Autoclaving and clinical recycling: Effects on mechanical properties of orthodontic wires

M Oshagh, MR Hematiyan¹, Y Mohandes¹, MR Oshagh², L Pishbin³

ABSTRACT

Background: About half of the orthodontists recycle and reuse orthodontic wires because of their costs. So when talking about reuse and sterilization of wires, their effects on mechanical properties of wires should be clarified. The purpose of this study was to assess the effects of sterilization and clinical use on mechanical properties of stainless steel wires.

Materials and Methods: Thirty stainless steel orthodontic wires were divided into three equal groups of control, autoclave (sterilized by autoclave), and recycle group (wires were used for orthodontic patients up to 4 weeks, cleaned by isopropyl alcohol and sterilized by autoclave). The mechanical properties (tensile test, three-point loading test for load-deflection curve) were determined.

Results: Fracture force, yield strength, stiffness and modulus of elasticity in recycle groups were significantly lower than the other groups (P < 0.05).

Conclusion: Although recycle wires were softer than those of control group, relatively small differences and also various properties of available wires have obscured the clinical predictability of their application. There is seemingly no problem in terms of mechanical properties to recycle orthodontic wires.

Key words: Mechanical properties, stainless steel wire, sterilization

Advances in metallurgy and wire manufacturing have led to the replacement of precious metals with different alloys for orthodontic purposes. Inexpensive stainless steel wires which have been used for many years do not possess ideal mechanical properties needed especially in the tooth alignment phase.¹ However, due to its adequate stability, strength and formability, stainless steel continues to be the main orthodontic alloy and a reference to which the characteristics of other orthodontic wires are compared.²,³ Though it is over several decades that stainless steels are used, the fundamental questions about their mechanical properties remain to be answered.³,⁴

In order to prevent cross-contamination, manufacturers’ instructions on the wire packages often emphasize the necessity of sterilization by autoclaving before clinical application. Microbiological studies have also shown that 12% of orthodontic arch wires cause development of microbial colonies when directly placed in culture upon purchase.⁵

Relatively high price of arch wires, particularly at dental schools, military health centers and other public dental centers could be a major concern.⁶ Re-application of used wires may be cost-effective but should be assessed against the probability of mechanical property loss. Since necessary bends are specific for each patient, not many practitioners reuse stainless steel wires. However, this would be more possible with the introduction of pre-adjusted systems and the application of preformed arch wires.⁷,⁸ Buckthal, et al.⁹ reported that 52% of orthodontists recycle NiTi arch wires. This may be due to the high cost of these wires. At the same time, 55% of these clinicians are concerned about the negative effect of sterilization and recycling on the mechanical properties of wires. The combination of multiple clinical usage and sterilization procedures could end up in corrosion, cold working and property loss.¹⁰

In the past, most practitioners used cold sterilization for pliers, wires and other instruments which actually rather disinfected the instruments. Consequently, autoclaving (preferably 134°C and 32 PSI for 3 minutes) was suggested.

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Access this article online

Quick Response Code: 
Website: www.ijdr.in

DOI:
10.4103/0970-9290.107382

Indian Journal of Dental Research, 23(5), 2012
as the method of choice for the sterilization of orthodontic wires.\textsuperscript{[7,11,12]}

It seems important to determine the most suitable infection control methods for the orthodontic instruments with the least negative effects and also to determine the impacts of sterilization on the physical properties of orthodontic instruments.\textsuperscript{[13]} For example, a decrease in final tensile strength of a wire will make it more prone to fracture, which could consequently cause problems for patients and the professionals.\textsuperscript{[7]} Wentz\textsuperscript{[14]} concluded that the impacts of sterilization on wires are related to wire type and sterilization method. Lee\textsuperscript{[15]} reported that maximum tensile strength, modulus of elasticity and bending fracture of NiTi wires do not decrease by sterilization; however, he reported an increase in pitting and corrosion. Since 1980, many studies have addressed this field with controversial results.\textsuperscript{[5,7,10,13,16]}

Kapila, et al.\textsuperscript{[18]} found that sterilization has a minimal impact on wires. However, they reported considerable impairment of mechanical properties when a combination of sterilization and clinical re-application was studied. Kusy and Mayhew\textsuperscript{[13]} demonstrated that sterilization has no impact on the tensile strength of NiTi wires, but their study was performed on rectangular NiTi wires. Staggers\textsuperscript{[7]} obtained similar results with round wires. Nikolai and Huerter\textsuperscript{[18]} reported that although considerable changes occur in round Nitinol wires due to a combination of sterilization and recycling, these wires are still clinically applicable. Although physical properties of rectangular wires appear to be different from the round wires which are used frequently in the first stage of tooth aligning,\textsuperscript{[6]}

Kapila, et al.\textsuperscript{[17]} also showed that NiTi and Nitinol wires which were clinically used and sterilized once or twice were applied higher loading and unloading forces compared to the control groups. Also, there were no significant differences in load-deflection characteristics between wires clinically used and sterilized once and those used and sterilized twice.

Considering the importance of infection control, high cost of wires and few available studies on mechanical properties of stainless steel wires after sterilization and clinical application, the objective of this study was to assess the effect of sterilization and clinical application separately and concomitantly on the mechanical properties of stainless steel wires. If these procedures are associated with negative impacts, it would not be scientifically correct to recycle orthodontic wires.

**MATERIALS AND METHODS**

In this experimental study, 30 preformed (0.016 inch) stainless steel orthodontic wires (TruForce, Ortho Technology Inc., Tampa, FL, USA) were divided equally into three groups (one control and two case groups). This wire was selected according to its wide clinical application and sample size was determined as per the studies of Kapila and Krishnan.\textsuperscript{[2,6,10,17]}

Specimens in the control group, as received from the company, were examined for mechanical properties. The evaluation consisted of tensile-related tests for drawing of load-deflection curve. Specimens in the autoclave group were sterilized in an autoclave, right after unpacking (134°C and 32 PSI for 3 minutes) and then examined for mechanical properties. Specimens in group three (recycle group) were used clinically for a period of 4 weeks (± 1 week) on orthodontic patients. After clinical application, the wires were cleaned with 70% isopropyl alcohol and dried in open air, and then autoclaved. The mechanical properties were then evaluated. The patients were those with mild to moderate crowding and an extraction treatment plan. They were treated with MBT (McLaughlin-Bennet-Trevisi) pre-adjusted wires (0.022 slot dimension; Dentarum, Pforzheim, Germany). Bended wires (by clinician or patient) were excluded. Samples were selected based on a simple and consecutive approach from patients referred to the Shiraz Orthodontic Department. In all the groups, the wires were placed far enough during autoclaving to avoid their close contact so as to reduce the corrosion and to help sufficient circulation of vapor around each specimen.\textsuperscript{[6,10,17,19]} Tension and load-deflection tests were accomplished by technician blind to the procedure using universal testing machine (Zwick Z050/TH3A, Zwick Inc., Ulm, Germany). Tensile rate of crosshead was set at 5 mm/second. Initial length of wires was measured by a digital caliper (Mitutoyo Corp., Aurora, IL, USA) at the accuracy level of 0.01 mm and then the wires were loaded till the point of fracture. The fracture force and its range were recorded. Finally, the mechanical properties of all groups were statistically compared. The collected data were analyzed by one-way analysis of variance (ANOVA) and Tukey tests.

**RESULTS**

No statistically significant difference in range was observed between the groups ($P = 0.224$). However, fracture force, yield strength (fracture stress), modulus of elasticity and stiffness showed significant differences between the three groups [Table 1].

Paired comparison indicated that fracture force, yield strength, and modulus of elasticity in the recycled group were significantly lower than the other groups ($P < 0.05$). The recycled group had the lowest stiffness. Moreover, the stiffness of the third group was statistically different from the control group ($P = 0.019$). The differences in the fracture force and yield strength between the autoclave and the control groups were not statistically significant ($P = 0.62$) [Figure 1].

**DISCUSSION**

Dental material recycling may have some economical benefit unless it affects the material properties. Since bends are
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Table 1: Range, fracture force, yield strength, modulus of elasticity and stiffness of three groups (group 1: Control; group 2: Autoclave and group 3: Recycle)

<table>
<thead>
<tr>
<th>Mechanical property</th>
<th>Group</th>
<th>Mean</th>
<th>Standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Range (mm)</td>
<td>1</td>
<td>3.82</td>
<td>0.42</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>4.71</td>
<td>0.85</td>
</tr>
<tr>
<td></td>
<td>3*</td>
<td>4.46</td>
<td>1.83</td>
</tr>
<tr>
<td>Fracture force (kg)</td>
<td>1</td>
<td>27.6</td>
<td>6.19</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>29.3</td>
<td>10.43</td>
</tr>
<tr>
<td></td>
<td>3*</td>
<td>22.7</td>
<td>7.183</td>
</tr>
<tr>
<td>Yield strength (GPa)</td>
<td>1</td>
<td>2.1</td>
<td>0.047</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>2.3</td>
<td>0.08</td>
</tr>
<tr>
<td></td>
<td>3*</td>
<td>1.8</td>
<td>0.55</td>
</tr>
<tr>
<td>Modulus of elasticity (GPa)</td>
<td>1</td>
<td>46</td>
<td>0.65</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>41</td>
<td>0.61</td>
</tr>
<tr>
<td></td>
<td>3*</td>
<td>22</td>
<td>0.78</td>
</tr>
<tr>
<td>Stiffness (N/mm)</td>
<td>1</td>
<td>73.2</td>
<td>9.09</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>63.3</td>
<td>7.96</td>
</tr>
<tr>
<td></td>
<td>3*</td>
<td>54.9</td>
<td>21.12</td>
</tr>
</tbody>
</table>

*P value <0.05

individualized for each patient in an edgewise system, the re-application of stainless steel wires in this system seems to be very unlikely. But since the introduction of pre-adjusted systems, the application of wires needless of bending has become more popular.[6-8] The results of this study showed a significant decrease in the fracture force, yield strength, modulus of elasticity and stiffness of wires after sterilization and clinical application (P < 0.05). Fracture force and yield strength after sterilization were insignificantly increased (P = 0.62) and modulus of elasticity after sterilization was insignificantly decreased (P = 0.215) compared to the control group. The proportion of yield strength to modulus of elasticity serves as a useful indicator for wire performance which is indicative of load-deflection curve, working range, stiffness and resilience.[20] It was increased after sterilization (P = 0.05) compared to the control group (P = 0.04) and also increased after recycling (P = 0.08) compared to the other two study groups. This finding might be attributed to a decreased modulus of elasticity due to sterilization or clinical application. Lower stiffness, which is partly dependent on the modulus of elasticity, in the sterilization and clinical application group confirmed this finding.[21] Therefore, recycled group had a lower modulus of elasticity compared to the control group and hence included softer wires. It must be remembered that to apply light continuous forces in the clinic, it is best suitable to use wires with lower stiffness, satisfactory spring-back characteristic, lower modulus of elasticity and a wide elastic range. Stainless steel wires do not possess all these properties and also their force decay is high with tooth movement. Despite these limitations, our study showed that autoclaved and recycled stainless steel wires could be used in cases where alignment with lighter (softer) wires has not yet been completed.[2,22]

The results of this study are not supported by the findings of Pernier, et al.,[5] which showed no changes in load-deflection curve after sterilization. This difference could be attributed to the different tests used in their study (three-point bending test) and in this study (simple tensile test). Also 0.019 × 0.025 inch stainless steel wires were used in the study of Pernier, et al., but in this study, 0.016 inch wires were used because of the more frequent use of recycled 0.016 inch wires in the primary alignment stage[6] and it is clearly proven that the wire stiffness was changed significantly by a little change in cross section of wires.[20] Controversial findings may be due to the adjustments of testing machines and manufacturing procedures. All manufacturers can formulate their own standards for their products. One wire lot can differ from the next lot from the same manufacturer. Information about the processing of the wires is proprietary to each manufacturer and was not available for this study. Nevertheless, this information is important because the processing during the production of orthodontic wires has an important influence on their mechanical properties.[3,23-25] Modulus of elasticity in the study of Pernier, et al. (170 GPa) was significantly more than our values (24-26 GPa). The difference could also be related to the cross section of wires, machine adjustments and manufacturing procedures. Also, the sample size in their study was too low to be statistically interpretable.[5]

In this study, wire stiffness significantly decreased after autoclaving and recycling. Clinical application of wires with small cross sections requires greater stiffness but if stiffness was more than needed, multi-looped technique can be used.[1,26] The effects of clinical use on properties of arch wires might be attributed to intraoral conditions.[6] In vivo evaluations have reported surface interruption, oxidation and pitting of Nitinol wires,[18] whereas Smith, et al. stated that other clinical tests have shown no obvious visible difference in terms of surface corrosion.[6] The combined effects of clinical use and sterilization may subject the wires to corrosion and cold working, with a resultant alteration in their properties.[10] Whether the change of the surface characteristics of the wires occurred or not was not evaluated in this study. The clinical use might cause work hardening as a consequence of repetitive intraoral mechanical stresses.
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to which the wires were exposed during clinical use. \(^{[17]}\) Although a limited range was applied in the selection of cases, the wires were subjected to various malocclusions, foods and oral environments. Tying these wires into poorly aligned teeth caused permanent deformation of them. There was little or no visible wire deformation after clinical use; however, the stainless steel wires were noted to have a permanent deformation of about 0.65 mm after a maximum deflection of 2 mm during testing. \(^{[22]}\)

In this study, modulus of elasticity decreased after sterilization and clinical use. Khier, et al. \(^{[4]}\) reported an increase in the modulus of elasticity after wire autoclaving, which does not support the findings of the present study. The different temperatures applied in the two studies (371 and 134°C, respectively) may explain this inconsistency. Smith, et al. \(^{[6]}\) suggested that high temperature rise during autoclave procedures could affect the properties of NiTi and TMA wires but these changes were not clinically significant. Smith, et al. \(^{[6]}\) also found that load-deflection curve did not change after sterilization and clinical application of 0.016 inch stainless steel wires. Their results were not in accordance with the outcomes of the present study. However, in the study of Smith, et al., 10 clinicians (8 postgraduate students and 2 orthodontists) used wires during 1-6 months and this duration difference in clinical use between the two studies would make their comparison invalid. These inconsistencies could also be attributable to the relation of the wires and brackets in different systems (standard edgewise and pre-adjusted). Also, different characteristics of orthodontic wires, observed between manufacturers and even between wires of a same package should not be overlooked. \(^{[6,20]}\)

The yield strength can be reported as the stress value corresponding to 0.1 or 0.2% permanent strain. This makes the comparison with previous studies more difficult. Sometimes, the very small amount of permanent deformation used for the determination of yield strength is not specified. \(^{[3,20]}\) Yield strength and fracture force were not significantly different between autoclave and control groups, which was consistent with the findings of Staggers, et al. \(^{[7]}\)

In our study, yield strength and fracture force decreased significantly after sterilization and clinical use. Usually, the main purpose of heat in clinic is to decrease remaining stress in wires and reduce the fracture, but it has no influence on yield strength. In our study, autoclaving, comparable to usual heat in clinic, did not decrease the fracture force and the yield strength but the combination of clinical application and sterilization, however, decreased fracture force and yield strength. \(^{[27]}\) It is not in agreement with Kheir, et al.’s study which showed that heating increases the yield strength of wires but the temperature applied in their study was 371°C which is not consistent to that of our study. \(^{[4]}\)

Although the examined characteristics of wires obtained through these laboratory tests do not necessarily reflect the behavior of the wires under clinical conditions, they provide a reliable basis for the comparison of these wires. \(^{[28]}\) In this study, only one cycle of autoclaving and clinical application was assessed and the effect of repeated cycles was not addressed. Also, the influence of disinfectants on stainless steel was not determined. However, no detrimental changes were seen in the mechanical properties of NiTi wires after cold-solution disinfection. \(^{[16]}\) The impact of sterilization and clinical application on more expensive wires (like NiTi) was not evaluated. Some authors have used isopropyl alcohol \(^{[17]}\) for wire cleaning while others have used iodophor. \(^{[6]}\)

Therefore, there was not any standard method for comparing the results. Although some differences in mechanical properties were found among the groups in this study, the clinical importance might be negligible because of the small size of the difference and the large variability among stainless steel wires. One must also consider the patient’s opinion about recycling because some patients may not be receptive to recycled appliances or wires in their mouth. \(^{[6,27]}\)

CONCLUSION

Autoclaved and recycled wires were softer compared to those of control group, under the circumstances of the present study. Although recycled wires were softer, relatively small differences also in the various properties of available wires have obscured the clinical predictability of their application. There is seemingly no problem in terms of mechanical properties to recycle orthodontic wires.

ACKNOWLEDGEMENT

This study was performed with the cooperation of the Department of Orthodontics, School of Dentistry, Shiraz University of Medical Sciences; Department of Mechanical Engineering, University of Shiraz; and the Department of Physics, Tarbiat Modarres University of Tehran. We would also like to express our sincere gratitude to the Dentistry Department of Science, Research and Technology, Institute of Farzan, and also to Dr. P.S. Eskevvari for revising this manuscript. We appreciate the help of Dr. D. Mehrabani for editorial assistance.

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How to cite this article: Oshagh M, Hematiyan MR, Mohandes Y, Oshagh MR, Pishbin L. Autoclaving and clinical recycling: Effects on mechanical properties of orthodontic wires. Indian J Dent Res 2012;23:638-42.

Source of Support: Nil, Conflict of Interest: There was no conflict of interest in this study.

Announcement

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