

**TOOTH ALIGNMENT, COATING LOSS,
COLOUR CHANGE AND PATIENT PERCEPTION
OF AESTHETIC ARCHWIRES: A RANDOMISED
CONTROLLED TRIAL**

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CONTROLLED TRIAL**

by

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TABLE OF CONTENTS

ACKNOWLEDGEMENT	ii
TABLE OF CONTENTS	iii
LIST OF TABLES	viii
LIST OF FIGURES	ix
LIST OF ABBREVIATIONS	x
LIST OF APPENDICES	xi
ABSTRAK	xii
ABSTRACT	xiv
CHAPTER 1 INTRODUCTION	1
1.1 Study Background	1
1.2 Problem Statement	5
1.3 Research Questions	6
1.4 Research Objectives	6
1.4.1 General Objective	6
1.4.2 Specific Objectives	7
1.5 Research Hypotheses.....	7
1.5.1 Null Hypothesis (H ₁)	7
1.5.2 Alternative Hypothesis (H ₂)	7
CHAPTER 2 LITERATURE REVIEW	8
2.1 Orthodontic Aesthetic Archwires	8
2.1.1 History of orthodontic archwires	8
2.1.2 Biomechanics of archwires.....	9
2.1.3 Fibre-reinforced Archwires	10
2.1.4 The Coated Metallic Archwire	12
2.2 Types of Coating Polymers	14

2.2.1	Polytetrafluoroethylene (PTFE)	14
2.2.2	Epoxy Resin.....	15
2.2.3	Parylene–Polymer Coating	16
2.2.4	Rhodium-Coated Archwires	17
2.3	Advantages and Drawbacks of the Coating Polymers	18
2.4	Coating Techniques.....	19
2.4.1	Thermal Method	20
2.4.1(a)	Thermal Plasma Spray (TPS)	20
2.4.2	Vapour Deposition.....	20
2.4.2(a)	Chemical Vapour Deposition	20
2.4.1(b)	Physical Vapour Deposition (PVD)	22
2.5	Properties of the Aesthetic Archwire	23
2.5.1	Colour Stability.....	24
2.5.2	Surface Topography	24
2.5.3	Coating Durability	25
2.6	Measurement/Assessment Methods	26
2.6.1	Measuring tooth alignment.....	26
2.6.2	Measuring Coating Durability	28
2.6.3	Measuring Colour Change.....	29
2.6.3(a)	Subjective Methods (Visual Measurements).....	29
2.6.3(b)	Objective Method (Traditional Instrumental Measurements).....	30
2.6.4	Colourimeter	30
2.6.5	Spectrophotometer.....	31
2.6.6	Computer Vision Measurements	32
2.6.7	Measuring Colour Perceptibility and Acceptability	35
2.6.7(a)	Orthodontic Application of Colour Measurement	36

2.6.8	Assessing Patient Perception in Orthodontics	38
2.7	Justification of the study	40
CHAPTER 3 MATERIALS & METHODS		42
3.1	Ethical Approval	42
3.2	Study Design	42
3.3	Trial Registration.....	42
3.4	Sample Size Calculation.....	42
3.5	Trial Participants	44
3.5.1	Inclusion Criteria	44
3.5.2	Exclusion Criteria	45
3.6	Trial Setting.....	46
3.7	Trial Outcome Measures	46
3.7.1	Primary Outcome Measure	46
3.7.2	Study Outcomes.....	47
3.7.3(a)	Coating Loss	47
3.7.3(b)	The Color Changes	47
3.7.3(c)	Patient perception	47
3.8	Study Materials	47
3.8.1	Experimental Group	47
3.8.2	Control Group.....	48
3.9	Trial Intervention.....	48
3.9.1	Control Group.....	48
3.9.2	Withdrawal Policy	48
3.9.3	Participant Enrolment	49
3.9.4	Participant Randomisation.....	49
3.9.5	Allocation Concealment	50
3.9.6	Blinding	50

3.9.7	Treatment Protocol	50
3.9.7(a)	Day of Bond-Up	50
3.9.7(b)	Week 4 Follow-Up	51
3.9.7(c)	Week 8 Follow Up.....	51
3.10	Trial Flow Diagram.....	52
3.11	Preparation of Collected Study Samples	53
3.11.1	Preparation of Dental Cast.....	53
3.11.2	Photography of the Retrieved Archwire Samples	53
3.12	Method of Data Collection.....	54
3.12.1	Measurement of tooth alignment.....	54
3.12.2	Percentage of Coating Loss	56
3.12.3	Colour Change.....	57
3.12.4	Patient Perception.....	58
3.13	Data Analysis	59
3.13.1	Reproducibility measurements	59
3.13.2	Descriptive Statistics	59
3.13.3	Inferential Statistics	60
3.14	Grant of study.....	60
	CHAPTER 4 RESULTS.....	61
4.1	Sociodemographic Characteristics	61
4.3	Tooth Alignment Change.....	61
4.3.1	Comparison of Tooth Alignment between Groups.....	61
4.3.2	Comparison of tooth alignment between Upper and Lower Archwires.....	62
4.4	Coating Loss Analysis.....	63
4.4.1	Comparison of Coating Loss between Groups.....	63
4.4.2	Comparison of Coating Loss between Upper and Lower Archwires.....	64

4.5	Colour Changes Analysis	65
4.5.1	Comparison of CC between Retrieved and As-received Archwires.....	65
4.5.2	Comparison of Visual Perception of between Groups	67
4.6	Patient Perception Analysis.....	67
CHAPTER 5 DISCUSSION.....		69
5.1	Introduction	69
5.2	Profile of the Study Sample	71
5.3	Tooth Alignment Efficiency.....	71
5.4	Coating Loss of Aesthetic Archwires.....	80
5.5	CC between Aesthetic Archwires.....	83
5.6	Patient Perception.....	85
5.7	Clinical decision of selecting the best archwire	86
CHAPTER 6 RECOMMENDATION AND LIMITATIONS		88
6.1	Recommendations	88
6.2	Limitations	88
CHAPTER 7 CONCLUSION		89
REFERENCES.....		91
APPENDICES		
LIST OF PUBLICATIONS		

LIST OF TABLES

		Page
Table 3.1	Distribution of participants	49
Table 3.2	Title goes here Original and Adopted Version of OASIS Questionnaire.....	58
Table 4.1	Participants' Demographic Data and Types of Archwires of the Trial.	61
Table 4.2	Mean Percentage of Tooth Alignment Change Between Four Archwire Groups	62
Table 4.3	Multiple Pairwise Comparison.	62
Table 4.4	Comparison of tooth alignment between upper and lower archwires for each group.	63
Table 4.5	Percentage of coating loss between Three Aesthetic Archwires.....	63
Table 4.6	Comparison of Coating Loss between Upper and Lower Archwires between Three Groups.	64
Table 4.7	Paired T-test Illustrating the Comparison between L*a*b* Parameters in All Aesthetic Archwire Groups.	65
Table 4.8	Comparison of Colour Change Values between the Three Aesthetic Archwire Groups.	67
Table 4.9	Descriptive analysis of OASIS Questionnaire Score in Three Experimental Groups.....	67
Table 4.10	Baseline data analysis	68

LIST OF FIGURES

		Page
Figure 1.1	Criteria for the Ideal Archwire (Kusy, 1997)	1
Figure 2.1	Optiflex wire (Agwarwal et al., 2011).....	10
Figure 2.2	Illustrate the Optiflex wire's cross-section, silica core, silicon resin middle layer, and nylon coatings.....	11
Figure 2.3	Illustrate the shape and colour of 0.014-inch PTFE-coated FLI® (Kravitz, 2013).....	14
Figure 2.4	Comparison between metal and epoxy coated archwires.	15
Figure 2.5	A polymer-coated archwire's cross section (Dany Aesthetic Archwire).....	17
Figure 2.6	The physical techniques used for coating by (Arango et al., 2013).....	20
Figure 2.7	Illustrate the grouping of procedures used for coating in industries for the chemical methods (Arango et al., 2013).....	21
Figure 2.8	Illustrate the CIE L*a*b* colour space (Afonso et al., 2017).....	34
Figure 3.1	Trial flow diagram based on CONSORT 2010	52
Figure 3.2	Photographed Archwire.	54
Figure 3.3	Measurement of tooth alignment using digital calliper.	55
Figure 3.4	Illustrate the little irregularity index (Little, 1975).....	55
Figure 3.5	Example of measurement using Autodesk® AutoCAD® software.....	57
Figure 3.6	Custom Made Archwire Holder.....	57

LIST OF ABBREVIATIONS

AMDI	Advanced Medical & Dental Institute
Ca	Calcium
Ca-P	Calcium phosphate
CVD	Chemical Vapour Deposition
Cl	Chlorine
CIE	Commission Internationale de l'Eclairage/International Commission on Illumination
CI	Confidence Intervals
ID	Identity Document
K	Potassium
KCL	Potassium chloride
KPDM	Klinik Pergigian Desa Murni
MM	Millimetres
Na	Sodium
NaCl	Sodium Chloride
NITI	Nickel-Titanium
OASIS	Oral Aesthetic Subjective Impact Scale
P	phosphorus
PVD	Physical Vapour Deposition
PTFE	Polytetrafluoroethylene
RCT	Randomised Controlled Trial
SLR	Single Lens Reflex
SS	Stainless Steel

LIST OF APPENDICES

Appendix A	Jawatankuasa Etika Penyelidikan Manusia (JEPeM).
Appendix B	Ethical Approval.
Appendix C	Assent form.
Appendix F	Patient information sheet
Appendix G	Consent form

**PENJAJARAN GIGI, KEHILANGAN SALUTAN, PERUBAHAN WARNA
DAN PERSEPSI PESAKIT TERHADAP WAYAR ARKUS ESTETIK:
PENYELIDIKAN TERKAWAL RAWAK**

ABSTRAK

Wayar arkus estetik membantu meningkatkan estetika pesakit semasa rawatan ortodontik. Tujuan penyelidikan terkawal rawak (RCT) ini adalah untuk membanding dan menilai peratusan penjajaran gigi, kehilangan salutan, perubahan warna dan persepsi pesakit terhadap tiga wayar arkus estetik nikel-titanium superelastik (SE NiTi) berbeza, yang disaluti dengan polimer serona gigi selama lapan minggu penggunaan intraoral. Kaedah: Penyelidikan terkawal rawak, pelbagai pusat, buta duaan telah dilakukan di: (1) Klinik Pakar Ortodontik, Institut Perubatan & Pergigian Termaju, Universiti Sains Malaysia (USM), (2) Klinik Pakar Ortodontik, Pusat Pengajian Sains Pergigian, USM dan (3) Klinik Pergigian Desa Murni, Pulau Pinang. Sejumlah 134 peserta yang memerlukan aplians tetap atas dan bawah direkrut untuk RCT ini. Semua peserta diagihkan secara rawak kepada salah satu daripada empat intervensi wayar arkus atas dan bawah: (1) 0.014" Orthocare Euroform®, (2) 0.014" RMO FLi®, (3) 0.014" G&H dan (4) 0.014" tidak bersalut. Ketiga-tiga wayar arkus estetik ini berbeza antara satu sama lain dari segi bahan salutan dan ketebalannya. Wayar-wayar arkus diikat dan dibiarkan *in situ* selama lapan minggu. Setelah wayar-wayar arkus ditanggalkan, penjajaran gigi, kehilangan salutan, perubahan warna dan persepsi pesakit telah dinilai, masing-masing dengan menggunakan Indeks Ketakteraturan *Little*, perisian Autodesk® AutoCAD®, Adobe® Photoshop® dan borang soal selidik *Oral Aesthetic Subjective Impact Scale* (OASIS). Keputusan: Analisis menunjukkan perbezaan yang signifikan secara statistik di antara

keempat-empat wayar arkus untuk penjajaran gigi ($p = 0.014$), dengan kumpulan RMO menunjukkan peratusan penjajaran gigi tertinggi (77.1%) dan kumpulan G&H menunjukkan peratusan penjajaran gigi terendah (63.7%). Wayar-wayar arkus Orthocare memiliki min perubahan warna terbesar (11.11) dan G&H dengan nilai terendah (9.01). Dalam perbandingan kehilangan salutan, kumpulan Orthocare mempunyai peratusan min kehilangan salutan tertinggi (33.4%) dan RMO mempunyai peratusan terendah (27.8%), walaupun tiada perbezaan yang signifikan secara statistik ($p = 0.137$). Kumpulan Orthocare mempunyai peratusan persepsi positif tertinggi (80.6%), sedangkan kumpulan RMO menunjukkan peratusan persepsi negatif tertinggi (33.3%). Kesimpulan: Telah diketahui bahawa terdapat pengurangan penjajaran gigi, perubahan warna, kehilangan salutan dan persepsi pesakit yang ketara, setelah penggunaan klinikal wayar arkus estetik. PTFE yang disalut sebahagian (kumpulan RMO) menunjukkan prestasi yang lebih baik daripada kumpulan lain untuk penjajaran gigi dan kehilangan salutan, tetapi ia paling tidak dapat diterima oleh pesakit. Walaupun PTFE yang disalut penuh (kumpulan Orthocare) mempunyai persepsi positif tertinggi, pada masa yang sama mempunyai min peratusan kehilangan salutan dan perubahan warna tertinggi selama lapan minggu penggunaan klinikal. Pengurangan penjajaran yang terendah selepas rawatan adalah untuk kumpulan wayar arkus estetik pelapisan kumpulan wayar arkus estetik G&H yang disalut penuh dengan epoksi dan nilai min perubahan warna terendah.

**TOOTH ALIGNMENT, COATING LOSS, COLOUR CHANGE AND
PATIENT PERCEPTION OF AESTHETIC ARCHWIRES: A RANDOMISED
CONTROLLED TRIAL**

ABSTRACT

Aesthetic archwires help improve aesthetics of patients during orthodontic treatment. The aims of this study of randomised controlled trial (RCT) were to compare and evaluate the percentage of tooth alignment, coating loss, colour change, and patient perception of three different aesthetic superelastic nickel-titanium (SE NiTi) archwires coated with tooth-coloured polymers over eight weeks of intraoral use. Methods: Multi-centre, double-blind, randomised controlled trial was done at three centres: (1) Orthodontic Specialist Clinic, Advanced Medical & Dental Institute, Universiti Sains Malaysia (USM), (2) Orthodontic Specialist Clinic, School of Dental Sciences, USM, and (3) Desa Murni Dental Clinic, Penang. A total of 134 participants requiring upper and lower fixed appliances were recruited for this RCT. All participants were randomly allocated to one of four upper and lower archwire interventions: (1) 0.014" Orthocare Euroform® (2) 0.014" RMO FLi®, (3) 0.014" G&H, and (4) 0.014" uncoated. These three aesthetic archwires differ from one another in terms of coating materials and thickness. The archwires were ligated and remained in-situ for eight weeks. After removal of the archwires, the tooth alignment, coating loss, colour change, and patient perception were assessed using Little's Irregularity Index, Autodesk® AutoCAD® software, Adobe® Photoshop®, and Oral Aesthetic Subjective Impact Scale (OASIS) questionnaire, respectively. Results: The analysis shows statistically significant differences between the four treatment

archwires for tooth alignment ($p = 0.014$), with RMO group showed the highest percentage (77.1%) and G&H group showed the lowest (63.7%). Orthocare archwires have the largest mean of colour change (11.11) and G&H the lowest value (9.01). In coating loss comparison, Orthocare group had the highest mean percentage of coating loss (33.4%) and RMO had the lowest (27.8%) despite no statistically significant difference ($p = 0.137$). Orthocare group had the highest percentage of positive perception (80.6%), whereas the RMO group showed the highest percentage of negative perception (33.3%). Conclusion: After the analysis it has been found out that there is significant tooth alignment, colour change, coating loss, and patient perception after the clinical use of aligning aesthetic archwires. The partially coated PTFE RMO group performed better than the other groups for both alignment reduction and coating loss, but it is the least acceptable to patients. Whilst the fully coated PTFE Orthocare group had the highest acceptable, but in same time had the highest mean percentage of coating loss and colour change over the eight weeks of clinical use. The lowest alignment reductions after treatment were for fully coating epoxy G&H aesthetic archwires group and the lowest mean value of colour change.

CHAPTER 1

INTRODUCTION

1.1 Study Background

Orthodontics deals with the treatment of malocclusion. Following treatment, the ideal outcomes are an aesthetic and functional occlusion that synchronizes with one's face. The orthodontic archwire is a necessary part of a fixed orthodontic appliance. The archwire desirable characteristics would have desirable stiffness, good aesthetics, good spring back, resilient modulus, low friction, formability biocompatibility, and exhibits optimum performance during orthodontic treatment (Silvia-Izabella et al., 2013). The criteria for ideal archwire can be illustrated in Figure 1.1.

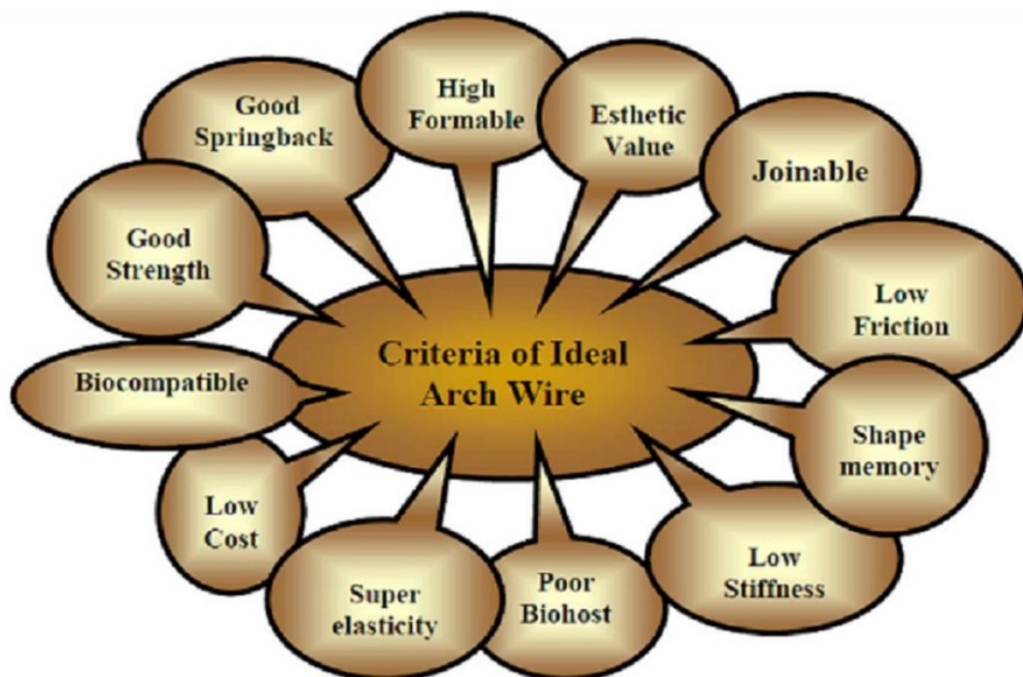


Figure 1.1 Criteria for the Ideal Archwire (Kusy, 1997)

With the use of an ideal archwire with light and continuous force, the required tooth movement can be attained. The correct application of the force results in fast and effortless movement of the teeth with minimal tissue damage (Agwarwal et al., 2011).

Due to deactivation of the appliance that results in the utmost tissue response and the ability of the archwire to go through large deflections without distortion, the constant level of force should be elastic over a weekly or monthly period (Valiathan and Dhar, 2006). Therefore, the archwire should be cautiously selected and a proper archwire will help attain the desired outcome after treatment while causing minimal distress to the patients (Rudge et al., 2015).

Four archwire alloys are presently used in orthodontics having required properties to attain this objective include the stainless steel (SS) alloy, the cobalt–chromium alloy, the beta-titanium alloy, and the nickel-titanium (NiTi) alloy (Alobeid et al., 2014). The development of superelastic NiTi (SE NiTi) archwires has become attractive and popular since they are highly elastic, exhibit minimum permanent distortion, and affect shape memory. They offer the consistent force that is relevant for tooth alignment in orthodontics by releasing continuous and light forces, giving the best outcomes for treatment, particularly during the levelling stage and the primary alignment (Lombardo et al., 2013). However, this type of wire is costly and has high frictional resistance (Kapila et al., 1990). It also causes hypersensitivity to nickel in some orthodontic treatment patients (Kapadia et al., 2018, Singh et al., 2019, Bass et al., 1993).

Although orthodontic archwires made of SS and NiTi that are used conventionally have poor aesthetic properties, they possess good mechanical characteristics (Abaas and Al-Huwaizi, 2015). Due to the good mechanical properties,

the SS and NiTi appliances have a high demand resulting in the production of aesthetically acceptable appliances for patients and medical practitioners (Mohsin and Al-Sheakli, 2016). The aesthetic appeal of these archwires is achieved by coating, resulting in aesthetic coated archwires (Abaas and Al-Huwaizi, 2015). Consequently, there are two kinds of aesthetic archwires: those that are metallic and coated and those that are non-metallic and transparent. The composite archwire is excellent because it has a higher kinetic coefficient of frictions than SS whereas fibre-reinforced composite wires have excellent formability and aesthetic appearance due to transparency, high tensile strength, elastic recovery, and varying values of stiffness for similar cross-sections, facilitating cross-sectional orthodontics (Philip et al., 2016).

Coated archwires are usually made of polymers, which include synthetic resin that contains fluorine or epoxy resin that are mainly made up of polytetrafluoroethylene (PTFE). PTFE is non-adhesive and has an aesthetic characteristic. Owing to this, it is used in orthodontic appliances such as archwires, brackets, and coatings of ligatures to match the colour of the natural tooth and aesthetic brackets (Ramadan, 2003). The polymeric chain with excellent mechanical stability reduces the resistance between the bracket and the archwire caused by friction when it is used as an archwire ligature (Leander & Kumar, 2011). Due to the warm and wet conditions of the oral cavity, corrosion could occur.

The conditions in the mouth are suitable for the biodegradation of metals since the mouth is warm and contains microbes and enzymes (Zreaqat et al., 2017). During orthodontic treatment, colour stability of the aesthetic archwires is of clinical importance since any aesthetic discoloration, change, or staining of patients affects treatment procedures such as patient cooperation. Reports indicating colour instability

of these archwires and, therefore, exposure of the wire beneath have been filed. To this effect, the findings of previous research show that 25% of the colour is lost intraorally within 33 days, degrading the wire aesthetically (Mahmood, 2009). According to Mohsin and Al-Sheakli (2016), materials that are suitable for making archwires are those that can withstand the conditions in the oral cavity. It has been found that in oral environments orthodontic alloys have shown exceptional resistance against corrosion.

Such resistance towards corrosion is significant for biocompatibility and orthodontic appliance durability (Chaturvedi & Upadhyay, 2010). Selection of wires and understanding material properties and characteristics is essential practice in the process of treatment.

Resources and materials used during the treatment of dentistry must have certain specified features including biological maintenance, proper tissue-material response, and anti-corrosion properties since they are used in the oral cavity where they are exposed to its properties. These properties, which stimulate the biodegradation of metals, are categorized as physical, microbiological, and chemical (Mohsin & Al-Sheakli, 2016).

PTFE-coated brackets reduce the decalcification of the enamel by decreasing the development of a biofilm during treatment (Demling et al., 2010). The appearance of coated aesthetic appliances are considered to be more acceptable and is preferred by many adults who are willing to incur extra costs for it (Rosvall et al., 2009). Moreover, during orthodontic treatment, these archwires can avert allergic reactions in nickel-alloy-hypersensitive patients.

Systematic review study highlighted the gaps of literature studies especially related with aesthetic archwires due to variations in results and opinions for the validity

of use and benefits. Moreover, various types of archwires got differences in manufacturing, characteristics, and benefits (Totino et al., 2015). However, significant gap of findings and opinions of trials implemented in Malaysia about the differences of colour changes, tooth alignment, patients' perceptions among brand archwires to address the advantages and disadvantages, which recommended be used in clinical practice.

1.2 Problem Statement

Arguments among research scholars for the differences in beneficials and disadvantages among different orthodontic archwires (Hepdarcan et al., 2016). Competitions among manufacturers with a priority of producing the best aesthetics archwires possessing the good features like coating durability, lasting colour stability (approximately six to eight weeks of intraoral use), and have low friction, resulting in faster tooth movement (Kravitz, 2013). However, these companies are not reliable about the best type recommended be used for dentistry purposes. These archwires showed are varied in their mechanical properties especially of colour changes, coating loss, tooth alignment, and patients' perception (Elayyan et al., 2008). As novelty of present study, no trial study has shown the optimal archwire with best beneficial characteristics (like the coating loss, colour changes, tooth alignment, and customers perception) among different types of archwires, especially about archwires be used in Malaysia. Moreover, the no study before compared the pros and cons of above characteristics of archwires, which measure the efficiency of use based on benefits to disadvantages. The knowledge of differences among archwires are still limited to many dentistry professionals especially the selection, use, benefits and disadvantages (Hepdarcan et al., 2016). In Malaysia, many dentists are knowledgeable about the

types of orthodontic archwires but, few who are familiar with optimal archwires have excellent effectiveness and ideal outcomes (Nor et al., 2020). The domains of knowledge should be improved for archwires have less coating loss, minimum colour changes, efficient tooth alignment, and comfortable patients' perceptions. Moreover, these aesthetic archwires are expensive than uncoated SE NiTi, thus it is essential to have clinical knowledge and data to let clinicians and patients make a reasonable choice on treatment and develop further research in this area.

1.3 Research Questions

1. Is there difference in the percentage of tooth alignment among the types of aesthetic archwires.
2. Is there difference in the percentage of coating loss among the types of aesthetic archwires.
3. Is there difference in the colour change among the types of aesthetic archwires.
4. Is there an effect of inter-bracket distance on the tooth alignment
5. What is the patients' perception following the use of aesthetic archwires.

1.4 Research Objectives

1.4.1 General Objective

To investigate the effectiveness of the aesthetic archwires.

1.4.2 Specific Objectives

1. To compare the percentage of tooth alignment amongst the aesthetic archwires and the uncoated aligning archwire (SE NiTi).
2. To compare the percentage of coating loss between the aesthetic archwires.
3. To compare the colour change between the used and unused aesthetic archwires.
4. To assess the effect of inter-bracket distance on the tooth alignment.
5. To assess the patients' perception following the use of aesthetic archwires.

1.5 Research Hypotheses

1.5.1 Null Hypothesis (H₁)

There is no difference in terms of tooth alignment, coating loss, colour change, and patient perception between the aesthetic archwires.

1.5.2 Alternative Hypothesis (H₂)

The aesthetic archwires have better performance in terms of tooth alignment, coating loss, colour change, and patient perception between the aesthetic archwires.

CHAPTER 2

LITERATURE REVIEW

2.1 Orthodontic Aesthetic Archwires

Of great importance in modern society is the aesthetic factor of appliances used in orthodontics, especially due to the high orthodontic care demand of many adult patients. Aesthetic orthodontic appliances have come into demand and increased in the early 1980s (Kaur et al., 2018). Aesthetic archwires were first introduced in the 1990s (Flanagan, 2015). Some of the alternatives to metal were found to make aesthetic archwires that are effective for orthodontic treatment with the appliance labially (da Silva et al., 2013a). The kinds of archwires that are existent are those that are metallic and coated, and those that are non-coated, non-metallic, and reinforced with fibres. The coated metallic archwires are ideal for dental use because the alternatives are still under experimentation (Elayyan et al., 2010).

2.1.1 History of orthodontic archwires

The first archwire used in the treatment in late 1800s as arch bow. The first archwire made from the nickel-silver or platinum-gold alloy to a diameter ranged from 0.032 to 0.036 inches. The arch bow characterised by threaded at ends and passed through tubes joined to bands. Localized auxiliaries were launched from the arch bow, which characterized by limited the movement of the tooth or levelling processes. Dr Edward Angle in the 1920s introduced the using of the edgewise appliance with the orthodontic uses. The prototype narrow bracket with wings with 0.028-inch slot to control the displacement of the tooth. In late 1920s a hard-drawn stainless steel wire, composed of chromium and nickel, used in the metallurgy. This had given more

strengths of metal predecessors with more elastic modules, ductility, and corrosion resistance. In 1930s the stainless-steel strips were produced with using the fluoride fluxes, and soldering with gold, silver, and platinum. Elgiloy wire was introduced, because of the overheating, to be more popular used than other old archwires. This archwire, composed of cobalt-chromium alloy. Nickel-titanium alloy was introduced in 1960s by the US Navy and the material was used with orthodontic archwires. Nitinol, the developed titanium alloy, was used with primary constituents' titanium and molybdenum, which gives 40% stiffness of the archwire. In mid 1980s two Ni-Ti alloy wires were used for dental purposes. A decade later, these archwires were developed to be more elastic uses and more practical for dental practitioners (Nikolai, 1997).

2.1.2 Biomechanics of archwires

The biomechanical properties of the archwire are subjectives to the stress/strain characteristics. The stress property is measured to determine the loaded force per unit area of the wire. The yield point of strength is the point where no more behaves elastically when load/force is applied, where starting the state of deformation of elasticity. The greatest stress is more inducing of the less elasticity and more ruptures to the archwires synthesis materials. Kusy defined the ultimate tensile strength as highest synthesised strength of materials in the state of tensions. The point of fracture of the point where the wire continues ultimate tensile stresses, reaching to the point of mechanical failure due to the influence of stress, heat, saliva, and other intra orally parameters of archwire materials after few couple weeks. The failure induced by the stress of archwire is expressed by (N/mm^2) (Obaidi & Al-Qassab, 2009).

2.1.3 Fibre-reinforced Archwires

The fibre-reinforced archwires are new generation of materials that incorporate long fibres such as glass or carbon, which possess properties approaching those of metals. The first aesthetic non-metallic orthodontic archwire, Optiflex, was developed as an appliance devoid of metals, an alternative to the metallic archwires that are currently in use (Figure 2.1).

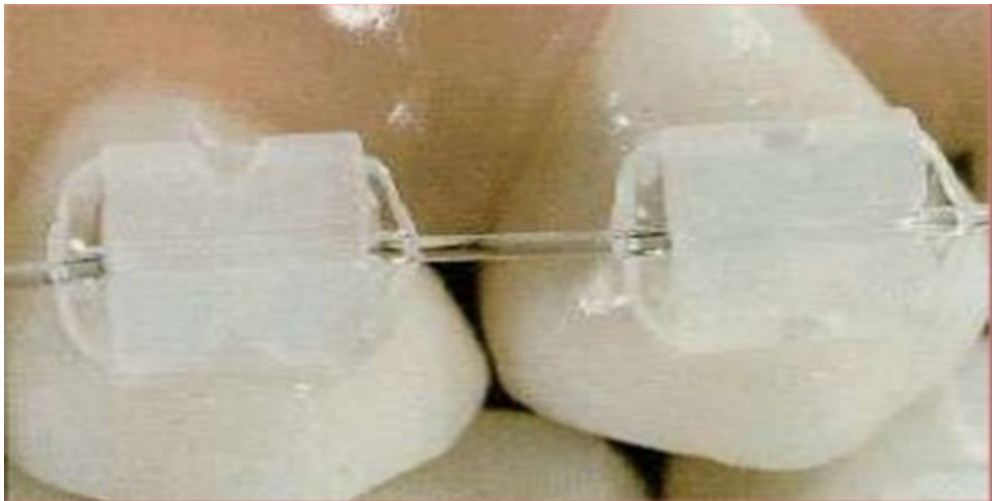


Figure 2.1 Optiflex wire (Agwarwal et al., 2011)

The Optiflex wire core is made up of silica dioxide, which offers the force required to move the teeth. The middle layer, which shields the core from moisture, is composed of a silicone resin, while the outer layer, which is made up of nylon, is resistant to stains. Therefore, it prevents the archwire from getting damaged and increases its strength according to (Singh, 2016) as in Figure (2.2).

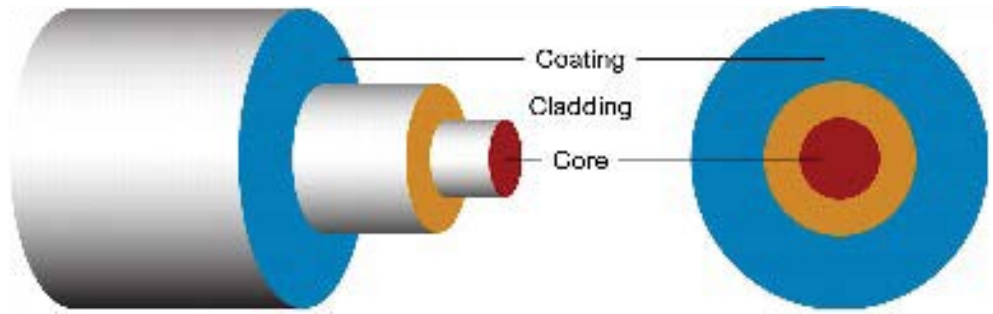


Figure 2.2 Illustrate the Optiflex wire's cross-section, silica core, silicon resin middle layer, and nylon coatings.

These archwires are suitable for levelling and aligning phase in cases with mild to moderate amounts of crowding (Kravitz, 2013). Recently Burstone et al. (2011) gave an account of a polyphenylene-extruded polymer archwire. Polyphenylene increases hardness, strength, stress relaxation resistance, and rigidity.

The resulting archwire provides forces like the NiTi and beta-titanium archwires that have smaller cross-sections. The amount of force produced by the proposed archwire is similar to those used in levelling and alignment. In the future, the polymer archwire can be used as an aesthetic archwire, although further research is required (Burstone et al., 2011). Although the various fibre-reinforced polymer archwires have an excellent appearance, their medical use is poor since they are brittle (Kravitz, 2013). They are also very tough, durable and have a stiffness almost similar to the beta-titanium archwire, which is different from the most flaccid archwire with multiple strands (Flanagan, 2015).

According to the findings of previous mechanical trials, these archwires have excellent elasticity until failure takes place. In addition, flexibility and spring back can be compared to those of NiTi (Fallis & Kusy, 2000). This archwire has resistivity towards stains and has good aesthetic and, the composite archwire is one of the best archwires as it exhibited a higher kinetic coefficient of frictions than stainless steel

(Philip et al., 2016). Fibre-reinforced composite archwires are a mixture of excellent formability, high tensile strength, high elastic recovery, excellent aesthetic appearance owing to their transparency, tendency to be wires of similar cross-sections. Still, varying stiffness values would facilitate cross-sectional orthodontic practice (Philip et al., 2016). The attachment can be directly bonded to composite archwires, which eliminates the need for soldering and welding. Attachment of archwires can be done directly to the teeth; therefore, supplementing the need for brackets under certain circumstances, especially when support from multiple teeth is necessary (Philip et al., 2016). Composite archwires can retain a high amount of functional resilience during the early stages and intermediary stages of orthodontic treatments (Philip et al., 2016), but their brittleness, severe and sharp curvatures may cause crack or fracture in the glass (SiO₂) core.

This type of archwire has poor spring back; thus, its clinical performance in different cases and ability has been claimed (Lim et al., 1994).

2.1.4 The Coated Metallic Archwire

The development of coated metallic archwires resulted from the inability to pair the mechanical properties of metallic archwires to their non-metallic alternatives. These coated metallic archwires permit some cosmetic adjustments while maintaining the necessary mechanical characteristics of metallic archwire. Aesthetic archwires and aesthetic brackets are now widely used as they offer a required and desirable result to patients who have demand for less noticeable and reduced visible appliance. Coated metallic archwires can be either coated SS or NiTi wires that are commonly treated with PTFE, epoxy resin, parylene polymer, and less commonly palladium covering to give a colour similar to the enamel. They are also called 'white wires' (Kravitz, 2013).

In orthodontic treatments, archwires coated with NiTi are recent inventions. During the coating process, the surface of the substrate is altered permanently by refining it using oxides, ethylene, PTFE, or nitride ions (Krishnan et al., 2012). The coating material differs in thickness around 0.002" and the usage process and procedure also differ in terms of mechanical efficacy and to increase aesthetics (Aksakalli & Malkoc, 2013; Zegan et al., 2012). In comparison to the uncoated metallic wires, the coated archwires are superior in terms of aesthetics and some mechanical advantages. Due to the stresses prevailing in oral environment, partial or complete loss of the coating may result in poor performance. Consequently there has to be some apprehension for it as patients using it should be aware regarding colour change (ΔE) and its texture after use (Bradley et al., 2013).

To reduce the undesirable effects of NiTi archwires while meeting the aesthetic needs of patients, multiple manufacturers have suggested different methods of obtaining and processing the archwires. To prevent corrosion, reduce nickel release by 80%, and prevent alteration of the archwire's mechanical properties, the NiTi appliances are coated with either PTFE-based material, composed resin, hydrogenated carbon, or zirconium oxide (Elayyan et al., 2008; Husmann et al., 2002; Ohgoe et al., 2007).

2.2 Types of Coating Polymers

2.2.1 Polytetrafluoroethylene (PTFE)

PTFE is an artificial polymer coating material made up of carbon and fluorine. Due to the carbon-fluorine bonds, PTFE has desirable characteristics, which are heat resistance, non-reactivity, and being hydrophobic. Based on an orthodontic perception, PTFE is both aesthetic and non-adhesive. Coating archwires with PTFE (Figure 2.3) gives them a hue that is likened to that of normal teeth (Farronato et al., 2011; Malik et al., 2015; Kravitz, 2013).

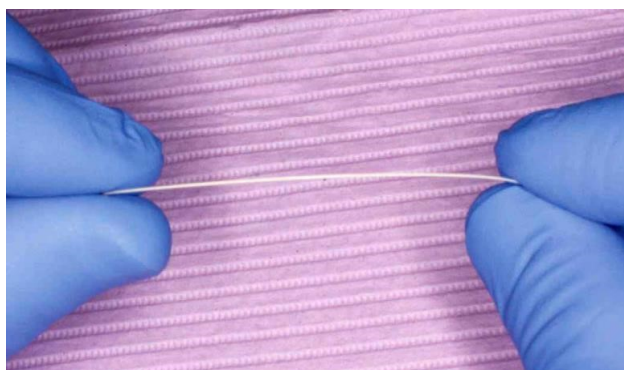


Figure 2.3 Illustrate the shape and colour of 0.014-inch PTFE-coated FLI® (Kravitz, 2013).

PTFE was developed to retain the functionality. Consequently, it helps in enhancing the aesthetics of metallic wires and cosmetic surface-coating application. PTFE-coated archwires are the most frequently used in the field of dentistry and medicine (Kameda et al., 2019). It has been explored that PTFE is helpful in refining the anti-cariogenic properties of composite resins, a coating of metallic stents for palliation of malignant biliary disease artificial muscles and a conduit for guided nerve regeneration (Flanagan, 2015).

PTFE is a polymer having physical and chemical properties with completely fluoridated chain. Coatings of PTFE are applied through an atomic process where the

air is compressed to add thick sediment (Approximately 0.0008–0.001 inch) to the archwire. PTFE-coated archwires have less frictional levels comparatively to other parallel uncoated archwires during heating in the chamber furnace (Husmann et al., 2002). As a result of sintering fabrication two coatings are formed: the classical non-microporous PTFE; and the expanded microporous PTFE, characterised by oriented micro-fibrils that are joined using solid junctions (Farronato et al., 2011).

2.2.2 Epoxy Resin

This is an artificial material that is formed from the combination of epoxide and another compound. It provides good adhesion, electrical insulation, chemical resistance, and dimensional retention. Epoxy resins are applied extensively in the production of materials used in orthodontics such as moulds, polyurethane aligners, and composite resins (Fujihara et al., 2004; Kravitz, 2013). Comparison between aesthetic and uncoated archwires was shown in Figure 2.4.



Figure 2.4 Comparison between metal and epoxy coated archwires.

The epoxy layer adds the thickness of 0.002 inches to the archwire. To make up for the coating layer thickness, manufacturers can use a small inner core alloy dimension (Kaphoor & Sundareswaran, 2012). Unavailability of metal primers is challenging for coating of metallic wires. These primers allow improved structure of the coating layer and archwire.

Currently, all-metal primers are toxic and unapproved for use in the oral cavity by the Food and Drug Administration. Studies have shown that within the first month in the mouth, a quarter of the epoxy layer is lost (Kravitz, 2013). According to Elayyan et al. (2008), after *in vivo* use for 4 to 6 weeks, the unloading forces produced by retrieved archwires with uncoated ligation and coated with epoxy resin are lesser than those produced by as-received coated archwires. On the contrary, based on the findings of a recent study by Bradley et al. (2013), retrieved epoxy resin coated archwires produce more unloading forces compared to as-received archwires. The researchers attributed this outcome to the loss of coating by the archwires, which is a similar characteristic of uncoated archwires.

2.2.3 Parylene–Polymer Coating

A silver primer is incorporated into these archwires to obtain a thin layer of aesthetic coating. The parylene layer surface consists of a rough morphology with considerably low rigidity. However, the mechanical properties of a major portion of the coated archwire are similar to those of non-coated archwires (Iijima et al., 2011b). The cross section of the archwire is in Figure 2.5.

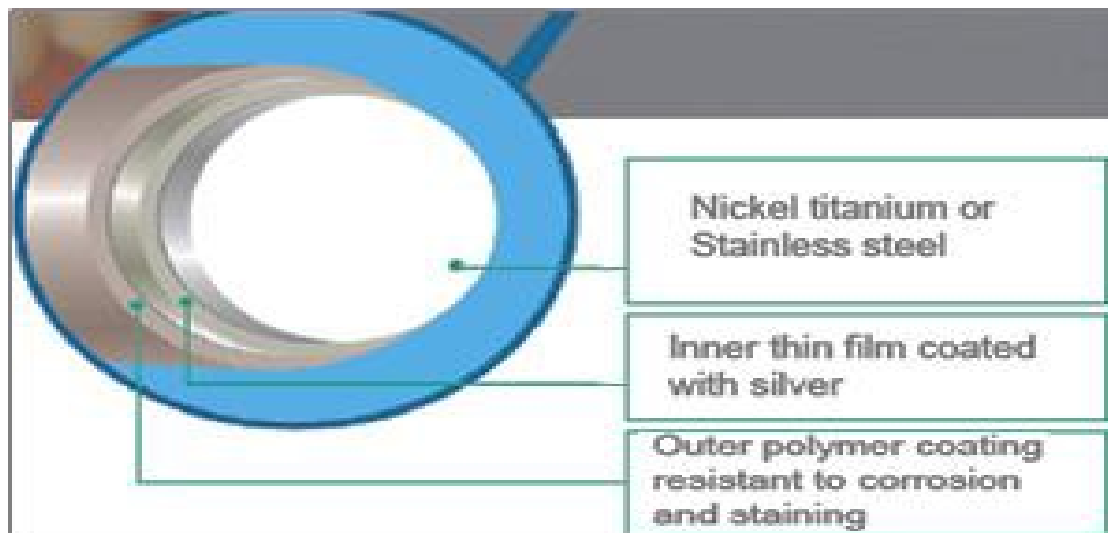


Figure 2.5 A polymer-coated archwire's cross section (Dany Aesthetic Archwire)

2.2.4 Rhodium-Coated Archwires

Permanent archwire surface modification occurs when ion implantation using rhodium is done. The silvery-white transition metal is hard and belongs to the platinum category. In the three-way catalytic converters used in vehicles, rhodium is one of the catalysts, making up 80 % of its use (Loferski, 2012). Palladium or platinum alloys are applied to corrosion-resistant and high-temperature archwires coated with rhodium. The availability of these archwires for commercial use began in 2008 (Flanagan, 2015). Rhodium is a precious metal and has high resistance. Due to its significant properties, rhodium is considered stable chemically. Additionally, orthodontic wires with rhodium coatings have more aesthetic value compared to other metals.

These archwires contain less reflectivity, which is helpful in improving aesthetics and reducing visibility. Even with these qualities, when examined using scanning electron microscopy or atomic force microscopy, rhodium-coated archwires show loss of natural morphology and deep-set cracks. The aesthetic characteristics and bio stability of archwires may get effected due to such change in surface morphology.

Similarly, due to the rough surface of rhodium huge friction is produced (Kim et al., 2014).

2.3 Advantages and Drawbacks of the Coating Polymers

Aesthetic archwires provide pleasant aesthetics like the aesthetic brackets. Moreover, coating polymers increase the physical and electrical resistance of the metals, provide more toughness, flexibility, and anticorrosive protection and good resistance to detergents chemically (Nascimento et al., 2013). In as much as the aesthetic coating offers stability against corrosion, corrosion in the oral cavity occurs if the archwires are exposed to oral fluids for a longer period (Neumann et al., 2002). On the other hand, the application of plastic coatings between orthodontic brackets and archwires decreases friction. This is a desirable characteristic when the required friction coefficient is low, for example, in teeth retraction and closure of space, or when the friction coefficient required is high, for example, for anchorage (Pacheco et al., 2012).

Coated archwire discoloration occurs easily when they are exposed to mastication and enzymes activity in oral cavity. In such cases coated archwires delamination results, damaging the aesthetic characteristics of archwires and interfering with satisfaction of patients (Aksakalli and Malkoc, 2013). On the other hand, poor mechanical properties that may function as a mere placebo was observed to be exhibited by uncoated transparent archwires (Singh, 2016).

Due to the prolong exposure in oral cavity the coated archwires undergo certain changes like discoloration, exposure of underneath metal and coat splitting. Furthermore, if the archwire is not cut with a sharp instrument, the free end may have

a tendency to fray (Aksakalli & Malkoc, 2013). Certain incoherence of the protective coating layer occurs in cosmetic archwire before use. This may disturb the properties and mechanical productivity of the archwire and may cause unwanted and uncontrolled dental movements (Zegan et al., 2012). During loading and unloading of coated archwires, they produce lesser forces in comparison to non-coated archwires of similar nominal diameters (Matias et al., 2018). Therefore orthodontic treatment is considered and reported as inefficient due to the frictional force between the archwire and bracket (Choi et al., 2012; Ryu et al., 2015).

Assessment of the influence of ageing inside the oral cavity on the surface properties of aesthetic and uncoated NiTi archwire revealed that aesthetic archwire creates a rough surface consisting of craters and bumps. Consequently, this increases the amount of surface friction on the metallic brackets (Rongo et al., 2013). Growth of plaque forms on uneven surfaces disrupting tooth movement because of entrapment and frame of brackets inside these shortcomings (Elayyan et al., 2008).

During the use coating may split within the oral cavity which can cause the exposure of underneath metal. Previous studies indicate a 25% loss of the coating intraorally 33 days after application degrading the archwire aesthetically (Elayyan et al., 2008).

2.4 Coating Techniques

The coating can improve the surface of the material. Consequently, multiple processes and materials have been used for the coating to improve the surface properties (Arango et al., 2013). Thermal and chemical techniques are usually followed during manufacturing and testing of coatings.

2.4.1 Thermal Method

The thermal method of coated archwires include the following characteristics as shown in Figure 2.6.

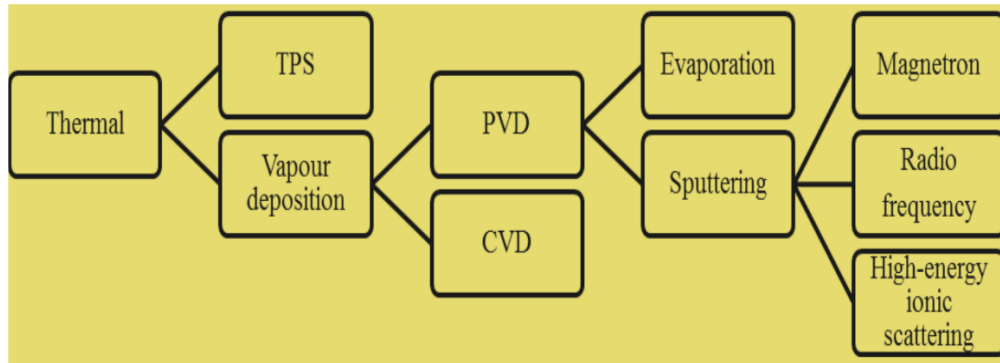


Figure 2.6 The physical techniques used for coating by (Arango et al., 2013)

2.4.1(a) Thermal Plasma Spray (TPS)

Using this technique, materials are exposed to high temperatures which melts them based on direct-current arc or radiofrequency inductively coupled plasma discharge. TPS technique involves depositing metallic or non-metallic materials that have been ground finely onto molten or semi-molten metal. As a result, an uneven coating ideal for application in orthopaedics and dental implantations is obtained (Fridman, 2008; Junker et al., 2010; Wang et al., 2009).

2.4.2 Vapour Deposition

2.4.2(a) Chemical Vapour Deposition

The grouping of procedures used for coating in industries in chemical vapour deposition (CVD) methods is shown in Figure 2.7.

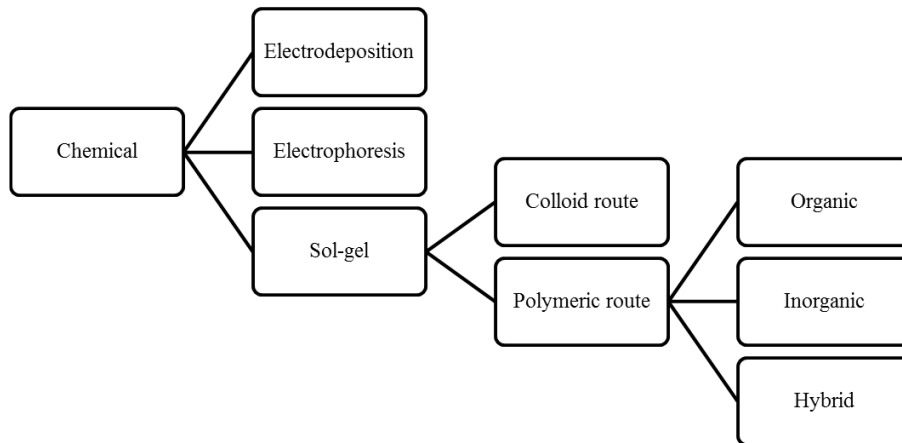


Figure 2.7 Illustrate the grouping of procedures used for coating in industries for the chemical methods (Arango et al., 2013)

This technique has a wide application in dentistry, for example, in the coating of metal burs and endodontic NiTi files. The chemical reactions involved in CVD take place around a hot surface in a chamber with a precursor gas flow. As a result of these chemical reactions, a thin film is deposited on the metal surfaces. Since the utilisation of this technology is still under study, it is not yet employed in orthodontics (de Vasconcellos et al., 2013). In this electrodeposition technique, the substrate to be coated is representative of the cathode while the anode is represented by the metal to be deposited in the form of salts dissolved in water and maintained at a controlled temperature. The electrolyte is located a short distance between the cathode and anode. Application of a direct current with a low voltage results in conversion and deposition of metal ions that move towards the cathode into metal atoms (Tanaka et al., 2010).

To produce coated archwires with reduced friction, Samorodnitzky-Naveh et al. (2009) used positive charge to move from the electrolyte towards the cathode during electrodeposition. As a result, the authors exhibited an important decrease in friction in coated archwires than in uncoated archwires. On the other hand, when using the solgel method, the temperatures for producing glass, glass/ceramic and ceramic

materials should be lower relative to other methods. Several shapes, including nanospheres or monoliths can be obtained (Arango et al., 2013; Pelaez-Vargas, 2005). Based on the findings of researchers that have used this method to coat SS orthodontic wires, it prevents the occurrence of dental plaque on the wires during treatment and reduces friction between the wires and ceramic brackets. This technique can be used in thin organic films and coatings (Rendón Arias et al., 2008).

2.4.1(b) Physical Vapour Deposition (PVD)

In contrast to CVD, PVD, which influences physical and mechanical characteristics, has been used by many researchers. CVD involves the vaporisation of solids and liquids and using atomic vapour which has been transferred up to thousands of nanometres for multilayer coating, freestanding structures, very thick deposits, and graded composition deposits (Arango et al., 2013). Divisions of this method are evaporation and physical sputtering. Evaporation is the simplest form of PVD. It is used to make film deposits of chemical elements. In this method, the material is heated to temperatures near its fusion or sublimation point. This procedure is carried out in a vacuum system.

In physical sputtering, a material's gaseous ions are accelerated in an electrical field. These energized atomic-sized particles bombard on the solid surface to vaporize atomic or molecular elements from the solid surface (Arango et al., 2013). Many researchers have used this technique to modify the surface of SS and NiTi alloys, and they found that it can be applied in the orthodontic field (Shah et al., 2011). High-energy ionic scattering, magnetron sputtering, and radiofrequency are the divisions of sputtering (Arango et al., 2013).

2.5 Properties of the Aesthetic Archwire

Initially, the coating appears to lower bracket-wire friction; however, with clinical use, the surface unevenness increases (Elayyan et al., 2008). During manufacturing, the stiffness of the archwires can be established without altering the dimensions of the wire by polymerising them adequately and changing fibre geometry and/or the ratios of fibre and matrix materials (Imaia et al., 1999, Zufall & Kusy, 2000). Non-coated wires generate higher forces when loaded and unloaded compared to coated wires of the same nominal diameter.

This results from the thickness of the coating since a wire of slightly lower section are used and should be considered because many orthodontists use the diameter of the archwire as a guide in some medical cases (Elayyan et al., 2010). Stiffness of the PTFE-coated SS archwire is higher than that of non-coated SS wire (Lim et al., 1994) and the PTFE coating prevents the corrosion of the wire (Neumann et al., 2002).

A recent study explored that four tested coated archwires out of eleven revealed unloading forces that were equal to the uncoated wires (Washington et al., 2014). Low unloading forces are necessary. However, they might be inadequate if they are below the optimal range for orthodontic tooth movement. Orthodontists might possibly require larger archwires to obtain the comparable and desired force value but with an increase in friction. The amount of force generated by the archwire is controlled by the friction between the ligature, bracket, and wire. Escalation in deflection results in an acute angle of emergence of the wire from the bracket.

The increase in friction lessen the effect of unloading, intensifies loading forces and may cause harm to the coating (Flanagan, 2015).

2.5.1 Colour Stability

The colour of the aesthetic wires, brackets, and teeth should be similar. Therefore, during orthodontic treatment, colour constancy of the aesthetic archwires bears clinical importance. da Silva et al. (2013a) stated that all the aesthetic archwires examined in their study showed noticeable colour change after 21 days in staining solutions. *In vivo*, these archwires are exposed to forces resulting from chewing and the enzymatic activity in the oral cavity within 3 weeks of use (Abdulkader et al., 2019).

2.5.2 Surface Topography

Surface topography study in the coated archwires showed higher surface unevenness in comparison to the conventional uncoated wires (Doshi & Bhad-Patil, 2011; Zufall & Kusy, 2000). Findings concerning surface evenness and friction varied. While some studies indicated a positive correspondence between surface evenness and frictional resistance, others demonstrated little correspondence between these factors (Farronato et al., 2012). Still, more research is required to prove the fact that coating layers enhance the frictional properties of coated wires. NiTi archwires retrieved from the oral cavity are covered with islands of unstructured precipitants and accrued microcrystalline particles. The archwires have a biofilm composed of proteins with amide, alcohol, and carbonate being the main organic components.

The elemental metals that precipitate on the surface of the material to form NaCl, KCl, and Ca-P precipitates are Na, K, Cl, Ca, and P. The properties of the wire surface that increase are pore size and permeability (Eliades et al., 2000). In comparison to as-received archwires, the surfaces of coated archwires are more uneven after use *in vivo* (Rongo et al., 2013), the main cause being the effect of brushing teeth