less in permanent deformation, but its percent force decay on the first day was greater than the closed form. Therefore, the geometric configuration of elastomeric chains also effected on elastic relaxation. The permanent deformation was performed at the solid bar area because the elastic material was lesser than the loop area.

The force degradations in this investigation were contrast to Young and Sandrik (1979) study, which were compared the loss force from four modules of Unitek CK (closed form) and C2 (open form) that were produced by injection process. The CK group had greater loss force than C2 because the CK was the farthest from the injection site, so it suffered the greatest distortion in tension. Moreover, the intermodular links did not suffer the greatest distortion and also the amount of stress relaxation.

The most important difference between Unitek and Ormco® elastomeric chains were the basis material and the production process, so the elastic properties of two brands were unlike. In addition, the experimental designs were also different. All mentioned reasons might be influenced on the contrast of the results.

The behaviors of elastomeric chains *in vivo* differed from *in vitro* due to many variables such as wide temperature swings, masticatory forces and parafunctional oral behavior (Kuster, 1986; von Fraunhofer, 1992). The oral environment was potentially more harmful to the polymeric materials of elastic elements than the normal air environment. Intraoral elastics were expected to experience more dramatic relaxation and, therefore, greater force loss than elastics that were activated by extraoral appliances (Ash and Nikolai, 1978; Howard and Nikolai, 1979; Nikolai, 1985; Kuster et al., 1986). Although the decline of the force value during intraoral used was greater than in the laboratory test, but their relaxation patterns were relatively similar (Ash and Nikolai, 1978).

De Gonava et al. (1985) presented differently that the elastomeric chains subjected in a thermal-cycled environment retained higher mean percentage of remaining force than in a constant temperature at 37°C. This was possibly related to an increasing in stiffness of the material caused by the temperature variations, which were 15°C and 45°C in synthetic saliva baths.

In clinical used, the orthodontists should recognize these environmental factors in the elastomeric chain using because the exerted force from the chains might be enough for tooth movement in shorter time than in laboratory test.

All in all, many variables effected on the remaining force and force degradation in this experiment such as elastic relaxation, reduction of chain extension, amount of initial force, permanent deformation and also the geometric configuration of elastomeric chain. All forms of elastomeric chain were initially extended beyond their elastic limits to provide an effective tooth movement force. Among three forms of elastomeric chain, the geometric configuration of closed form could be easily adjusted by varying the number of loops for different initial distances. In addition, it also had the greatest generated force at elastic limit and the least percent force decay rate. Therefore, the closed form seemed to be the most suitable elastomeric chain for canine retraction. The open and the wide forms of elastomeric chains were favorable for only some specific distances with less permanent deformation, and they should be replaced within a short time period, approximate three and two weeks respectively. Although the results from this investigation might be slightly different from intraoral used, but their trends could be advantage for clinical application.

ERROR OF THIS INVESTIGATION

Since the force gauge in Part I differed from Part II, so the accuracy in force measurement was also different. This may be the reasons of some errors in transfering the force values from Part I to Part II.

LIMITATIONS OF THIS INVESTIGATION

1. All variables that effected on force degradation could not be controlled as the same. For example, the initial distances were fixed equally, the amount of initial forces were varied because of the different forms of elastomeric chains.

2. The force measurements for each sample in each time period were measured only one time because of their elastic properties.

3. Although temperature effected on force condition, it was necessary to do periodic force measurement at room condition instead of simulated oral condition (37°C with 100% humidity).

4. It is rather difficult to completely simulate oral environment such as thermal cycling, pH condition, saliva and so on. Hence, the limitation of instrument used in Faculty of Dentistry, Chiang Mai University, so the condition in Part II was designed at constant 37°C.

5. The elastomeric chains were brought from the local vendors, so the life span was decreased and influenced on the exerted force.

SUGGESTIONS FOR FUTHER STUDY

1. The actually load cell of the universal testing machine in tension test should be smaller than 10 kilonewtons for more sensitivity.

2. For comparable on the slope of the force-displacement curves among groups in Part I, the scale on displacement axis (X-axis) should be the same.

3. The initial force of three groups of elastomeric chains were different, so the statistical analysis that was used for comparing the remaining force should be Analysis of Covariance (ANCOVA) for better comparison and lesser error than ANOVA using.

4. For the best results in clinical application, the experimental condition the investigation of force degradation should be similar to the oral environment such as thermal cycling and oral pH condition or should be done in clinical study.