Mechanical compression testing for three-dimensional printed orthodontic springs with different coil numbers: in vitro study

Ahmed Othman (1); Sophie Ruckenstuhl (2); Dragan Ströbele (3); Jassin Arnold (4); Constantin von See (5)

Abstract:

Objective: *Purpose of this study was to evaluate the influence of different design parameters regarding the number of coils for orthodontic 3D printed springs using the computer aided design/ computer aided manufacturing (CAD/CAM) technology.* ***Materials and Methods:*** *Test specimens using 3D printable experimental flexible material (Code: BM2008, GC, Tokyo, Japan) were printed using 3D printer MAX (Asiga, Sydney, Australia). The specimens were divided into five groups according to their coil numbers, including a control group C with four coils (n=10), group A with two coils (n=10), group B with three coils (n=10), group D with five coils (n=10) and group E with six coils (n=10). All specimens were mechanically tested using Zwick Z010 machine (Ulm, Germany) and digitally designed using Autodesk Netfabb CAD software (San Rafael, CA, USA). Statistical analysis was performed using t-test to compare the values of the groups (p<0.001).* ***Results:*** *The highest value in all groups was achieved by 6.23N/mm in group B while the lowest value was achieved by 0.87N/mm in group E. Moreover, significant results can only be detected between groups A and B when compared to master group C (p<0.001). Step-wise compression testing with 0,1mm steps, each with 5 minutes holding time, was conducted with 10 steps for each group with the exception of group A, which was tested with 5 steps.*

Conclusion: *3D printed springs are mechanically affected by the number of coils. The smaller the coil numbers, the higher is the significance level (p<0.001).*

Key words: *CAD/CAM; 3D printing; Orthodontics; mechanical testing; material evaluation*

Introduction:

Orthodontics is the science of teeth movement within the periodontium to attain aesthetics and occlusion [1,2]. Orthodontic tooth movement is a process in which the application of a force induces bone resorption on the pressure side and bone deposition on the tension side.

Thus, conventional orthodontic tooth movement results from biological cascades of resorption and apposition caused by the mechanical forces [3-5]. The amount of orthodontic tooth movement depends on magnitude and duration of force applied, the number and shape of roots, quality of bony trabeculae, individual response, and patient compliance [6,7].

Application for a specific force magnitude with either fixed or removable orthodontic appliances can be capable of evoking the desired response of teeth within the biological system.

Removable functional appliances with implementation of active auxiliary springs can

(1) Assistant Professor, Research Center for Digital Technologies in Dentistry and CAD/CAM, Department of Dentistry, Faculty of Medicine and Dentistry, Danube Private University, 3500 Krems, Austria.

(2) Private Dental Practice, Vienna, Austria.

(3) Researcher in the Research Center for Digital Technologies in Dentistry and CAD/CAM, Department of Dentistry, Faculty of Medicine and Dentistry, Danube Private University, 3500 Krems, Austria.

(4) Private Practice, Waldbroel, Germany and researcher in Research Center for Digital Technologies in Dentistry and CAD/CAM, Department of Dentistry, Faculty of Medicine and Dentistry, Danube Private University, 3500 Krems, Austria.

(5) Professor and Director of Research Center for Digital Technologies in Dentistry and CAD/CAM, Department of Dentistry, Faculty of Medicine and Dentistry, Danube Private University, 3500 Krems, Austria.

be considered for orthodontic treatment [8].

The introduction of computer software in orthodontics has allowed orthodontists to provide more precise diagnosis and treatment planning [9-12]. Nowadays, considering the era of the technological development, a combination of intraoral scanning, digital setup, custom-made brackets, wires and indirect bonding may soon become the orthodontic standard measurements for daily clinical usage [13,14]. However, digital designing of orthodontic 3D printed springs with functionality is still not considered. Although, differently designed springs can be laboratory fabricated depending on the aim of clinical usage, however having the possibility for independent design with different parameters including the springs coil numbers depending on the type of tooth movement, range of force activity, tooth morphology and treatment plan, is still not proved. The necessary requirements are influenced by the individual design of each spring; accordingly, the springs should be tested in vitro prior to clinical consideration. The aim of this study is to investigate the exerted mechanical compression forces on 3D printed orthodontic springs with different coil numbers.

Materials And Methods

Fifty specimens were 3D printed via 3D printer MAX (Asiga, Sydney, Australia) with DLP (digital light processing) technology using an experimental flexible material (Code:BM2008, GC, Tokyo, Japan) for this study. The specimens were designed using a computer-aided program (Autodesk Netfabb, San Rafael, CA, USA) with one different design parameter which was the coil number (Fig. 1-5). The post processing of the specimens was performed by GC-Europe according to the manufacturer's instructions. Unheated ultrasonic reusable isopropanol solution with a concentration of 96% was used to clean the specimens for 2 minutes followed by 2 more minutes of a clean isopropanol bath with the same concentration.

The specimens were withdrawn from the solution bath and dried with compressed air in-between the two cleaning cycles. Surface polymerization was done using Labolight DUO (GC, Tokyo, Japan) with double wave length LED technology in a range of 380nm – 510nm with spectrum ranges peaks of 465nm - 485nm (12 Blue LED's) and 390nm - 400nm (3 Violet LED's). Two periods of 3 minutes duration each were operated and the samples were turned for curing from both sides. After post curing, carbide bur and nipper were used to remove supports.

After eliminating all specimens' printable supports, the specimens were divided into five different groups according to their different design parameters, containing a control group with four coils (n=10), group A with two coils (n=10), group B with three coils (n=10), group D with five coils (n=10) and group E with six coils (n=10) (Table 1). The control group with 4 coils was selected referring to a study conducted by Othman et al who found that comparing between the conventional laboratory fabricated springs with the CAD/CAM methods had a significant difference for material as well as design comparing compression to force ratio. The design with 4 coil numbers and variable wire thickness directly affects the mechanical properties for printable orthodontic resins and exhibit that CAD/CAM orthodontic springs can be printed and mechanically tested in order to bring out a new treatment possibility in orthodontics using the 4 coils springs design [15].

The way of this study investigation was by linear compression of all springs in mm with resultant forces were recorded in N (Newton) and the minimum and maximum values for each specimen were documented (Fig.6).

Testing followed the principle of step-wise compression with consecutive steps of 0.1mm each with 5 minutes holding time at each step. For all groups 10 steps were conducted with the exception of group A, because it was designed with only 2 coils and more than 5 steps would result in spring breakage.

Results:

The t-test indicated a highly significant influence of the used design when comparing both groups, A and B to group C ($p<0.001$). However, for the groups D and C no significant difference was detectable ($p<0.362$). Additionally, the values for groups E and C were also not statistically significant ($p<0.113$).

The highest measured value was found for group B (6.23 N/mm) (Fig.6). The lowest scores showed in group E (0.873 N/mm).

Groups A and B revealed highly significant values other than groups D and E.

The SD value between groups B and C was 0.033. While, the lowest SD difference was determined between groups E and C 0.007. Concerning the mean value, group B represented the highest value 0.313, while the lowest value was shown in group E 0.058 (Fig.7-11).

Discussion:

This present investigation was to mechanically analyse the influence of differently designed coil numbers for 3D printed orthodontic springs using the material coded BM2008 (GC, Tokyo, Japan). CAD/CAM has been already established in orthodontics, in which the aligner can be used for 2-3 weeks. The 3D printed springs have different degree of freedom, in this study only one degree of freedom will be tested and the other should be tested in other studies independently. However, within this study it was proved that changing the design parameters has a significant influence on the mechanical compression forces. Various parameters could be considered for testing the material specific properties but in this study the number of coils was used for material evaluation.

Regarding materials and methods, all specimens were 3D designed (Autodesk, Netfabb, San Rafael, CA, USA) and 3D printed (MAX Asiga, Sydney, Australia). For post processing which was manipulated by GC Europe, the study protocol followed the manufacturer's instructions to ensure uniform specimens surface treatment. First, all specimens were cleaned using an unheated ultrasonic reusable isopropanol solution with a concentration of 96%. Before the specimens were placed in a clean isopropanol bath with the same concentration for another 2 minutes cleaning cycle, they were dried with compressed air.

Surface polymerization was performed within two periods of 3-minutes durations for each sample using Labolight DUO (GC, Tokyo, Japan) with double wave length LED technology in a range of 380nm – 510nm with spectrum range peaks of 465nm - 485nm (12 Blue LED's) and 390nm - 400nm (3 Violet LED's). During this procedure the specimens were turned in order to cure them from both sides. In the following step, all printable supports were eliminated using carbide bur and nipper.

After all specimens' supports had been removed, the samples were divided into five different groups depending on their number of coils which was the only difference regarding the design parameters of the springs.

Group A (n=10) counted two coils, group B (n=10) had three coils, group D (n=10) consisted of five coils and group E (n=10) had six coils. All of the mentioned experimental groups were mechanically tested against group C (n=10), which represented the control group in this study and counted four coils (Fig. 12).

In the present investigation, there was no significant difference between the two groups D and E compared to the control group while groups A and B represented highly significant values compared to the control group ($p<0.001$).

However, clinical usage cannot be entirely in vitro simulated but it is possible to find material-specific properties. Accordingly, the initial in vitro testing was important for fundamental understanding.

Moreover, the highest values were reached by group A (1.49 N/mm) and B (6.23 N/mm), while the lowest value was detected for group E (0.873 N/mm). The values in group A were ranging from 1.03 N/mm to 1.49 N/mm. For group B, the values were ranging between 2.1 N/mm to 6.23 N/mm, while in group C the values were ranging between 0.868 N/mm to 1.24 N/mm. In group D, the values span from 0.515 N/mm to 1.31 N/mm.

For statistical evaluation, the values in which the materials were mechanically compressed were evaluated and statistically analysed ($p<0.001$).

Nevertheless, further investigations should be performed in order to inspect the design effect on the mechanical forces in depth.

The limitations of this study are not concerning the intraoral environment including salivation and time evaluation into consideration, which should be tested for clinical consideration of the 3D printed orthodontic springs.

Conclusion:

To summarize the findings of this in vitro study it should be noted that the springs belonging to group B (n=10), consisting of 3 coils, showed the best results regarding the mechanical compression forces (6.23 N/mm) in comparison to all other testing groups including the master group. Moreover, only between groups A and C ($p<0.001$), as well as between groups B and C highly significant values were detectable ($p<0.001$).

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Table:

Group	Control **(C)**	**A**	**B**	**D**	**E**
Specimens	10	10	10	10	10
Feature	4 coils	2 coils	3 coils	5 coils	6 coils

Table 1: Overview of the group classification.

Figures:

Fig. 1: Spring design of Group A

Fig.2: Spring design of Group B

Fig.3: Spring design of Group C

Fig.4: Spring design of Group D

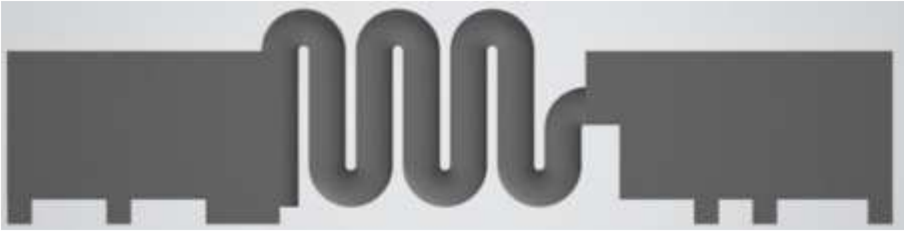

Fig.5: Spring design of Group E

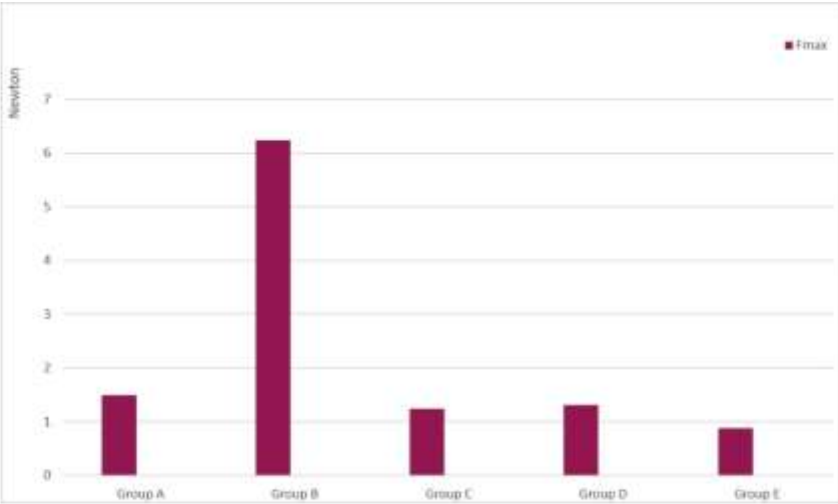

Fig.6: Maximum force values (Newton) for all groups

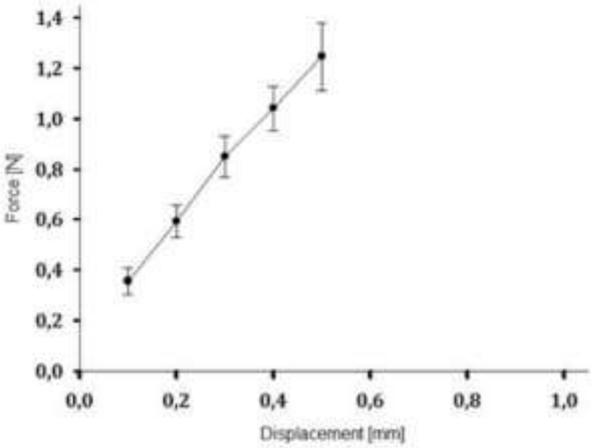

Fig. 7: Graphs of all groups' start force for each step

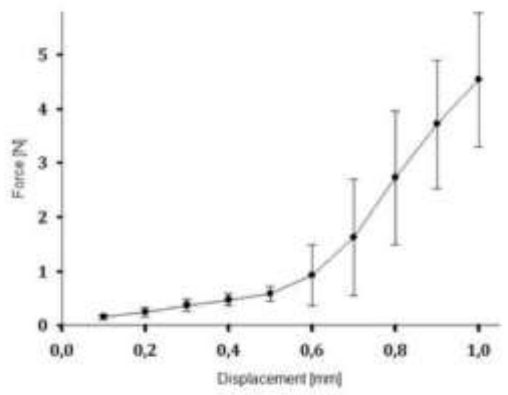

Fig. 8: Graphs of all groups' start force for each step

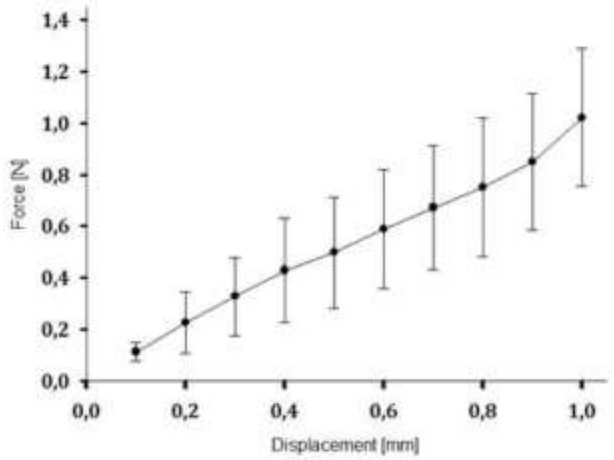

Fig. 9: Graphs of all groups' start force for each step

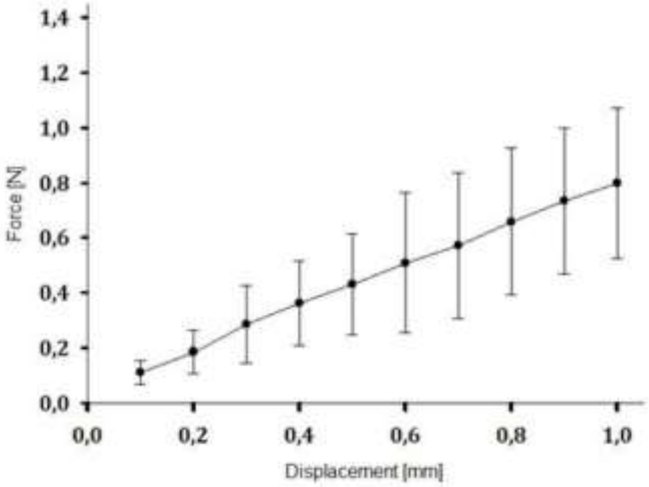

Fig. 10: Graphs of all groups' start force for each step

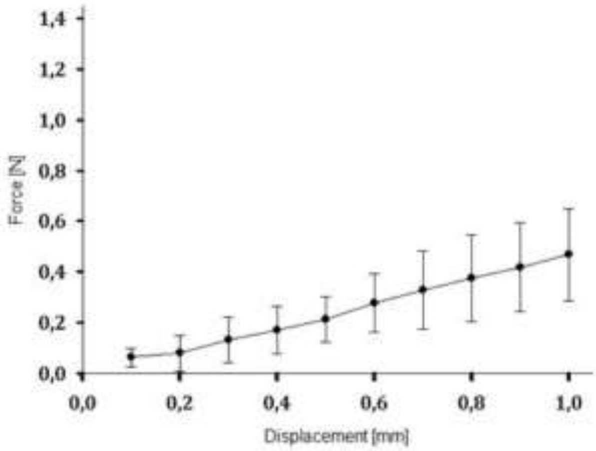

Fig.11: Graphs of all groups' start force for each step

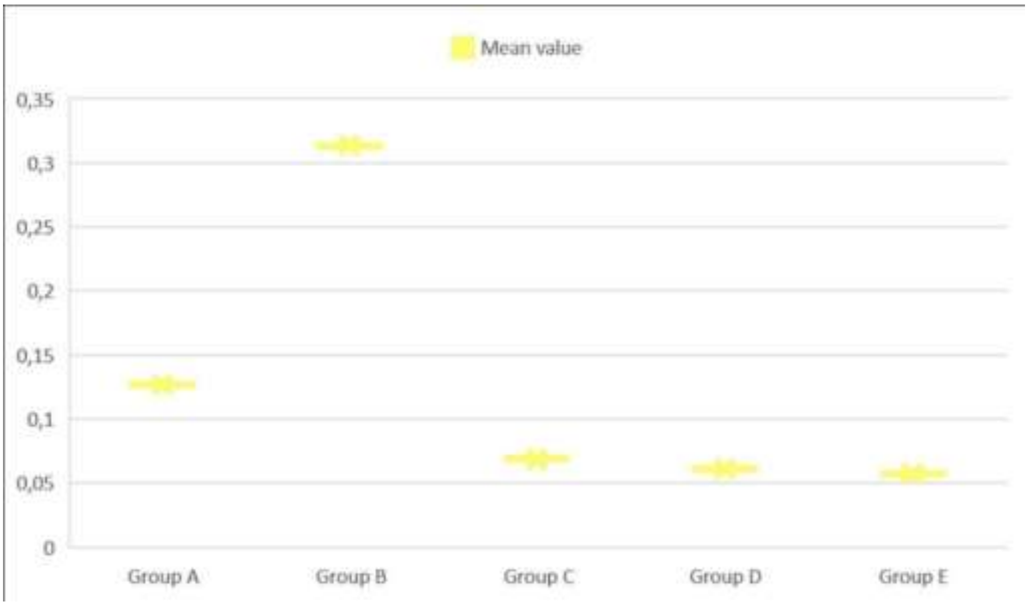

Fig. 12: Mean values of all groups