REVIEW ARTICLE

Volume 19 Issue 2 2024

DOI: 10.21315/aos2024.1902.RV02

ARTICLE INFO

Submitted: 21/11/2023
Accepted: 14/09/2024
Online: 23/12/2024

Understanding the Effects of Sterilisation Methods on Orthodontic Archwires Properties: A Review

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To cite this article: Abood AZ, SNFM Noor, FM Suhaimi, FAAH Al-Fatlawi, NAA Shafiai (2024). Understanding the effects of sterilisation methods on orthodontic archwires properties: A review. *Arch Orofac Sci*, **19**(2): 79–95. https://doi.org/10.21315/aos2024.1902.RV02

To link to this article: https://doi.org/10.21315/aos2024.1902.RV02

ABSTRACT

Sterilisation is the removal of all microorganisms, vegetative or spore-forming, from an article, surface or medium that can be accomplished through steam autoclaving, dry heat and cold solution following strict guidelines for efficient archwire sterilisation. Orthodontic archwire sterilisation is a concern because patients are often exposed to contaminated dental products. Thus, new and used arch wires will not show significant differences in terms of properties while in usage. This article presents a review of the sterilisation methods effects on the characteristics and properties of several types of orthodontic archwires including stainless steel (SS), nickel-titanium (NiTi), copper NiTi, beta titanium (β-Ti), heat-activated NiTi and titanium molybdenum (TiMb). Available records in "all databases" of Web of Science, PubMed, ScienceDirect, Scopus and Elsevier were searched, and other studies were manually searched using keywords, retrieved and compiled. Studies related to sterilisation of orthodontic archwires such as archwire type, sterilisation method, characterisation techniques and mechanical properties were summarised based on articles published from 1st July 2015 to 29th February 2024, and it is shown that the characteristics of orthodontic archwires may be affected by sterilisation techniques. Heat sterilisation can change the load-deflection properties of some wires, while the chemical composition and surface structures of archwires are unchanged. After sterilisation, the number of nickel ions released from the archwires does not increase significantly. The findings support the idea that archwire sterilisation procedures are an effective infection control treatment and facilitate the mechanical characterisation of orthodontic archwires.

Keywords: *Arch wire; characterisations; infection control; mechanical properties; sterilisation*

INTRODUCTION

Sterilisation removes all microorganisms, vegetative or spore-forming, from an article, surface or medium (CDC, 2003). The American Dental Association Council on Dental Materials states that the techniques for sterilising metal and heat-resistant instruments with an autoclave, chemical vapour or dry heat are appropriate (ADA, 2015). Additionally, the Centres for Disease Control and Prevention (CDC) recommends sterilising any tool that comes into contact with the oral mucosa (Rutala *et al.*, 2008). Since the 1980s, the impact of sterilisation on orthodontic wires either coated or non-coated has been investigated, but the outcomes of these studies conflicted with one another; some studies reported mechanical changes such as reduction in tensile strength of superelastic nickel-titanium (NiTi) wires tensile strength after autoclave sterilisation and clinical reuse (Bavikati *et al.*, 2016), and reduction of aesthetic wires unloading plateau after cold sterilisation (Mousavi *et al.*, 2018). However, other researchers reported that the shape memory property was not affected by clinical use or after one sterilisation cycle (da Silva Vieira *et al.*, 2019), and no significant differences between new and sterilised orthodontic archwires highlighting that sterilisation process do not affect archwire tensile strength (Kaur *et al.*, 2024).

Sterilisation may lead to the production of desirable or undesirable biomechanical forces affecting progressive tooth movement during treatment. Archwires are commonly marketed, and cross-contamination is prevented by wrapping the archwires individually in separate bags (Ardeshna *et al.*, 2023). Approximately 12% of the unused orthodontic archwires are not subjected to sterilisation procedures and may trigger bacterial growth when cultured (Pernier *et al.*, 2005). Hence, the manufacturer's instructions on the packaging recommend sterilisation before utilising the archwire (Pernier *et al.*, 2005).

Orthodontic archwires composed of diverse alloys are utilised throughout all phases of therapy. The topographical features of an orthodontic archwire play a fundamental role in determining its mechanical capabilities, aesthetic outcomes, corrosion behaviour and biocompatibility (Daems *et al.*, 2009). The resulting surface structure is determined by the specific alloy employed, the intricate manufacturing procedure, and the treatment applied to achieve the desired surface finish (Bourauel *et al.*, 1998). Stainless steel (SS), NiTi and beta-titanium (β-Ti) archwire usage is prevalent in orthodontics practice. Surface roughness may alter the frictional coefficient by interfering with the correct bracket sliding along the archwire (Downing *et al.*, 1994). Nevertheless, it was shown that sterilisation using autoclave has no effect on the archwire corrosion resistance (Barros & Gomes, 2021), while other study found significant differences in the forces exerted by the various superelastic NiTi wires after clinical use and sterilisation (Alcaraz *et al.*, 2023). Different sterilisation techniques were tested on round 0.016 in orthodontic wires that is commonly used for initial levelling and alignment to determine their impact on tensile strength, and results showed these tensile properties were not significant among the wires tested creating awareness that orthodontic wires can be autoclaved for ensuring patient safety (Kaur *et al.*, 2024). These contradictory findings highlight the need for identifying whether sterilisation may potentially change these characteristics. Limited research on sterilisation's impact on orthodontic archwire properties with contradictory results is available. Hence, it is crucial to discuss these topics in a review further to enhance knowledge related to this issue. This study was aimed to determine the impact of various sterilisation techniques on orthodontic archwires physical and mechanical characteristics.

MATERIAL AND METHODS

Study Design and Search Strategy

An electronic search for articles was performed on 20th December 2022, and English-language articles published from 1st July 2015 to 29th February 2024 in all databases of Web of Science, PubMed, ScienceDirect, Scopus and Elsevier were searched. Other studies were manually searched and retrieved from the reference lists of related articles. The data were assembled using keywords such as archwires, sterilisation, characterisations and mechanical properties. The title and abstract of derived articles were analysed, and data were extracted by the authors such that the topic could be sufficiently summarised in a narrative style. A reference list of chosen papers was hand-searched for further related articles.

Identifying Research Questions

The study question was developed in line with the aim of the present study: "What are the effects of various methods of sterilisation on the characteristics and mechanical properties of different types of archwires?". The arch wires under study were SS, NiTi, copper NiTi (CuNiTi), β-Ti, heat-activated NiTi and titanium molybdenum (TiMb).

Inclusion and Exclusion Criteria

A total of 2,990 articles were identified in the databases. Many articles (N = 100) were excluded because they were retrieved from other sources, such as textbooks, and the remaining 2,890 articles were selected and used in studying archwires and methods of sterilisation in orthodontics. Additional articles were removed because of duplication (N = 668) and irrelevant titles and abstracts (N = 2,137). Articles that studied archwires for other fields rather than orthodontics were also excluded (N = 39). A total of 24 studies were chosen based on their adherence to methodological study criteria, and they were conducted between 2015 and 2024, and analysis using Visualisation of Scientific (VOS) Landscapes version 1.6.20 (VOSviewer, Leiden University) were performed to identify and extract the important clusters related to the mentioned studies by constructing and visualisation of network occurrences of important terms from the scientific records.

The data collected from these studies includes several factors such as experimental groups, writers, year, title, analysis techniques, and significant outcome. In addition, specific studies were used as references to help with the transition process.

RESULTS

After removing duplicates, two authors (AZA and SNF) individually sorted the titles and abstracts. The full text of the remaining studies was read, and concerned studies according to the qualification criteria were selected. A third author (FAA) eliminates any disagreements between the reviewers. Two authors (AZA and SNF) individually extracted the following information from the studies: author(s), year of publication, types of arch wire, sterilisation methods, time of sterilisation, evaluation properties, and results. Any disagreement relating to this process was resolved by a third author (FAA). In the final analysis, this review included 24 studies that met the inclusion criteria and were selected from a total of 46 articles published between 2015 and 2024. In research, the process of synthesising results is crucial, especially in academic studies, scientific research, and data analysis using proper research methodology and focusing on relevant topics (Snyder, 2019). It involves combining and integrating findings from various sources, experiments, or studies to draw meaningful conclusions, identify patterns, and derive insights. The aim of synthesising results is to create a cohesive and comprehensive understanding of a particular topic or research question as shown in the Fig. 1.

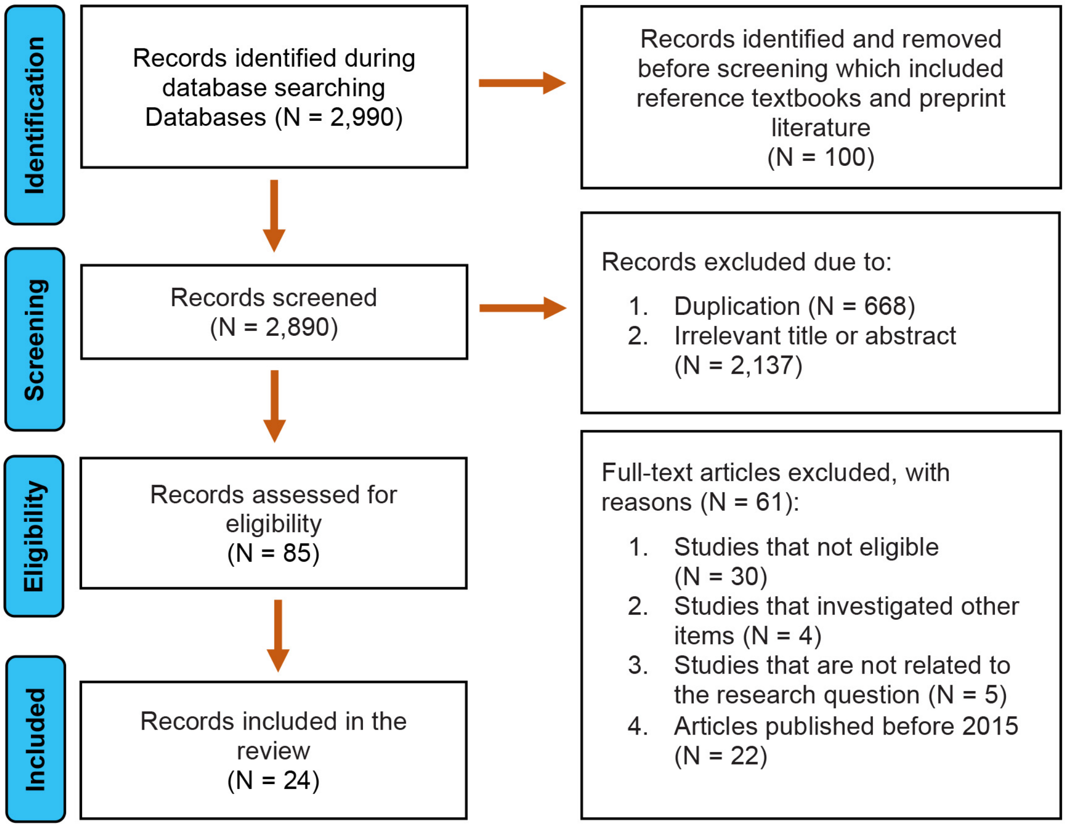

Fig. 1 Flowchart of research based on the PRISMA protocol (Page *et al.*, 2021).

Pre-sterilisation Cleaning

All archwires and instruments or tools contaminated with blood, saliva or other impurities must be debrided by hand washing these instruments with detergents, soap and soft plastic brushes (Rohit *et al.*, 2016). Ultrasonic cleaners and instrument washers are used normally performed between 10 minutes to 20 minutes depending on the type of tools loaded. Then, the tools are dried with absorbent paper and air-drying equipment (Khatri *et al.*, 2017; Jankare *et al.*, 2019). Special attention should be given to the joints, hinges and tips of the tools that may need pre-wetting with proper oil or emulsion as corrosion may occur in these areas, especially when other sterilisation techniques are used (Reddy *et al.*, 2011). Cross-contamination can be prevented by storing sterilised archwire in a dry environment.

Heat Sterilisation

This method has a wide range of sterilisation protocols as shown in Table 1. Dry heat using hot air oven causes oxidative stress and toxic effects that damage bacterial cells by destroying the oxidative constituents and inducing the denaturation of bacterial proteins. A holding period of 160 °C (320 °F) at 60 minutes is used in sterilising archwires. Hot air sterilisation includes cycles at 190 °C for 6 minutes to 12 minutes and is also known as rapid dry hot air sterilisation (DHS). Moist heat sterilisation using an autoclave causes the denaturation of proteins and coagulation of bacterial enzymes. Steam sterilisation is the most widely used sterilisation method and is considered the gold standard. The basic principle states that when the pressure inside a closed chamber increase, the temperature at which water boils also increases. The traditional

Table 1 Different methods of heat sterilisation for archwires

Method of sterilisation	Temperature and duration	Advantages	Disadvantages
Dry heat using oven	160 °C for 60 minutes	No corrosion on arch wires High capacity at a low cost Archwires are dry after the cycle	Duration of sterilisation is longer
Rapid dry heat sterilisation	190 °C for 6–12 minutes	No corrosion on arch wires Short-term cycle Archwires are dry after the cycle	High cost per capacity of low loading
Moist heat using steam under pressure (Autoclave)	Pressure ranges from 15–20 psi at 121 °C to 134 °C with holding time of 15–20 minutes at 121 °C	Excellent penetration Time saving	Non-stainless-steel elements may corrode
Rapid cycle using steam under pressure (Autoclave)	Pressure ranges from 15–20 psi at 134 °C for 3 minutes	Good sterilisation	

technique for autoclaving using moist heat includes pressure within a range of 15 psi to 20 psi at 121 °C to 134 °C. A holding time of 15 minutes to 21 minutes at 121 °C (traditional technique) or 3 minutes at 134 °C (rapid cycle) is necessary for suitable sterilisation. The cycle from the beginning of sterilisation to the next cooling stage is completed within 45 minutes to 60 minutes (Rohit *et al.*, 2016).

Cold Sterilisation

This method uses chemicals and solvents, such as formaldehyde, glutaraldehyde and alcohol, without additional temperature treatment. Heat-sensitive instruments are immersed in antimicrobial fluids, such as glutaraldehyde or concentrated hydrogen peroxide, to kill bacteria, fungi, mycobacteria, or viruses. Formaldehyde from aldehyde groups acts actively against amino groups in protein molecules. Formalin at a concentration of 10% (weight per volume, w/v) and 0.5% (w/v) sodium tetraborate are commonly used in sterilising metallic-based instruments. Formaldehyde in its aqueous form exerts bactericidal and sporicidal effects and is lethal to viruses (Padmini *et al.*, 2017). It is used in 2% (w/v) glutaraldehyde ($C_5H_8O_2$) sterilisation methods worldwide. This solution has a molecular weight of 100.12 g/mol and exists as a colourless oil with a boiling point of 187 °C to 189 °C. It is soluble in water, and 2% glutaraldehyde produces a mildly acidic solution that effectively kills microorganisms at a pH of 8.5 (Khatri *et al.*, 2017) and is activated before the addition of adequate buffers. It is the most common high-level disinfectant in dentistry and the most efficient method for inactivating bacterial spores. The period of sterilisation is about 6 hours to 10 hours at room temperature (Khatri *et al.*, 2017). Alcohol is an excellent antiseptic for the skin and a valuable disinfectant for medical instruments. Ethyl and isopropyl alcohol are often used, but isopropyl alcohol is preferred as a fat solvent because it has a stronger bactericidal effect and is less volatile. It is active at a concentration of 50% to 70% (w/v). It denatures proteins and lipids and leads to cell membrane disintegration. Lipid-enveloped virus families are susceptible to many disinfectants, including alcohol (Table 2).

Table 2 Types of chemical solutions and reagents used in cold sterilisation methods

Chemical sterilisation	Advantages	Disadvantages
Formaldehyde (10% formalin containing 0.5% sodium)	Sterilise metallic instruments	Gas vapour released is irritating and toxic May retain smell on the disinfected surface
Glutaraldehyde 2%	Sterilise metallic instruments	Long immersion duration Release odour May irritate mucous membrane (eyes)
Alcohol 50%–70%	Sterilise orthodontic archwires	Lack of sporicidal activity May cause metal corrosion

Orthodontic Archwire Sterilisation

Research into the effects of sterilisation on the properties of orthodontic archwires produces variable results since 1980s towards 2024. Earlier studies from 1980s to 1990s have investigated the tensile strength of NiTi wires after three cycles of sterilisation using three different methods, namely, dry heat, autoclaving and chemical vapour showed that these methods did not affect the tensile strength of the NiTi wires (Mayhew & Kusy, 1988). A similar study assessed the influence of cold sterilisation solutions on NiTi wires and showed that following three cycles of cold sterilisation, the physical characteristics of the wires were not altered (Buckthal & Kusy, 1988). During this period, NiTi archwires are widely reused for orthodontic treatment because of their high flexibility and spring back and can be perfectly used in alignment without any loops and can be reused since they are expensive (Kapila *et al.*, 1991; Crotty *et al.*, 1996).

As the trends for steam autoclaving increased during the years, earlier research that adopted the dry heat or cold sterilisation has shown minimal or no effect on the mechanical properties of SS, NiTi and titanium archwires (Smith *et al.*, 1992). Stagger and co-workers discovered that there is no significant change in the mean tensile properties of orthodontic SS arch wires after five cycles of sterilisation with an autoclave or ethylene oxide sterilisation (Staggers & Margeson, 1993).

As the years progress into 2000s, opposing outcomes on the influence of sterilisation methods on the surface parameters and mechanical properties of the NiTi archwires have been reported where steam and dry-heat sterilisation alter the mechanical properties of superelastic NiTi arch wires, and sterilisation has no negative impact on their surfaces and mechanical properties (Pernier *et al.*, 2005; Alavi *et al.*, 2009). Furthermore, no significant difference in nickel ion concentration in saliva was observed after sterilisation with dry heat or autoclave sterilisation of recycled NiTi wires (Poosti *et al.*, 2009). Heat sterilisation and other cycling processes do not have an adverse influence on the elastic moduli, topographic surfaces or tensile strength of nitinol or titanium archwires (Khatri *et al.*, 2017).

Based on the selected studies from 2015 towards 2024, the use of steam autoclave as sterilising methods for orthodontic archwires tend to increase and comparison were made between cold sterilisation using chemical reagents as shown in Table 3. The adaptation of using recycle and coated archwires in the laboratory and also archwires that were previously used by patients highlights the importance of sterilisation protocols in the clinical setting. Table 3 shows the influence of different types of recycling processes on the mechanical properties and topographic surfaces of nitinol or NiTi wire and the influences of different sterilisation methods on other types of archwires. This finding is supported by the network visualisation obtained from the Visualisation of Scientific (VOS) Landscapes version 1.6.20 (VOSviewer, Leiden University) as shown in Fig. 2. There are 38 terms related to the network visualisation with 314 links and a total link strength of 1,287. For cluster 1 (red) there are items with keywords like "archwire", "change" and "autoclaving", whereas in cluster 2 (green), the "sterilisation", "wire" and "effect" have the highest density. There are four items in cluster 3 (blue) with "test" and "significant difference" became the keywords with highest occurrences. These clusters co-occurrence extracted from the 24 scientific articles showed newer studies trends adopted nickel titanium more compared to SS archwires as shown by the larger densities of nickel titanium.

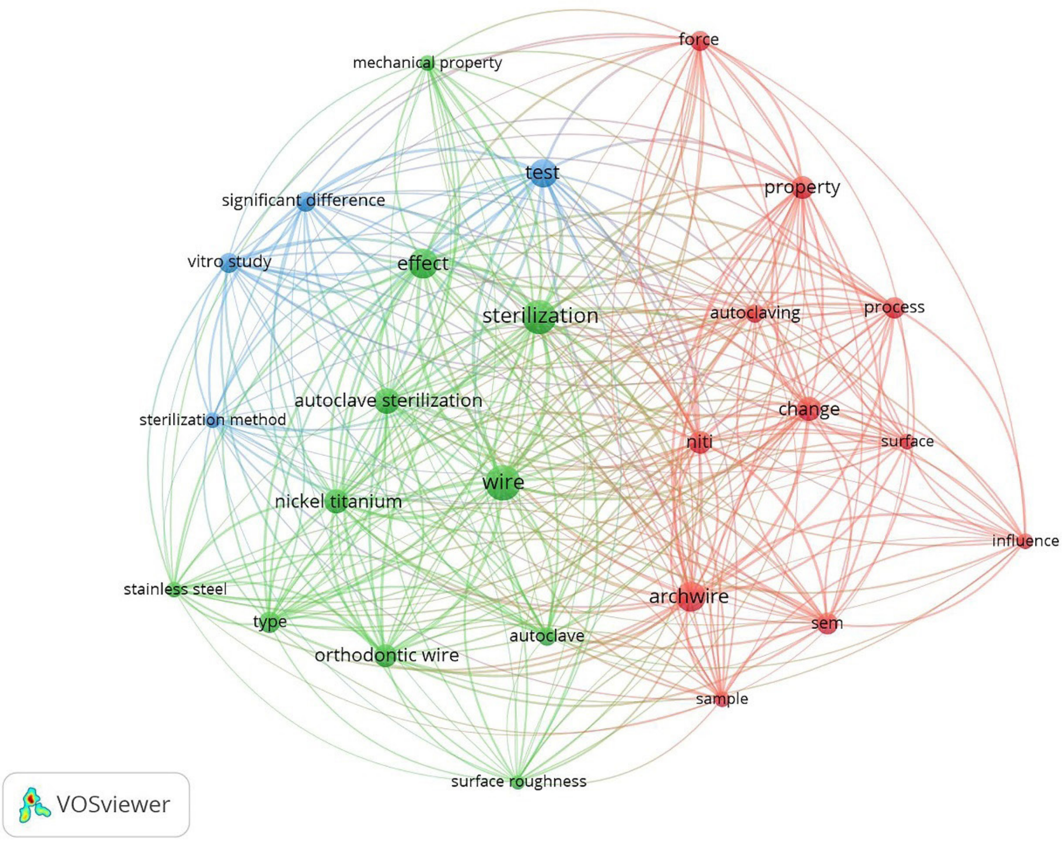

Fig. 2 The visualisation of scientific terms based on the VOSviewer (version 1.6.20).

Table 3 Influence of different types of sterilisation methods on orthodontic archwires

No	Author	Sterilisation methods	Tested archwire	Evaluated parameters	Outcome
1	Petrov, Andreeva *et al*. (2015)	Type B autoclave at 121 °C for 21 minutes	SS, NiTi, β-Ti, CuNiTi	Archwire composition using SEM-EDS	Autoclaving process did not cause significant changes in crystal structure and chemical composition of archwires.
2	Petrov, Terzieva *et al*. (2015)	Type B autoclave at 121 °C for 21 minutes	CuNiTi	Morphological features and chemical profile of used archwire	Autoclaving processes have no effect on the properties of the archwires, allowing orthodontists to ensure the maximum safety of their patients.
3	Isac *et al*. (2015)	Autoclave at 134 °C for 18 minutes at 2.1 kg/cm^2	SS, NiTi and β-Ti	Surface roughness and surface topography	Surface characteristics of archwires were not significantly affected by autoclave sterilisation either after clinical use or as-received.
4	Isac *et al*. (2016)	Autoclave at 134 °C for 18 minutes at 2.1 kg/cm^2	SS, NiTi and β-Ti	Ultimate tensile strength, elastic modulus and yield strength	Mechanical properties did not change for as-received archwires. The tensile strength of all archwires decreased significantly after intraoral exposure.
5	Bavikati *et al*. (2016)	Autoclave sterilisation at 121 °C with 15–20 psi for 20 minutes	Superelastic NiTi from different manufacturers	Physical and mechanical properties	Superelastic NiTi wires tensile strength can be reduced by autoclave sterilisation and clinical reuse. Autoclave sterilisation can reduce the surface topography of the clinically recycled superelastic NiTi wire.
6	Petrov *et al*. (2017)	Type B autoclave at 121 °C for 21 minutes	SS, NiTi, Ti-Mb, heat-activated-NiTi, CuNiTi	Surface structure and chemical composition using XRD, DSC, SEM-EDS	No significant alteration in the chemical composition or surface structure of the archwires.
7	Shamaa (2018)	Autoclave at 134 °C for 18 minutes	Teflon-coated NiTi, un-coated NiTi, aesthetic NiTi	Surface profiles and three-bending point	Surface roughness and mechanical properties of unused NiTi wires may change after autoclave procedures.
8	Sayed *et al*. (2018)	Steam autoclave at 134 °C for 18 minutes at 2.1 kg/cm Chemical sterilisation through immersion in 1% hydrogen peroxide for 30 minutes	NiTi, CuNiTi	Surface topography and tensile properties	Autoclave and chemical sterilisation did not affect wires properties after one cycle. However, used and recycled wires properties were affected after autoclave sterilisation.
9	Mousavi *et al*. (2018)	Cold sterilisation through immersion in 2.45% glutaraldehyde for 10 hours Hot sterilisation using autoclave at 121 °C with 15 psi for 20 minutes	Aesthetic coated arch wires	Load deflection characteristics using universal testing machine	Cold sterilisation may result in reduction of unloading plateau, but sterilisation usually does not affect loading or hysteresis plateaus.

(*continued on next page*)

Table 3 (*Continued*)

No	Author	Sterilisation methods	Tested archwire	Evaluated parameters	Outcome
10	Zarif Najafi & Gavareshki (2019)	Autoclave at 121 °C with 15 psi for 30 minutes	Superelastic NiTi, β-Ti and CuNiTi	Load deflections with and without intra oral aging	NiTi and CuNiTi wire showed significant reduction in the deactivation mean load in most deflections compared with the control after all autoclaving condition. Sterilisation did not influence the deactivation mean load in β-Ti wire compared with the control.
11	da Silva Vieira *et al*. (2019)	Steam heat (autoclave) at 121°C for 20 minutes at 15–20 psi with and without clinical use	Thermally activated NiTi (NeoSentalloy, CuNiTi , Flexy Thermal, Heat Activated NiTi)	Differential scanning calorimetry	The shape memory property was not affected by clinical use or after one sterilisation cycle.
12	Shamohammadi *et al*. (2019)	Cold sterilisation using 2.45% glutaraldehyde Hot sterilisation using autoclaving at 134 °C for 18 minutes	Coated and uncoated NiTi	Surface roughness and topography using SEM, AFM, profilometry	No significant differences of studies properties between coated and uncoated NiTi. Surface roughness of coated wires may increase after autoclave procedures.
13	Mousavi *et al*. (2020)	Hot sterilisation using autoclaving at 134 °C for 18 minutes Cold sterilisation using 2.45% glutaraldehyde	Aesthetic coated archwires	Rate of coating loss using digital stereomicroscope and SEM	Glutaraldehyde and autoclave sterilisation may not affect the average speed of coating loss in all brands since not many changes were observed.
14	Yadav *et al*. (2020)	Reuse archwire after cold sterilisation using 2% acidic glutaraldehyde for 10 hours	NiTi alloy	Load deflection properties and surface characterisation	Minimal surface changes and no significant changes of loading and unloading properties of reused NiTi wires.
15	Suresh & Kalidass (2020)	Autoclave at 134 °C for 18 minutes	SS, superelastic NiTi, and Neo Sentalloy with ion guard, TiMo alloy and Timolium	Surface parameters using SEM and AFM, and mechanical properties	Surface roughness and mechanical properties of selected orthodontic wires are not affected by autoclaving.
16	Noorollahian & Zakizade (2021)	Immersion in 10% hydrochloric acid for 1 minute Immersion in 5.25% sodium hypochlorite for 5 minutes Steam autoclave at 121 °C for 10 minutes	NiTi open coils	Unloading force	No significant changes of NiTi open spring force properties following the sterilisation regime either at one or three repeated cycles.
17	Singaraju *et al*. (2021)	Autoclave at 121 °C and 15 to 20 psi for 20 minutes Dry heat sterilisation at 160 °C for 2 hours Cold sterilisation using 2.4% glutaraldehyde for 20 minutes	CuNiTi wires and superelasticity with shape memory	Load deflection	Stiffness of superelastic copper NiTi wire may increase after autoclave and dry heat sterilisation.

(*continued on next page*)

Table 3 (*Continued*)

No	Author	Sterilisation methods	Tested archwire	Evaluated parameters	Outcome
18	Stoyanova-Ivanova *et al*. (2021)	Autoclave at 121 °C for 60 minutes full cycle	CuNiTi arch wire	Chemical structure, elemental analysis and topography surface properties	Chemical compositions are not altered after autoclaving and after clinical usage for first phase orthodontic treatment.
19	Barros & Gomes (2021)	Autoclave at 121 °C and 15–20 psi for 20 minutes	NiTi and CuNiTi	Corrosion resistance challenge before and after sterilisation	Autoclaving of these wires before and after corrosion did not influence the passivated oxide layer, hence not affecting corrosion resistance.
20	Canongia *et al*. (2021)	Chlorhexidine, sodium hypochlorite, 70% alcohol) followed by immersion in enzymatic detergent	NiTi, SS, TMA	Archwires surface properties before and after immersion	Microbial load was reduced leading to improved surface properties of the wires.
21	Ardeshna *et al*. (2023)	Steam autoclave at 121 °C and 15 psi for 30 minutes Dry heat autoclave at 121 °C and 15 psi for 30 minutes UV light for 15 mins at both sides 70% ethanol for 1– 3 minutes 2% glutaraldehyde overnight	SS and NiTi and wires	Determine the bacterial contamination on the orthodontic properties of braces	The orthodontic wire received from the manufacturer showed bacterial contamination. All the sterilisation methods tested, including UV light, were efficient in eliminating bacterial contamination on the orthodontic braces. UV light does not alter material properties.
22	Noorollahian & Khaleghi (2023)	Immersion in 10% hydrochloric acid for 1 minute Immersion in 5.25% sodium hypochlorite for 5 minutes Steam autoclave at 134 °C for 10 minutes	NiTi archwire	Force characteristics for repeated sterilisation cycles	NiTi closed coils can be reused, and these immersion protocol can be recommended as a cleaning method prior to autoclave sterilisation.
23	Alcaraz *et al*. (2023)	Heat sterilisation	NiTi	Load deflection	Significant differences were found in forces exerted by various superelastic (SE) NiTi wires after clinical use and sterilisation.
24	Kaur *et al*. (2024)	Different sterilisation techniques: Autoclave, dry heat, ethylene oxide and glutaraldehyde	β-Ti, SS, Australian SS, CuNiTi, NiTi	Tensile strength	No significant differences between new and sterilised orthodontic archwires highlighting that sterilisation process do not affect archwire tensile strength.

Notes: SS (stainless steel); NiTi (nickel titanium); TMA (titanium-molybdenum alloy); CuNiTi (copper nickel titanium); β-Ti (beta titanium); TiMo (Titanium molybdenum)

DISCUSSION

Heat sterilisation methods using high temperatures and cold sterilisation are commonly used for orthodontic archwires. As precautionary measures, cleaning the archwires before the sterilisation process ensures patient safety. The six types of archwires commonly used in the sterilisation process for the research activities based on the selected 24 articles, and as selected in the inclusion criteria are SS, NiTi, CuNiTi, β-Ti, heat-activated NiTi and TiMb.

The process of sterilisation and/or disinfection encompasses the use of disinfectant either alone or in conjunction with a steam autoclave, dry heat, or cold solution sterilisation methods. There were no significant variations of clinical significance observed between the sterilised new and the old archwires. The surface characteristics of archwires were not significantly affected by autoclave sterilisation after clinical use (Isac *et al.*, 2015). However, the superelastic NiTi wires tensile strength can be reduced by autoclave sterilisation and clinical reuse (Bavikati *et al.*, 2016), and the surface topography and tensile properties of used and recycled NiTi and CuNiTi wires' properties were affected after autoclave sterilisation (Sayed *et al.*, 2018).

The direction in which the load is applied to the archwire and the specific segment of the archwire being tested can lead to inherent variations in the generated loads for certain types of archwires which highlights the significance of considering these factors when evaluating the archwire performance. The influence of high temperatures from the autoclave or dry heat steriliser on archwires is a plausible consideration. If this effect exists, its magnitude is modest, hence, the clinical significance is minimal.

Many of the studies utilised the archwires that are commonly used in the clinical settings, namely NiTi, Nitinol, Titanal, SS, β-Ti, CuNiTi, supereleastic NiTi, and recently, the aesthetic-coated archwires, to assess the effects of sterilisation methods on archwires. The evaluated parameters involved were surface morphologies, mechanical, chemical and physical characteristics, and the functional properties of these archwires. As shown in Fig. 2, the NiTi orthodontic archwires were frequently used to assess the effects of sterilisation in recent years. The surface roughness and mechanical properties of unused NiTi wires either Teflon-coated NiTi, un-coated NiTi, or aesthetic NiTi may change after the autoclave procedures (Shamaa, 2018). The hot and cold sterilisation may lead to the increase surface roughness of coated and uncoated NiTi archwires (Shamohammadi *et al.*, 2019). Nevertheless, when NiTi open coils were used in cold sterilisation and steam autoclave, the unloading force of these NiTi open coils did not show significant changes following the sterilisation regime either at one or three repeated cycles (Noorollahian & Zakizade, 2021).

The mechanical properties of different brands of superelastic NiTi archwires were assessed after repeated use by the patients; these archwires were sterilised prior to the clinical recycling process before being used on the patients (Alcaraz *et al.*, 2023). Their results showed that these archwires may return to normal behaviour and recover their initial properties following sterilisation, and this behaviour may allow the archwires to be reused in certain circumstances (Alcaraz *et al.*, 2023).

Orthodontic archwires are sometimes recycled, however the recycling significantly changed the CuNiTi wires' loading and unloading characteristics, with increased pitting, hence recycling is not recommended (Singaraju *et al.*, 2021). The surface characteristics of archwires before and after sterilisation examined under the scanning electron microscope and atomic force microscopy, showed no significant changes of the archwires after sterilisation, and this provide assurance to dental practitioners that they should sterilise the archwires prior to use on patients to ensure patient's safety

(Suresh & Kalidass, 2020). In a clinical scenario, it must be assumed that recycled archwires have been exposed to saliva and repetitive stresses from functional challenges. Hence, some impairment in functions might occur, although some types of wires may behave to their original state following sterilisation (Alcaraz *et al.*, 2023). While the existing recycling procedure may effectively handle the mechanical functionality and cross-infection control concerns, it is crucial to further examine the subjective aspects about the social and ethical consequences associated with recycling orthodontic appliances. The act of recycling resulted in an augmentation in surface roughness and friction coefficients (Lee & Chang, 2001). However, it was observed that these effects were deemed to be of negligible clinical significance.

Dry heat and steam sterilisation methods resulted in a reduction in the exerted force during both the loading and unloading phases (Alavi *et al.*, 2009). This phenomenon can be attributed in the context of clinical application where the insertion of an archwire into a malposition tooth's bracket leads to its deformation, which corresponds to the force applied. The archwire exhibits a propensity to revert to its initial configuration after the loading stage, commonly referred to as the unloading phase. The differences in load direction applied to the various segment of archwires before and after sterilisation using autoclave or dry heat steriliser can cause intrinsic changes when the archwires are in use but these changes are relatively small and did not have clinical significance (Suresh & Kalidass, 2020). Temperature transitions from martensite to austenite lead to reversible or irreversible changes in the alloys, which are expected to be useful for tooth movement. The use of CuNiTi archwires generally improved the movement of the teeth within the biologically tolerable range. In this way, the patient's comfort is combined with sufficient force to move teeth or teeth segments into the desired position during the treatment (Stoyanova-Ivanova *et al.*, 2021).

The sterilisation of the NiTi arch wire with either dry heat or steam does not affect the release of nickel ions into artificial saliva (Poosti *et al.*, 2009; Ramazanzadeh *et al.*, 2014). The level of nickel ion concentrations leaching out from the artificial saliva was negligible following both sterilisation methods (Poosti *et al.*, 2009). Thus, in clinical scenarios, autoclaving NiTi archwires to ensure patient safety is recommended. No mechanical issues arise in recycling the orthodontic wire, but clinical usage may result in work hardening because of recurring intraoral mechanical stresses to which the archwires were subjected during clinical usage (Potnis *et al.*, 2011).

Autoclaving processes do not affect the properties of the archwires, allowing orthodontists to ensure the maximum safety of their patients (Petrov, Andreeva *et al.*, 2015; Petrov, Terzieva *et al.*, 2015; Isac *et al.*, 2016; Sayed *et al.*, 2018). Current trends adopt the use of coated archwires in clinical settings for aesthetic reasons. A notable disparity occurred in the surface roughness parameters between coated and uncoated NiTi wires (Shamohammadi *et al.*, 2019). The coating qualities are affected by the production approaches such as surface roughness of the metal substrate and metal quality, adhesion quality of metal bond coating, viscosity and composition, polymerisation stages of the used materials, and procedures used for smearing the aesthetic material over metal surfaces such as surface or heat treatments (Mousavi *et al.*, 2018). Furthermore, the roughness of the underlying metal surface and the quality of the adhesion bond between the coating material and the alloy used also contribute to these differences (da Silva *et al.*, 2015).

It was noted that the microbial load from *Streptococcus mutans* and *Candida albicans* on the archwires had been reduced while improving the surface properties when chemical agents (chlorhexidine, sodium hypochlorite, 70% alcohol) were utilised and immersed in an enzymatic detergent (Canongia *et al.*, 2021). A material that correctly sanitises the orthodontic wire, but at the same time does not alter its properties is needed in the orthodontic field. The orthodontic wires received from the manufacturers had shown bacterial contamination (Ardeshna *et al.*, 2023). All sterilisation methods including the UV light were efficient in eliminating the bacterial contamination on the orthodontic braces and it does not alter material properties, however the forces exerted by various superelastic NiTi wires after clinical use and sterilisation were slightly affected (Alcaraz *et al.*, 2023). In a study, it was shown that there were no significant differences on the surface properties of the new archwires and the archwires that were subjected to various cycle of sterilisation using autoclave, dry heat sterilisation, ethylene oxide sterilisation and 2.45% acidic glutaraldehyde (Kaur *et al.*, 2024).

Recycling orthodontic archwires may not be totally obliterated in certain circumstances due to the monetary problems, the high cost or the environmental issues. Stainless steel wires that were used clinically, after being cleaned with isopropyl alcohol and then sterilised by autoclave has lower stiffness and elastic modulus but it does not affect their clinical predictability when recycled (Oshagh *et al.*, 2012).

CONCLUSION

Dry heat sterilisation and autoclaving have minimal effects on the tensile strength of several types of wires but may alter the load-deflection characteristics of some archwires and increase loading and unloading forces as the number of cycles increases. Cold sterilisation does not cause adverse changes in the mechanical properties or topographic surfaces of exposed archwires; however, no increase in the surface pitting is observed, indicating the absence of corrosion caused by the oral environment or the sterilisation process with 2% glutaraldehyde solution. After sterilisation, the number of nickel ions released from the archwires does not increase significantly. For the sterilisation of orthodontic wires, dry heat sterilisation, autoclave, and 2% glutaraldehyde solution can be safely recommended, and is in favour of incorporating the archwire sterilisation approach into the infection control protocol for the reuse of archwires. Hence, orthodontic professionals seeking to optimise patient safety may opt to sterilise orthodontic wires prior to their placement, as this practice does not compromise the wires' physical and mechanical characteristics.

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