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A new technical study on the characteristics of Nickel-Titanium Orthodontic archwires using stimulated infrared thermography

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Abstract

Background: Orthodontic treatment becomes an essential field in dentistry since it creates a healthy, functional "bite," which promotes oral health and general physical health.
Aim: This study aimed to determine the defects in an old nickel-titanium orthodontic wire in the mouth after four weeks as compared to a new one, as well as their impact on orthodontic treatment quality, and to underline the necessity of restoring these defects using various methods.
Methods: For this reason, this research extensively differentiates between two sets of samples of orthodontic arches, both new and used, and quantified their deterioration condition by examining their thermal responses in static and dynamic systems and joule heating.
Results: The results showed that the used archwires bear more surface defects in terms of size and area when compared to unused ones. These affirmative conclusions were obtained with accurate results up to 99%.
Conclusion: The importance of this study lies in the repetition of this technique for three famous companies in this field that increases the quantity of wire used (291 wires used and new), as no previous study has ever experimented with this large number of patients, if this indicates anything, it is the validity followed in this research, which is reflected in the reduction of errors.
Keywords: orthodontics; Nickel Titanium; wire; tomography technic; used; new.

1. Introduction

Currently, the study on the nickel-titanium (NiTi) dental and orthodontic arches entails an assessment of the characteristics of new arches primarily. Only a few studies have focused on understanding the changes that occur when new arches are used intra-orally [1,2]. The current research attempted to bridge this research gap.

Uniformly corroded zones appear in used NiTi wires coupled with traces of organic deposits of substances such as salivary compounds, microorganisms, and other food materials. In a microscopic study, Eliades et al. found a layer of organic substances formation on the surface of NiTi causing roughness on it, which is responsible for undermining the sliding mechanism needed during orthodontic treatment [3].

Infrared Thermography (IRT), commonly known as thermal imaging, is a technology that is essentially based on the assumption that bodies generate magnetic radiations. According to this theoretical concept, some visible light is known to occupy only a narrow spectral range between 0.4 and 0.7 µm. In this case, the ability of the specialised imager to identify signals and radiation within a thermal region of the infrared spectrum light is critical [4].

IRT is used in the field of non-destructive testing to detect defects on the surface and subsurface, as well as to enable online monitoring. The ability to monitor the thermal patterns of the objects being tested is vital to IRT's performance. Typically, subsurface defects exhibit anomalies in thermal patterns, which are utilised as evidence of defect identification. Abnormal thermal patterns on the skin are utilised in medicine to detect underlying clinical illnesses [5,6].

In addition, thermal video is a classic example of a scientific infrared imaging technology. Typically, cameras detect identical radiation, with the exception that it occurs in a long band of the infrared electromagnetic spectrum or aggregately 9000-14000 nm. The images produced by this process are known as thermos-grams. Regardless of the existence of visible illumination, any infrared radiation emissions from an object with a temperature over absolute zero increases visibility of the environment.

It is evident from the preceding sections that all objects emit some form of thermal radiation that characterises their physical state. It has also been demonstrated that using a particular device as a heat signature, it is possible to distinguish between different types of radiation. In line with this, IRT can detect radiation by characterising it in terms of several thermo-physical body properties such as emissivity, then analysing it, as illustrated in figure 1.

Figure 1. Visible Image (Left) and infrared (right) of a transformer of electrical connection.

Corrosion is a destructive process that occurs on all metal surfaces. There are several methods for measuring corrosion in the literature, but only a few of them have examined at approaches that are non-destructive, non-contact, or have direct features for accurately measuring corrosion range. Using a non-destructive infrared imaging device, IRT easily records electromagnetic waves emission from material and biological objects. IRT is a non-destructive test that analyses defects on a material by inducing temperature or using the temperature that is already present, making it a very safe and precise approach to utilise [7]. IRT's usage in medical science has received a lot of attention in the literature, and it's also popular in dentistry [8-10].

In the current study, our object was to detect the size of the area of defects and the number of areas with defects in old wires, which were materials studied, and to analyze the differences between new and old ones. The authors also hoped to be able to identify and quantify the extent of the alterations in maxillary and mandibular arches and reasoned that these alterations would be the surface defects attributable to the oxidation process and/or depositions, as well as subsequent to micro-cracks, porosity, striations, and micro-laminations.

2. Materials and methods

The wires were fabricated by three manufacturers; AZ Dent, American Orthodontic and Ortho Classic, were used in the study. Tests have been conducted on more than 180 patients including both men and women, teenagers and adults, and finally lower and upper arches were included in the study. So, all the variables needed to accomplish this study were presented including the patient's gender, age, type of arch, whether new or old, and the location of the arch in the lower or upper jaw.

2.1 Experimental protocol

Thermograms were extracted prior to heating and at the end of the warm-up phase, and then analysed at their peak temperature in the current study. Two major instruments were utilised to carry out this experiment: an electrode and a FLIR camera. A new technic for detecting defects in orthodontics archwires has been developed using infrared thermography. In this technique, a sample was attached to both of its ends using two connectors. An observation was then made using FLIR thermal imaging cameras clocked at 6.25HZ. During this period, the samples were placed at equilibrium with the ambient temperature.

The arch was held in position using the same devices and connectors, and a power stabilizer was used to traverse electric current through it. A dental arch was then used as an electric current resistance. Through observation of the joule effect, by use of a thermal camera, a dynamic model of studying is possible. A study of the stressed sections, situated between both terminals, in all samples of approximately 50mm, was then performed. A voltage of exactly 1.7v at a 2.4A was then applied to the sections for approximately 15secs and then observed for 35 seconds. Of these, 15 seconds were used to heat the sample and 20 seconds were used for cooling. By the use of thermal transition, it was possible to observe visualize the defects in the material studied. The procedure for observation was as previously reported. Vardasca devised an interpolation-based comparison technique for several areas of interest (ROI) from diverse thermal images to allow comparison between them. In this case, ROIs are aligned semi-automatically.

2.2 Thermal image of an electric current arc in dynamic test

The static analysis would help to concentrate on superficial defects as characterized by variations in emissivity since all the samples were in thermal equilibrium. The medium and the signal measures depended exclusively on the environment and emissivity parameters. Thermograms obtained using thermal cameras would assist in performing quantitative and qualitative analysis. The qualitative analysis would aid in sorting of samples, while the quantitative analysis would aid in classifying samples objectively.

Open-source software (both its image and counting module, "analysis particles") was then be utilized to count faults in each arch under the study, and in measuring, various parameters (see Figures 2). After a thermal holding operation, it will become easier to gather interesting information about the observed defects and their characteristics, including but not limited to area, parameters, and area. The information gathered would then be used to position arches according to their relative differences.

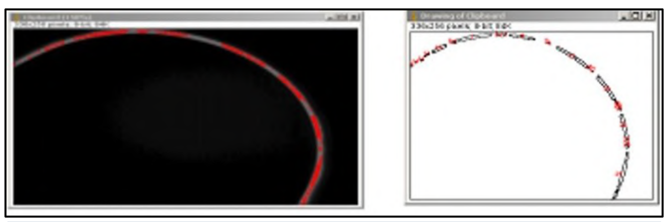

Figure 2. Transformation Using Special Software from Bit-Switching to Clear Image to Begin the Counting of Surface Defects.

As shown in the figure 2, the thermal effect was quite visible when the wire is in the dynamic model. The images avail crucial information on the defect of the wire.

3. Results

Tests have been conducted on more than 180 patients with a sample of 18 patients. The current analysis was limited to the description of thermograms. The focus of the current experiment was to observe the area of the defects and to detect absence/presence therewith.

3.1 In dynamic regime analysis

As previously described, imaging software was used to count the number of faults. The number of defects along with their area of both the used and new archwires are given in table 1.

Table 1. Comparison between new archwires and used archwires.

Status	Used Arch Wires		New Arch Wires	
Sample	Number of Defects	Total Area of Defects	Number of Defects	Total Area of Defects
1	3	84	15	86
2	0	0	24	166
3	4	4	10	18
4	9	13	6	16
5	5	6	19	167
6	5	5	12	41
7	5	14	12	411
8	5	98	23	225
9	2	80	18	385
10	3	3	13	38
11	6	357	9	226
12	2	167	17	226
13	5	45	26	194
14	0	0	15	104
15	3	19	10	205
16	2	77	27	188
17	4	179	24	254
18	8	30	15	153

Initially, this study looked at the validity of previous observations that had shown that the old samples had relatively a high number of defects. Figure 3 shows a true representation of this observation as a histogram. In each of the variants of the sample (material brand and diameter), the ratio of defects of new to used samples is shown to be greater than four in some cases (see samples 8 and 14 in figure 3).

3.2 Analysis by Manufacturer

Figure 4 demonstrate the results of various brands of archwires used in the study when the number of defects is added to their area. The data for new and used samples was then cross, yielding the results shown in figures 5 and 6 for the three manufacturers.

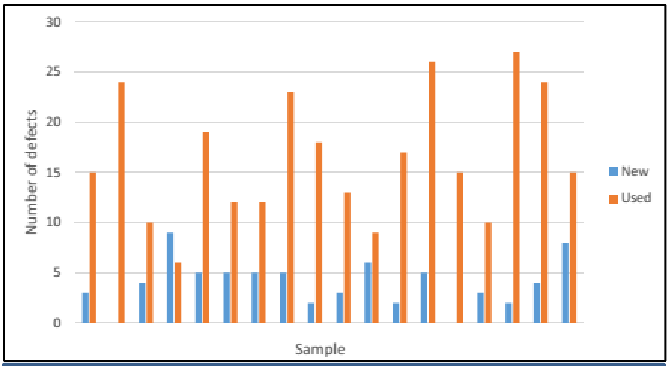

Figure 3. Comparison of number of defects in New and Used samples.

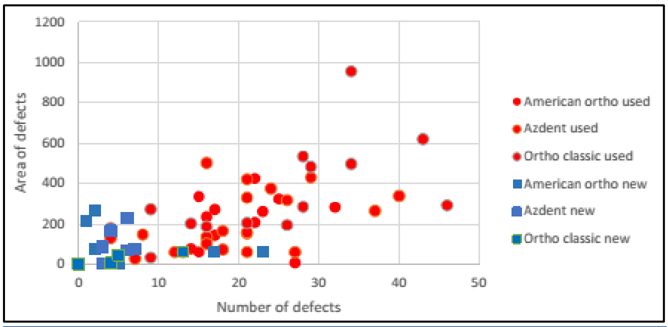

Figure 4. Number of defects vs. area of defects for all three manufactures.

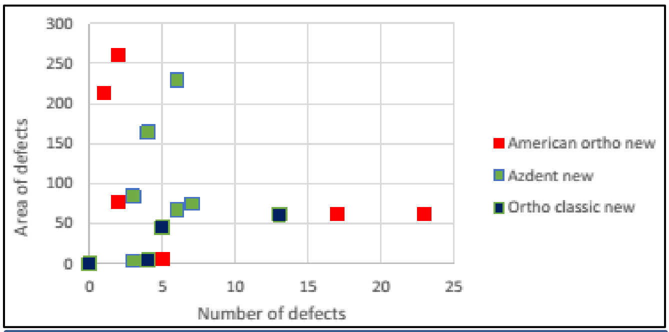

Figure 5. Comparison of all new samples.

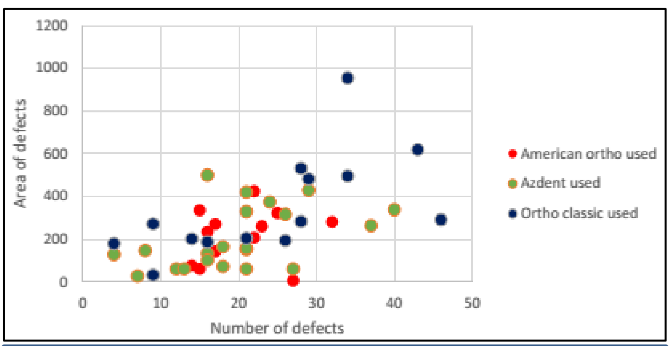

Figure 6. Comparison of all used samples.

3.3 Comparison of all Archwire Types Using a Higher Number of Samples

3.3.1 Comparison based on wires size, patient's gender, age, and arch location

This study demonstrated multiple defects in all types of arch wires compared to new ones. This section adds more parameters that include position, age and gender for more samples. An analysis based on these parameters showed substantial differences and between new and used samples (0.016 and 0.016-0.022 inch of rectangular wire). The figure 7 is a graphical view of the differences that arise between used and new arches, but only for 0.016 pieces of wire for all manufacturers. When different types of arches are analysed, the enormous scale of the variances in terms of mean was also evident. The estimated mean difference between used and new arch wires at 0.022 and 0.016-inch arch wires is depicted in figure 8. The results of the comparison of the area of defects of the samples from three manufacturers are as shown in figure 9. The number of defects in different archwires depending on the patient's gender, age and arch location are depicted in figures 10, 11 and 12, respectively.

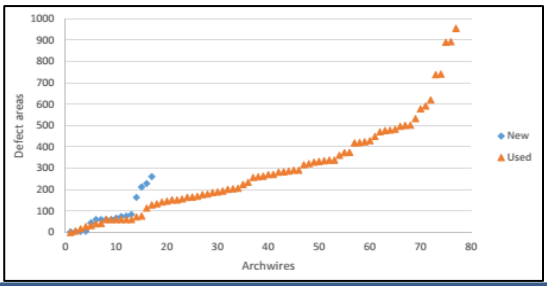

Figure 7. Difference in area of defects between New and Used for 0.016 inch wires.

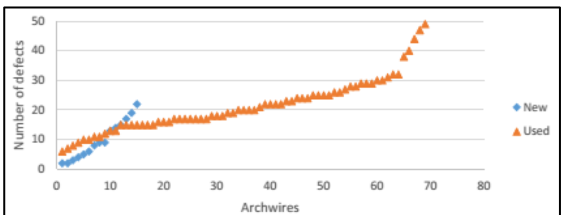

Figure 8. Number of defects between Used and New Archwires in 0.016-0.022 inch.

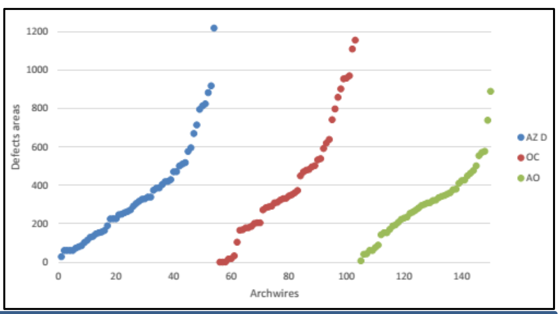

Figure 9. Area of defects of used 0.016 Archwires for all three manufacturers.

4. Discussion

Based on the findings, it is obvious that the number of defects in old archwires is significantly higher than the number of faults in new archwires. Furthermore, greater damage between the archwire's surfaces has an impact on the wire's appearance [3]. In this study, various characteristics were compared, including wire diameters, patient age, gender, and wire position. The findings revealed that there are differences in the archwires used by adults and teenagers, implying that the differences are due to the age disparity. Differences in saliva discharges (i.e., its quality and quantity) may also contribute to the disparity between the upper and lower arches. The reasons for these differences are certainly complex, but the most important element is that the archwires that have already been used are more corroded by salivary secretions, chewing, grinding, and friction potency between the archwires and the braces [10,11]. Despite the surface quality of the same archwire changing slightly and the varying smoothness in the posterior and anterior sections, this study revealed undulated contacts with processing scratches and cracks.

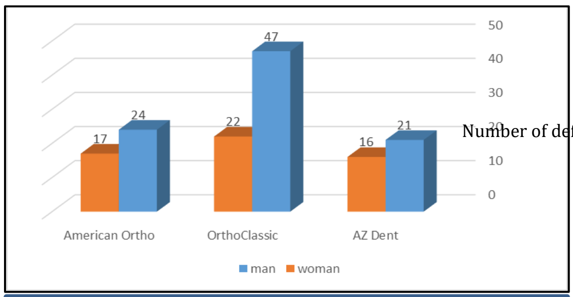

Figure 10. Number of defects based on gender.

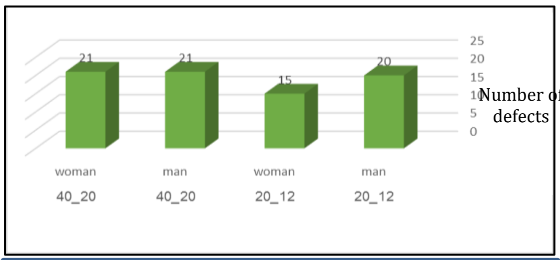

Figure 11. Number of defects based on age.

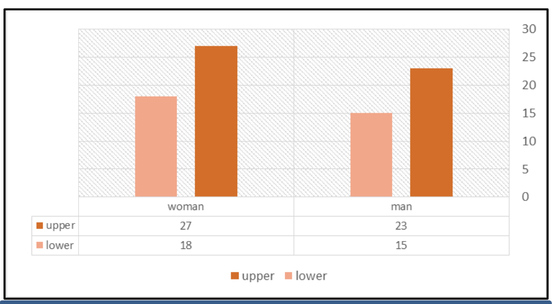

Figure 12. Number of defects based on arch location.

Microscopic analysis of NiTi wire exposed to static anodic polarity, (i.e., simulations of the oral environment) validated pitting and normal fields of corrosion, as well as the most crucial alterations in the surface morphology proceed by anodic dissolution. These outcomes of this study concur with the previous studies [3] demonstrated that the mineral-rich coating was suspected to convey better resistance to decay. Furthermore, it could also be the justification to the reason that metallic orthodontic devices indicate different outcomes in vivo in comparison with those in vitro experiment approaches [12]. Additionally, the extreme leaching of metal ions from orthodontic struts and NiTi cable were observed on the 30 days interval (trials tested before, at 30days, three months, and six months interim). As indicated in numerous studies [13], the likely justification meant for this occurrence could be the creation of crystal-like precipitates and very thin biofilms on trucks exterior surfaces, therefore, providing better protection.

The results of this study are in accordance with previous studies, which indicated that the discharge of metal ions from brackets and arch cables were implemented under clinical utilization circumstances. The quantity of metal ions discharged indicated an inclement when orthodontic devices remained exposed towards fluoride reactive agents throughout the span of utilization. Metal ions discharge furthermore would have an effect of oxidative stress and genotoxic harm to buccal mucosal tissues unattended for a period of time. Nonetheless, it is important to consider that a number of variables are accountable for total effect in vivo circumstances.

Though the risk of caries occurring during orthodontic treatment is low (rational arch arrangement, perfect enamel feature, no prevailing carious lesions, and repair of perfect mouth hygiene eminence), non-fluoridated toothpaste and mouth cleans, as well as changes in the exterior characteristics of brackets and arch wires, may be of great benefit in reducing metal ions discharged [14].

In comparison to the non-fluoridated set, the volume of metal ions discharged demonstrated a conclusive inclement in the fluoridated wire and brackets set. Usually, the effects of diet on changes in the surface appearances of orthodontic devices are difficult to distinguish, and food vary in origin and composition, so it breaks down and depreciates rather fast.

Furthermore, another research was scrutinizing the impact of nutrition on corrosion nature and frictional resilience of the orthodontic wires utilized Food Simulating Liquids (FSLs) to imitate the authentic type of food. Citric acid, heptane, and ethanol were utilized in the position of fatty diets, citric acid types of fruits, and alcoholic beverages. It was proven that the citric acid types of food indicated significant alterations impacting the corrosion resilience and frictional characteristics of the archwire. This specific concept was challenging to prove in some type of patients, which formed the basis for proposing an in-depth analysis for better understanding [15].

Endorsing the outcomes of this research, Parvizi and Rock stated that all tested NiTi arch wires indicated some grade of perpetual deformation, being importantly expressive only for heat stimulated NiTi arch wires [15]. In the midst of verified super plastics NiTi, the total recovery of the first configuration was kept between 88 and 96%, while for the heat simulated NiTi arch wires, it was maintained between 71 and 82% [15].

Additionally, on the other side, the outcome of this particular research was steady as indicated by Sakima et al. [16] which via Force System Identification (FSI), indicated that the Neo Sentalloy NiTi F200 (GAC) arch wires we the one presented the unloading plateaus amidst the maximum loadings, therefore, resulting to the most inflexible archwire in this study that is adapted to our research in that the examined NiTi intra-orally utilized archwire exposed clear signs of similar corrosions with the existence of a small field of organic deposits. The electron microscopic examination of the archwire intra-orally used piloted by Eliades et al. [3] have indicated the creation of a layer of organic matter on the exterior surface of NiTi arch wires may result into the amplified coarseness of the surface and indirectly affect the sliding mechanism.

The microscopic investigation of the intra-orally used arch wires was steered in a number of studies [17]. The authors observed that a loss of the beautiful cover is directly comparable to the time of intra-oral utilization. Elavyan [17] observed a destruction of the film coating in a proportion of 26% after 33 days of usage. The outcomes of this study are in line with Elavyan observations [17]: the damage of the coating being directly proportional to the period of exposure, albeit crucial damage was detected even when utilizing the arch wire for a period; less than one month in an intraoral atmosphere. The mechanical nature of NiTi arch wire is pretentious after only four weeks of intra-oral usage.

5. Conclusion

This study examined the thermal reactions of two sets of orthodontic arches, both new and used, and assessed their deterioration by analyzing their thermal responses in static and dynamic systems as well as joule heating. The dynamic study expressly stated that the new samples had less defects than the used samples, as expected. It has been established that stimulated infrared thermography is a reliable method of investigation that allowed to detect changes in the orthodontic arches. The source of these modifications, on the other hand, has never been established. The main findings are summarized below:

1. Used arch wires bear more surface defects in terms of size and area when compared to unused ones.
2. Arches used by females showed more defects to those won by males.
3. Ortho Classic brand had higher defects compared to that of other manufacturers.

4. In comparison with the other two manufacturers, the Ortho Classic presented the highest quantity of defects for the 0.016-inch mode.
5. Used adult archwires displayed an advanced number of defects in comparison to those used by teenagers.

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