

A Comparative Study of Orthodontic Coil Springs

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ABSTRACT

Several types of force delivering system are used to carry out tooth movement in orthodontics. Coil springs being one of them are used for the same thus requiring minimal operator manipulation.

Aims and objectives: The purpose of this study was to determine the effect of wire diameter, lumen size and length of coil spring on the load produced as a function of displacement of SS and NiTi coil spring.

Materials and methods: The study consisted of 60 samples of open and closed coil springs (30 each). Open coil springs were tested in compression and closed coil spring in tension using a Lloyd universal testing machine. The data obtained was subjected to statistical analysis using student's t-test.

Results: Mean values, standard deviation and t-value were calculated. Statistically significant difference were obtained in between the groups ($p < 0.05$), ($p < 0.001$).

Discussion: The heaviest load value at 60% compression was recorded in 0.010×0.030 spring with 20 cm initial length due to its large wire diameter and reduced lumen size among the coil springs tested. Straight line of load deflection curve bears clinical significance due to unpredictable behavior of spring beyond a certain limit. Permanent deformation exhibited by SS coil spring is due to high stiffness is low spring fact.

Conclusion: Coil linear load delivered by SS open coil springs on compression changes the original length from 33 to 50% which depends on wire diameter and lumen size of coil spring.

Keywords: NiTi open and closed coil spring, SS open and closed coil spring, Loading, Unloading, Lumen size, Wire diameter and length of spring.

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INTRODUCTION

Orthodontic tooth movement requires the application of a force delivering system capable of eliciting the desired response of individual dental units within the biological ecosystem. Ideally, a force delivering system should provide an optimum and continuous force, it should be comfortable and hygienic to the patient, require minimal operator manipulation, less chair time, minimal patient cooperation and economical. On the whole several force delivering systems have been proposed for fulfilling these criteria which include intra-arch and interarch force systems, coil springs being one of them.

Originally, coil springs were made of stainless steel and cobalt chromium nickel alloys. The invention of nickel-titanium alloys has resulted in the production of a new generation of coil springs delivering a lower and more constant force during deactivation.¹

The purpose of this study was to determine the effect of wire diameter, lumen size and length of coil spring on the load produced, as a function of displacement of stainless steel (SS) open and closed coil spring having same pitch angle (angle at which coils deviate from a perpendicular line to the long axis of the spring, an increase in pitch angle leads to a higher load deflection rate)² to comparatively evaluate the load mentioned by the manufacturers with the load produced as a function of displacement of nikle-titanium (NiTi) open and closed coil springs.

MATERIALS AND METHODS

The present *in vitro* comparative study of coil springs was undertaken in the Department of Orthodontics, Faculty of Dental Sciences, King George's Medical College, Lucknow, with the help of Central Institute of Plastic Engineering and Technology (CIPET), Lucknow, India.

A total of 60 samples, comprising thirty open coil and thirty closed coil springs, were used for the study:

- SS (Hi-T™ II coil springs, Unitek Corporation)
- NiTi (Sentalloy™, GAC).

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Table 1: Design of open coil springs (group I)

Types of alloy	Wire diameter (inch)	Lumen size (inch)	Initial effective length (mm)	Force value (gm)	Catalogue no.	No. of samples
SS (group IA)	0.010	0.030	20		341-531	5
	0.010	0.030	15		341-531	5
	0.010	0.032	15		341-541	5
	0.009	0.030	15		341-431	5
NiTi (group IB)						
Light (blue)	0.010	0.035	15	100	Kit 10-000-21	5
Medium (yellow)	0.010	0.035	15	150	Kit 10-000-22	5

Table 2: Design of closed coil springs (group II)

Types of alloy	Wire diameter (inch)	Lumen size (inch)	Initial effective length (mm)	Force value (gm)	Catalogue no.	No. of samples
SS (group IA)	0.010	0.030	6	–	341-530	5
	0.010	0.030	3	–	341-530	5
	0.010	0.032	3	–	341-540	5
	0.009	0.030	3	–	341-430	5
NiTi (group IB)						
Light (blue)	0.009	0.035	3	100	10-000-03	5
Medium (yellow)	0.010	0.035	3	150	10-000-02	5

Stainless steel open and closed coil springs were in the form of self-sealing bobbin of three-feet (910 mm) length. NiTi stop wound open coil springs were in the form of seven inch lengths. Both (SS and NiTi) open coil springs and SS closed coil springs were cut to required length for the experiment to be undertaken. NiTi closed coil springs were commercially available as 3 mm length with laser fused eyelets for easy engagement.

According to the type of coil springs, they were divided in (Tables 1 and 2) two groups as follows:

Group I: Open coil springs (Fig. 1)

1. Stainless steel open coil springs
2. Nickel-titanium open coil springs

Group II: Closed coil spring (Fig. 2)

1. Stainless steel closed coil springs
2. Nickel-titanium closed coil springs

Tests for both tensile and compression were conducted using an Lloyd universal testing machine LR-100 K (Fig. 3), fitted with a load cell of 100 Newton (Software version 6.12 Research grade) at CIPET, Lucknow.

To test the effect of spring length upon the load produced as function of displacement, a group of five stainless steel open coil and five closed coil springs of 20 mm and 6 mm length of 0.010 × 0.030 inch respectively were tested. To establish the variability of each group, five identical springs were tested.

For compression tests, SS and NiTi open coil springs were slid over a 0.017 × 0.022 inch rectangular stainless steel arch wire which allowed 1 mil (1 mil = 1/1000 inch) clearance on each corner between the archwire and a 0.030 inch lumen coil spring (Fig. 4). This tolerance was large enough to prevent undue friction, yet small enough to permit only minimal buckling of

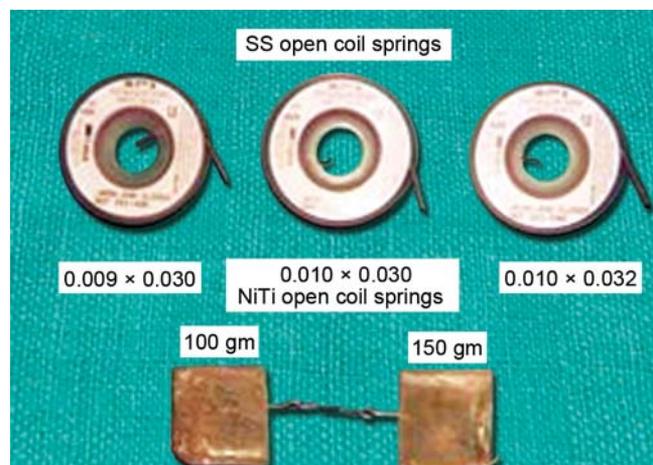


Fig. 1: Open coil springs

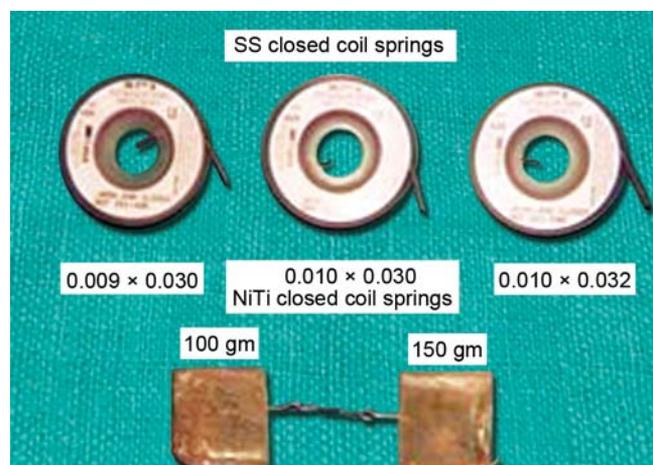


Fig. 2: Closed coil springs

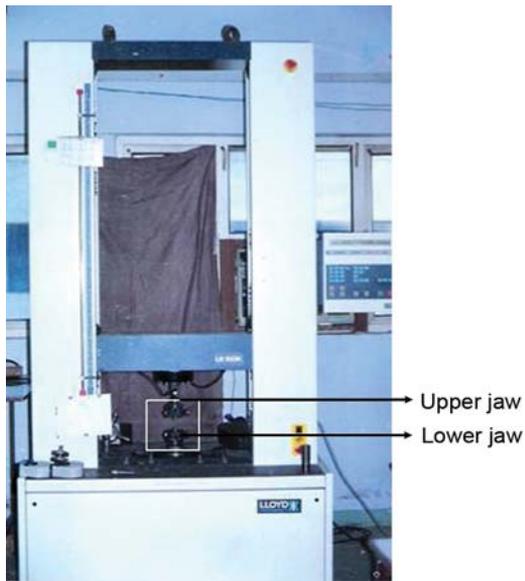


Fig. 3: Lloyd universal testing

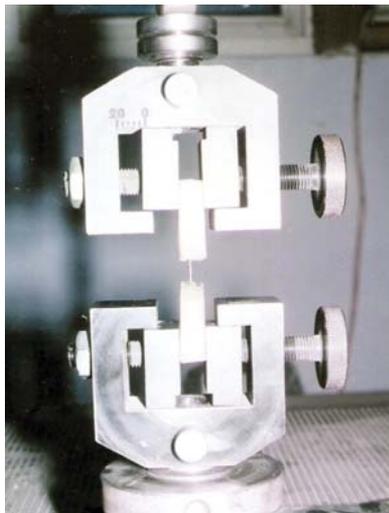


Fig. 4: Open coil springs mounted on the jaws

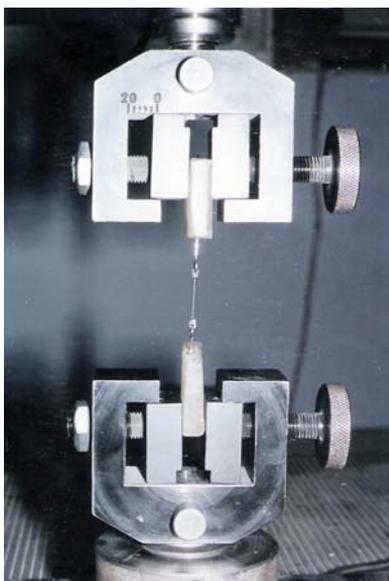


Fig. 5: Closed coil springs mounted on the jaws

the spring. The archwire at the lower end was attached to a acrylic block and upper end of the archwire slid through the buccal tube of dimension 0.022×0.028 inch attached to another acrylic block. This procedure resulted in the specimen being held on the archwire between two acrylic blocks. Acrylic block with archwire was fastened to the lower jaw and the acrylic block with the buccal tube to the upper jaw of the testing machine. The archwire was free to slide through the buccal tube, thereby allowing the upper jaw to slide downward toward the lower jaw, when crosshead was lowered.

Stainless steel open coil springs were compressed at a rate of crosshead movement of 5 mm/min from initial effective length of 15 to 6 mm and 20 to 8 mm. Nickel-titanium open coil springs were compressed from the initial length of 15 mm to extent when load started rising steeply (according to manufacturer, this spring delivers an almost constant force of more than 9 mm as it expands from its compressed length of 3 mm). On deactivation, crosshead movement direction was reversed and the springs were unloaded back till the point load value comes back to zero.

During activation of SS open coil springs having 15 mm initial length, load was recorded at 0.5, 1, 2, 3, 4, 5, 6, 7, 8, 8.5, 9 mm and for SS open coil springs having 20 mm initial length, load was recorded at 0.5, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11 and 12 mm for analysis. During activation of NiTi open coil springs having 15 mm initial length, load was recorded at each mm from 0.5 mm onwards till it starts to rise steeply.

On deactivation of SS and NiTi open coil springs load was recorded at each mm from the point of maximum activation till the point load becomes zero.

For the tension test, the samples of 5 and 8 mm length of stainless steel closed coil springs were prepared by attaching stainless steel ligature wire of 0.010 inch diameter to the both ends of the springs so that the initial effective length becomes 3 and 6 mm respectively.

Nickel-titanium closed coil springs were commercially available as laser fused eyelets for easy engagement with the initial effective length of 3 mm. These springs were fastened by their eyelets or ligature wire with stainless steel hooks of 0.032 inch diameter attached to the acrylic blocks to the jaws of the machine, jaws were moved apart at the rate of 5 mm per minute until the activation of spring was from the 3 to 18 mm from NiTi coil springs and 3 to 9 mm and 6 to 18 mm for stainless steel coil spring (Fig. 5). On deactivation, the crosshead movement direction was reversed and the springs were unloaded back till the point load value comes back to zero.

During activation of SS closed coil springs of initial length of 3 mm, load was recorded at 0.5, 1, 2, 3, 4, 5, 5.5, 6 mm and, for SS closed coil springs of initial length of 6 mm, load was recorded at 0.5, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 11.5 and 12 mm for analysis. During activation of NiTi 0.5 and 1 mm, thereafter, load was recorded at each mm till 15 mm.

On deactivation of SS and NiTi closed coil springs load was recorded at each mm from the point of maximum activation till the point load value becomes zero.

Statistical Analysis

The data obtained was subjected to statistical analysis. Mean and standard deviation were calculated for all the groups. Student's t-test was used to test the equality of two means.

OBSERVATIONS

This study is based on 60 samples of open and closed coils springs. Open coil springs were tested in compression and closed coil springs in tension. The load values produced by coil springs, as a function of displacement, were measured twice both during activation (loading) and deactivation (unloading). All the data obtained was subjected to the statistical analysis. Mean value, standard deviation (SD) and t-value were calculated to determine the significance (based on p-values) of load difference within the group and between the groups. Graphs were plotted and superimposed for better understanding of comparisons (Tables 3 to 14).

Table 3: Comparison of mean load value of SS open coil spring of different wire diameter (length 15 mm)

	Load (mean ± SD in gm)		t-value	p-value
	0.010 × 0.030"	0.009 × 0.030"		
Activation	426.36 ± 258.06	190.74 ± 126.48	2.0410	p < 0.05
Deactivation	292.74 ± 181.56	142.80 ± 69.36	2.7192	p < 0.05

p < 0.05: Statistically significant

Table 4: Comparison of mean load value of SS open coil spring of different lumen sizes

	Load (mean ± SD in gm)		t-value	p-value
	0.010 × 0.032"	0.010 × 0.030"		
Activation	248.58 ± 166.26	426.36 ± 258.06	1.5222	NS
Deactivation	177.48 ± 112.20	292.74 ± 181.56	1.4699	NS

NS: Not significant

Table 5: Comparison of mean load value of SS open coil spring of different initial lengths

	Load (mean ± SD in gm)		t-value	p-value
	0.010 × 0.030" (initial length 15 mm)	0.010 × 0.030" (initial length 20 mm)		
Activation	426.36 ± 258.06	485.52 ± 256.02	0.5620	NS
Deactivation	292.74 ± 181.56	190.74 ± 148.92	1.1564	NS

NS: Not significant

Table 6: Comparison of mean load value of NiTi open coil spring (100 and 150 gm)

	Load (mean ± SD in gm)		t-value	p-value
	NiTi (100 gm)	NiTi (150 gm)		
Activation	128.52 ± 57.12	180.54 ± 71.40	2.0512	p < 0.050
Deactivation	60.18 ± 21.42	173.22 ± 38.76	2.2568	p < 0.001

p < 0.05: Statistically significant; p < 0.001: Highly significant

Table 7: Comparison of mean load value of NiTi and SS open coil springs

	Load (mean ± SD in gm)		t-value	p-value
	NiTi (150 gm)	SS open (0.010 × 0.032)		
Activation	180.54 ± 71.40	284.58 ± 166.26	2.0501	p < 0.05
Deactivation	113.22 ± 38.76	177.48 ± 112.20	3.4124	p < 0.01

p < 0.05: Statistically significant; p < 0.01: Highly significant

Table 8: Comparison of mean load of SS closed coil spring of different wire diameter

	Load (mean ± SD in gm)		t-value	p-value
	0.010 × 0.030	0.009 × 0.030		
Activation	424.32 ± 211.14	195.84 ± 106.08	2.7349	p < 0.05
Deactivation	319.26 ± 195.84	169.32 ± 89.76	1.5563	p < 0.20

p < 0.05: Statistically significant; p < 0.20: Highly significant

Table 9: Comparison of mean loads of SS closed coil spring of different lumen sizes

	Load (mean ± SD in gm)		t-value	p-value
	0.010 × 0.032	0.010 × 0.030		
Activation	394.74 ± 200.94	424.32 ± 211.14	0.2870	NS
Deactivation	287.64 ± 185.64	319.26 ± 195.84	0.2620	NS

NS: Not significant

Table 10: Comparison of mean load value of SS closed coil spring of different initial length

	Load (mean ± SD in gm)		t-value	p-value
	0.010 × 0.030 (3 mm)	0.010 × 0.030 (6 mm)		
Activation	424.32 ± 211.14	466.14 ± 221.34	0.1618	NS
Deactivation	319.26 ± 195.84	337.62 ± 207.06	0.4332	NS

NS: Not significant

Table 11: Comparison of mean load value of NiTi closed coil spring (100 and 150 gm)

	Load (mean ± SD in gm)		t-value	p-value
	0.010 × 0.030 (3 mm)	0.010 × 0.030 (6 mm)		
Activation	424.32 ± 211.14	466.14 ± 221.34	0.1618	NS
Deactivation	319.26 ± 195.84	337.62 ± 207.06	0.4332	NS

NS: Not significant

Table 12: Comparison of mean load value of NiTi closed coil and SS closed coil spring

	Load (mean ± SD in gm)		t-value	p-value
	NiTi (100 gm)	SS (0.010 × 0.032)		
Activation	159.12 ± 27.54	394.74 ± 200.94	4.9970	p < 0.001
Deactivation	121.38 ± 26.52	287.64 ± 185.64	3.7849	p < 0.001

p < 0.001: Highly significant

Table 13: Comparison of mean load value of NiTi open and closed coil spring (100 gm)

	Load (mean ± SD in gm)		t-value	p-value
	Closed	Open		
Activation	98.94 ± 17.34	128.52 ± 57.12	2.0261	NS
Deactivation	84.66 ± 15.3	60.18 ± 21.42	2.3555	p < 0.005

NS: Not significant; p < 0.005: Statistically significant

Table 14: Comparison of mean load value of NiTi open and closed coil spring (150 gm)

	Load (mean ± SD in gm)		t-value	p-value
	Closed	Open		
Activation	159.12 ± 27.54	180.54 ± 871.40	1.1665	NS
Deactivation	121.38 ± 26.52	113.22 ± 38.76	0.6289	NS

NS: Not significant

DISCUSSION

Orthodontic coil springs were primarily made up of stainless steel (SS) but these have relatively higher force decay rate. Thus clinical use of these springs requires a minimal extension and use of force gauge to keep the force levels in optimal range. Since, only 1 to 2 mm of activation may be needed, high deflection rate may cause slower tooth movement. Therefore, frequent activations may be required to keep force level constant. Nickel-titanium coil springs possess a high resistance to permanent deformation and the potential for relatively constant force delivery during unloading. NiTi springs have a high spring back or maximum elastic deflection, maximum flexibility, range of activation, range of deflection or working range. Higher spring back of NiTi wire provides the ability of large activations with a resultant increase in working time of appliance.

Two types of springs, open and closed, were taken for the study. Force characteristics of two types of springs also differ, as for any given coil spring of specified wire size, lumen size, alloy type and length, an open coil spring is stiffer than a closed coil spring. Because, as the open coil spring is compressed, its lumen size increases and, as closed coil spring is elongated, its lumen size decreases.

Factors affecting the load produced by coil springs, as a function of displacement, include alloy type, wire diameter, lumen size, pitch angle (angle at which coils deviate from a perpendicular line to the long axis of the spring, an increase in pitch angle leads to a higher load deflection rate)² of the coil and the length of the spring. In this research, the aim of the study was to see the effects of wire diameter, lumen size and length of the spring, having same pitch angle.

SS Open Coil Springs

All the SS open coil springs were subjected to compression of 60% of their initial length of 15 and 20 mm, and graphs were plotted after recording the load (Figs 6 to 8).

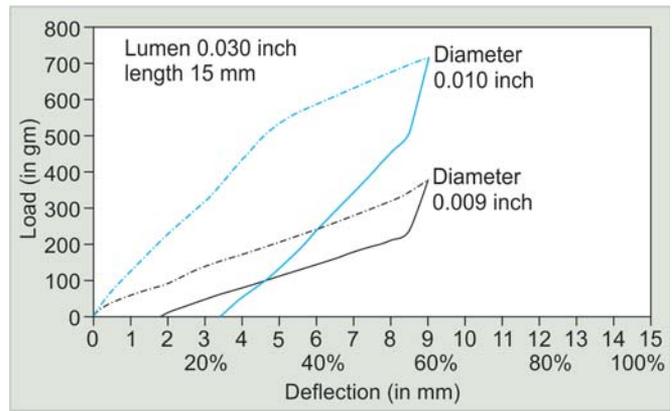


Fig. 6: Comparison of SS open coil springs of different diameter (length 15 mm)

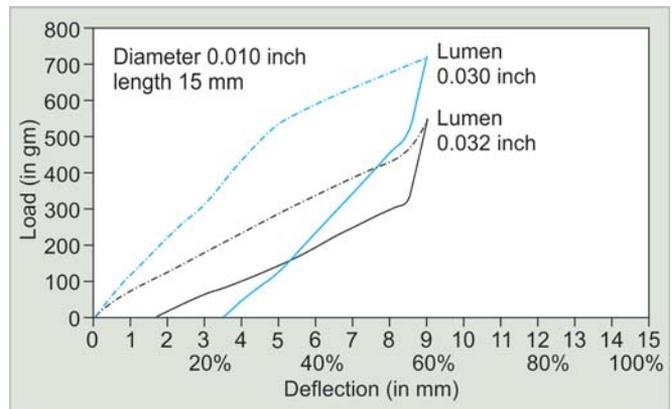


Fig. 7: Comparison of SS open coil springs of different lumen sizes

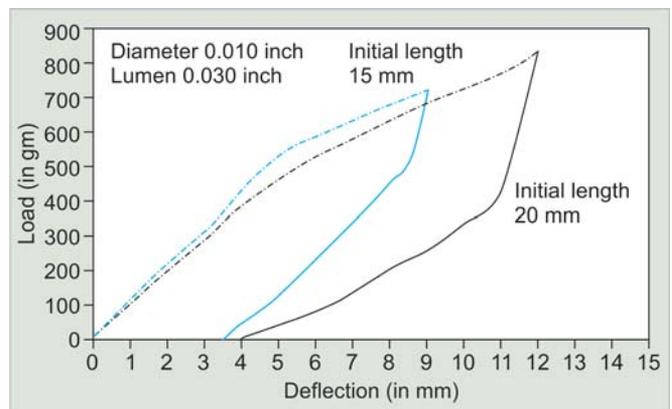


Fig. 8: Comparison of SS open coil springs of different initial lengths

During activation, SS open coil springs show a linear increase in load, as a function of displacement, up to 8 mm (in 0.009 × 0.030 and 0.010 × 0.032) then the load deflection curve shows a change in plateau and load increases rapidly up to 9 mm. But in 0.010 × 0.030 coil spring load initially increases linearly up to 5 mm and later load increases slowly as a function of displacement.

During deactivation, all the springs showed a sharp decrease in load as springs are deactivated 0.5 mm and then show a linear decrease in load until load becomes zero. The highest load value at 60% compression was recorded in 0.010 × 0.030 (485.52 gm) spring with 20 mm initial length due to its large wire diameter and reduced lumen size among the coil springs tested.

These findings were in accordance to the findings of Chaconas³ who proved that the spring exhibits an unpredictable or nonreproducible behavior beyond a certain linear portion of the load deflection curve. Thus, the straight line (linear) portion of the load deflection curve is clinically important (in 0.009×0.030 and 0.010×0.032 , it is 8 mm, and, in 0.010×0.030 , it is 5 mm).

The mean load during deactivation by the open coil springs was found to be less as compared to mean load during activation. This difference in the load can be attributed to the phenomenon of hysteresis as shown by Barwart.⁴ He found that the load value for activation and deactivation were about parallel at different levels.

All the SS open coil springs irrespective of wire size, lumen size or lengths showed permanent deformation. The permanent deformation was ranging from 11 (in 0.009×0.030 spring) to 20% (in 0.010×0.030 , 20 mm length). This finding of our study is consistent with the study of Kapila (1989)⁵ who found that due to high stiffness and low spring back, all the stainless steel wires exhibit permanent deformation and it increases as the wire dimension increases.

When load deflection curves and loads produced from springs of various dimensions were compared, it was found that wire diameter had a significant effect on the mean load values, maximum load attained, spring rate and permanent deformation. It was found that 0.009×0.030 spring showed a significantly less mean load and maximum load as compared to the load of 0.010×0.030 springs during activation and deactivation. All these findings are duly supported by the study of Chaconas³ who found that with a constant lumen size, an increase in wire size produced an increase in the force at given activation. Boshart⁶ concluded that, as the diameter of wires were increased, the spring rate was also found to be increased.

When SS open coil springs of same wire diameter but different lumen dimensions were compared, it was found that lumen size have less effect on the mean load value than the effect of wire diameter. Spring with 0.010×0.030 dimension showed a higher mean load, maximum load attained and permanent deformation as compared to the 0.010×0.032 springs. This difference in the load value can be attributed to the increased flexibility due to incorporation of more wire in 010×032 springs.

When SS open coil springs of same wire diameter and lumen size but with different lengths were compared, the spring with 20 mm length showed a lesser load at similar activation and deactivation as compared to 15 mm springs. Spring having 20 mm length also showed a greater difference between load values of activation and deactivation. Thus, the loss of load due to hysteresis is more in 20 mm SS spring as compared to 15 mm spring. Permanent deformation in longer spring was found slightly more as compared to smaller spring. Similar findings were reported by Boshart⁶ who found that a shorter spring is stiffer than a longer spring of the same type, which is directly proportional to ratio of the length of the spring.

NiTi Open Coil Springs

Sentalloy open coil springs deliver consistent force delivery due to its superelasticity. NiTi open coil springs (100 and 150 gm) were compressed to the extent till load starts to rise steeply (Fig. 9). During activation, initially load increases linearly as a function of displacement up to 3 mm and then it increases non-linearly up to 11 mm at which point load started to rise steeply. During deactivation, there was a sudden drop in load value as the coil spring is deactivated from maximum activation to 11 mm. Then the load decreases nonlinearly very slowly up to 3 mm. So, these springs show superelasticity in the range of 3 to 11 mm. Similar findings were reported by Fraunhofer⁷ who found that NiTi coil springs would deliver a relatively constant force over a range of 7 mm tooth movement with one activation.

On deactivation of coil springs from 11 to 3 mm, the load delivery was in between 92.82 to 57.12 gm (100 gm) and 160.14 to 113.22 gm (150 gm). These findings differ from the findings of Manhartsberger⁸ who recorded a load delivery between 133 and 90.3 gm for 100 gm spring and 201.4 to 145.6 gm for 150 gm spring on deactivation from 11 to 3 mm. The variation in the results may be because the tests done by Manhartsberger⁸ were at 37°C and these test conducted at room temperature. In these findings, there is a drop in load values which is in accordance with the findings of Barwart,⁴ who found that an increase in the temperature of 1°C resulted in increase in the load, an average of 3.3 for 100 gm spring and 3.8 for 150 gm spring.

COMPARISON OF LOAD PRODUCED FROM NiTi (150 GM) AND SS OPEN COIL SPRINGS (0.010 × 0.032)

When open coil spring of SS and NiTi were compared, SS open coil springs showed a linear load deflection curve with significantly greater mean load as compared to the mean load of NiTi open coil springs (Fig. 10). NiTi spring showed nonlinear loading and unloading curve. This difference in load deflection behavior of both types of springs can be explained on the basis of superelastic property of the NiTi coil springs.

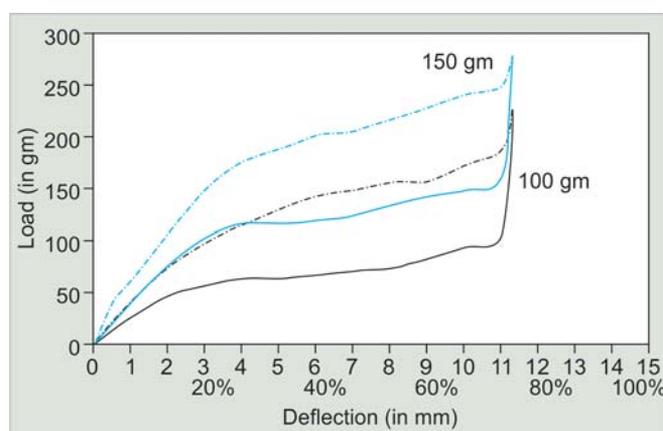


Fig. 9: Comparison of NiTi open coil springs (100 and 150 gm)

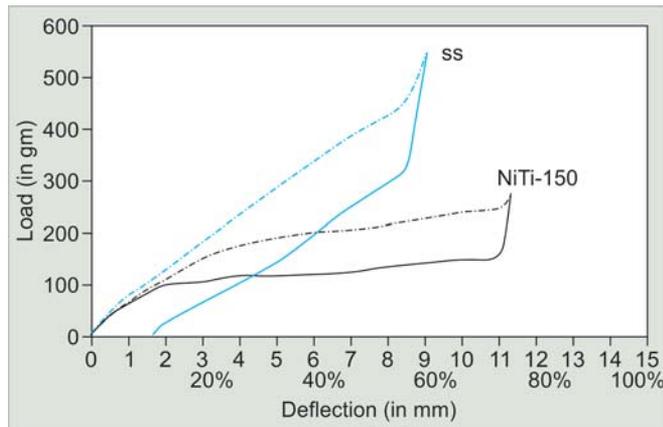


Fig. 10: Comparison of NiTi and SS open coil springs

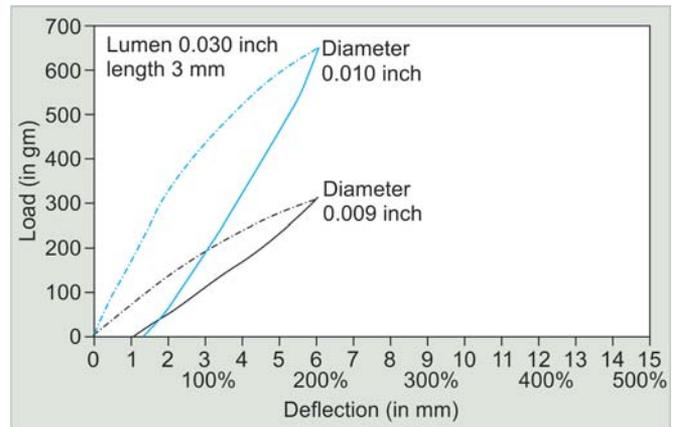


Fig. 11: Comparison of SS closed coil springs of different wire diameter

Superelasticity allows the spring to exert a fairly constant stress value during deformation over a wide range and produces a constant part of load deflection curve. This constant part of curve is called as martensitic plateau. These findings are supported by Miura⁹ who found that the load deflection curve of SS coil spring expressed a linear relationship up to its proportional limit but the NiTi showed only slight increase in stress despite a larger change in the strain due to superelasticity.

SS Closed Coil Springs

All the SS closed coil springs were subjected to tension of 200% of their initial length and graphs were plotted after recording the load (Figs 11 to 13).

During activation, SS closed coil springs showed a linear increase in load as a function of displacement up to approximately 100% extension, then the load deflection curve shows a slight change in plateau and load increases slowly up to 200% extension. During deactivation, all the springs show a linear decrease in load as a function of displacement. Thus, the clinically important range is 100% extension. The highest load values at 200% extension were recorded in 0.010 × 0.030 spring (709.92 gm) attributed to its large wire diameter and reduced lumen size among the coil springs tested. These findings were in accordance with the findings of Boshart⁶ who reported maximum load deflection rate in 0.010 × 0.030 closed coil spring.

All the springs showed a permanent deformation ranging from 34% in SS closed coil (0.009 × 0.030, with initial length of 3 mm) to 55% (in 0.010 × 0.030 with initial length of 6 mm).

When the load deflection curves from closed coil springs of various dimensions were compared, it was found that wire dimension had a significant effect on the mean load value, maximum load attained, spring rate and permanent deformation. It was found that 0.009 × 0.030 spring had a significantly lesser mean load and maximum load during activation and deactivation as compared to that of 0.010 × 0.030 coil spring. Chaconas³ found that with a constant lumen size an increase in the wire size produced an increase in the force at a given activation. Permanent deformation was also found to be greater in 0.010 × 0.030 spring as compared to the 0.009 × 0.030 coil springs.

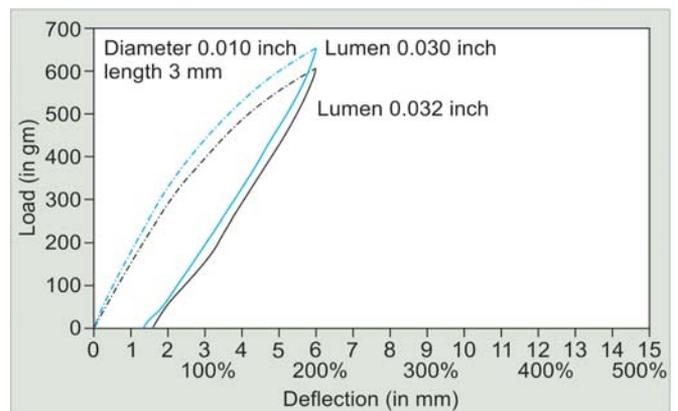


Fig. 12: Comparison of SS closed coil springs of different lumen size

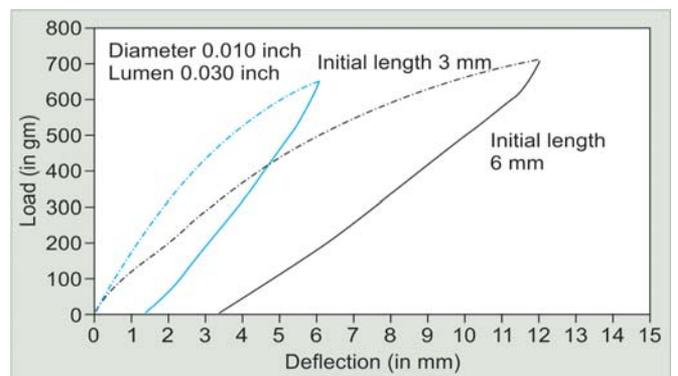


Fig. 13: Comparison of SS closed coil springs of different initial length

When SS closed coil springs of same wire size but different lumen sizes were compared. It was found that lumen sizes have less effect on the mean load value, maximum load attained, spring rate and permanent deformation than the effect of wire diameter. The difference in load value can be attributed to the increased flexibility due to incorporation of more wire in 0.010 × 0.032 springs than in 0.010 × 0.030. Boshart⁶ supports these findings.

When SS closed coil springs of same wire diameter and lumen size having different lengths were compared, the spring with 6 mm length showed less load at similar activations and deactivations. This spring also showed a greater difference between load values on activation and on deactivation. Thus,

the loss of load due to hysteresis was found to be more in 6 mm SS closed coil springs. Permanent deformation in longer spring was found slightly increased as compared to smaller spring. Similar findings were reported by Boshart.⁶

NiTi Closed Coil Springs

Sentalloy closed coil springs should produce consistent force delivery which is due to superelastic phenomenon. In this study, we extend NiTi closed coil springs (100 and 150 gm) to 500%, i.e. from initial length of 3 to 18 mm, during activation load increased sharply up to 0.5 mm and then load becomes nearly constant up to 15 mm (Fig. 14).

During deactivation, load started to drop rapidly from 15 to 13 mm then the load becomes nearly constant. These springs exhibit superelasticity in the range of 0.5 to 13 mm. Similar findings were reported by Fraunhofer⁷ who found that NiTi closed coil springs produced light continuous forces within the 75 to 100 gm range (100 gm spring) over a long range of activation.

On deactivation of coil springs from 11 to 1 mm load delivery was 92.82 to 77.52 gm for 100 gm springs (mean load of 84.6 gm that is 15.4% less that mentioned by manufacturer) and 135.66 to 113.22 gm for 150 gm springs (mean load of 121.38 gm that is 19% less that mentioned by the manufacturer). These findings differ from the findings of Manhartsberger.⁸ The variation in results may be attributed to the tests done by Manhartsburger at 37°C and these tests conducted at room temperature.

When the load deflection curves of NiTi closed coil springs of 100 and 150 gm load values were compared, none of the springs showed any permanent deformation even after 500% that is five times elongation. The 150 gm spring showed a greater gap between the loading and unloading curve as compared to that of 100 gm coil springs meaning that there was a greater loss of force due to hysteresis in 150 gm closed coil springs. Tripoli¹⁰ concluded that standardized NiTi coil spring can produce a relatively constant force during deactivation.

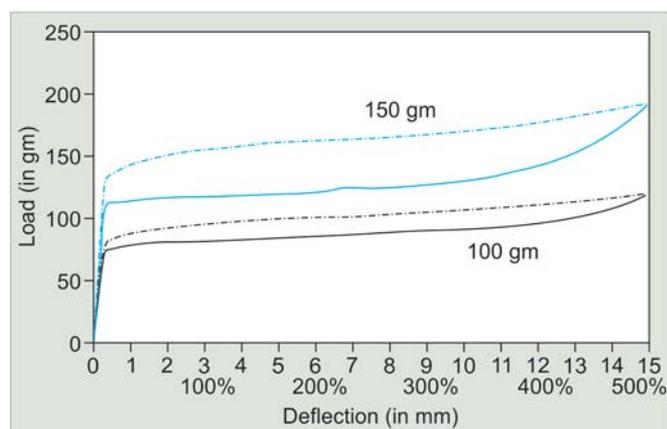


Fig. 14: Comparison of NiTi closed coil springs (100 and 150 gm)

COMPARISON OF LOAD PRODUCED FROM NiTi (150 GM) AND SS (0.010 × 0.032) CLOSED COIL SPRINGS

When closed coil springs of SS and NiTi were compared to SS coil spring showed a linear load deflection curve with a significantly greater mean load as compared to mean load of NiTi closed coil spring (Fig. 15). NiTi spring showed nonlinear loading and unloading curve. This difference in load deflection behavior of both types of springs can be explained on the basis of superelastic property of the NiTi closed coil springs. Melsen¹ found that many of the superelastic products are in reality, only springs delivering a low force level. Only GAC, Sentalloy spring showed a true superelastic behavior.

COMPARISON OF LOAD PRODUCED FROM NiTi OPEN AND CLOSED COIL SPRING

When the open and closed NiTi coil springs were compared, it was seen that during deactivation mean load of open coil springs were less as compared to mean load of closed coil springs (Figs 16 and 17). The open coil springs showed a greater gap between loading and unloading curve meaning by that there was a greater loss of load due to hysteresis than closed coil springs. These findings also indicate that NiTi closed coil springs deliver a more constant load during activation and deactivation as compared to NiTi open coil springs. None of the spring showed any permanent deformation.

CONCLUSION

The following conclusions can be derived from this study:

1. SS open coil springs deliver a linear load when compressed to 33 to 50% of their original length (15 mm) depending on the wire diameter and lumen size of the spring.
2. NiTi open coil springs deliver a nearly constant load during deactivation over a range of 20 to 73%, (3-11 mm) of their original length (15 mm).
3. SS closed coil springs produce a linear load when extended to 100% of its original length (3 mm).

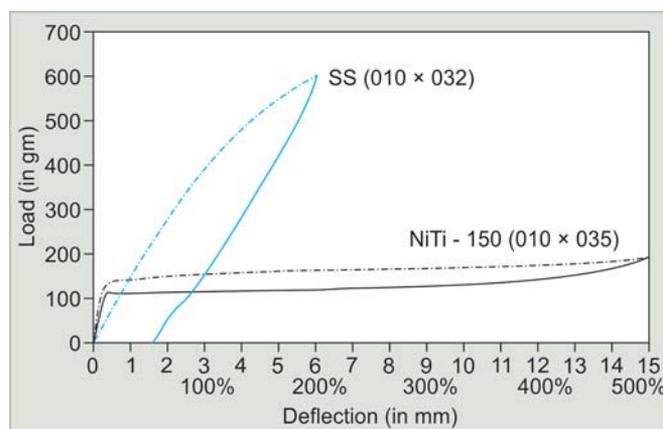


Fig. 15: Comparison of NiTi and SS closed coil springs

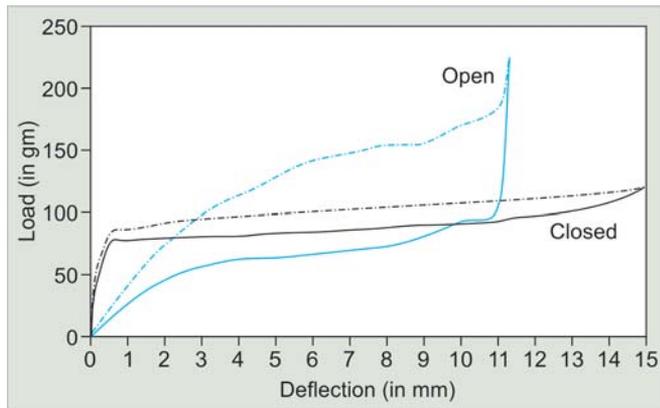


Fig. 16: Comparison of NiTi open and closed coil springs (100 gm)

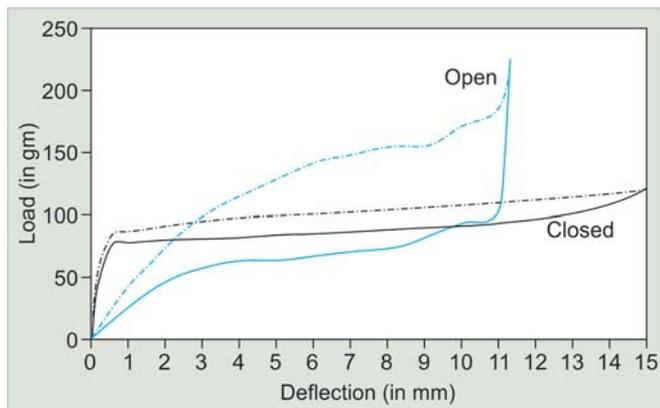


Fig. 17: Comparison of NiTi open and closed coil springs (150 gm)

4. NiTi closed coil springs deliver a nearly constant load during deactivation over a range of 15 to 43.5% (0.5-13 mm) of their original length (3 mm).
5. The diameter of the wire has a significant effect on the mean load and maximum load attained of SS open and closed coil springs. As the diameter of the wire is increased, load produced as a function of displacement increases.
6. Lumen size of SS open and closed coil spring has less effect on mean load value and maximum load attained than the diameter of the wire. As lumen size of the spring increases, load produced as a function of displacement decreases.

7. Length of the SS open and closed coil spring has lesser effect on load delivery of the spring than the effect of wire diameter and lumen size. When the length of the spring increases load produced as a function of displacement decreases.
8. All the springs of SS exhibit permanent deformation ranging from 34 to 55% (for closed coil) and from 11 to 20% (for open coil). As the diameter increases, or lumen size and length of the spring decreases, permanent deformation increases.
9. During deactivation, NiTi open and closed coil springs deliver a load less than the load mentioned by the manufacturer.

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