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Colour stability of aesthetic brackets: ceramic and plastic

Hibernon Lopes Filho,[*] Lúcio Henrique Maia,[*] Marcus V. Araújo,[*] Carlos Nelson Elias[†] and Antônio Carlos O. Ruellas[*]

Department of Orthodontics, Federal University of Rio de Janeiro (UFRJ) Dental School[*] and Biomaterials Laboratory, Military Institute of Engineering (IME),[†] Rio de Janeiro, Brazil

Background: The colour stability of aesthetic brackets may differ according to their composition, morphology and surface property, which may consequently influence their aesthetic performance.
Aims: To assess the colour stability of aesthetic brackets (ceramic and plastic) after simulating aging and staining.
Methods: Twelve commercially manufactured ceramic brackets and four different plastic brackets were assessed. To determine possible colour change (ΔE^*_{ab}) and the value of the NBS (National Bureau of Standards) unit system, spectrophotometric colour measurements for CIE L*, a* and b* were taken before and after the brackets were aged and stained. Statistical analysis was undertaken using a one-way ANOVA analysis of variance and a Tukey multiple comparison test ($\alpha = 0.05$).
Results: The colour change between the various (ceramic and plastic) materials was not significant ($p > 0.05$), but still varied significantly ($p < 0.001$) between the brackets of the same composition or crystalline structure and among commercial brands.
Conclusion: Colour stability cannot be confirmed simply by knowing the type of material and crystalline composition or structure.
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Hibernon Lopes Filho: hibernonlopes@hotmail.com; Lúcio Henrique Maia: luciohenriquemaia@yahoo.com.br; Marcus V. Araújo: mvaa@uol.com.br; Carlos Nelson Elias: elias@ime.eb.br; Antônio Carlos O. Ruellas: antonioruellas@yahoo.com.br

Introduction

With increasing numbers of adults seeking treatment, the unsightly appearance of fixed orthodontic appliances has become a concern.[1,2] Aesthetic appliances have been introduced to satisfy a clinical demand[3-5] and, as a result, orthodontic material industries have endeavoured to develop alternative appliances, such as lingual brackets, transparent orthodontic aligners (Invisalign®) and transparent or tooth-coloured aesthetic (ceramic and plastic) brackets.[6,7] Of these, the lingual appliances and invisible aligners have the most aesthetic appearance.[6,8] Only aesthetic labial brackets and lingual brackets allow a conventional orthodontic procedures to be performed; however, the colour and stability of labial brackets during treatment are critical factors in enhancing visual perception.

It has been reported that monocrystalline and polycrystalline ceramic brackets are resistant to staining and discolouration caused by orally-ingested substances.[9] Plastic brackets are affected by undesirable darkening (staining) after a short period of time in the oral cavity.[10] However, in use, ceramic and plastic brackets may be affected by a variety of endogenous and exogenous factors.[11,12]

Exogenous discolouration may be caused by food colourings and coloured mouthwashes.[10,13-16] Endogenous discolouration may be in the form of UV irradiation and thermal energy. Ultraviolet light is capable of inducing chemical-physical reactions in the constituent polymer which may cause irreversible colour change in the brackets.[10] The influence of aging or chemical substances on the colour stability of aesthetic brackets may differ according to their composition, morphology and surface characteristics.[9,17,18] Although several studies have assessed the physical and mechanical properties

Figure 1. (a) digital spectrophotometer VITA, (b) prefabricated positioner, (c) spectrophotometer positioned to do the reading and (d) measured according to CIELAB.

of aesthetic brackets,[19,20] there are few studies which have evaluated their optical properties. Accordingly, unlike plastic brackets, generalisations have been made regarding the acceptable colour stability of ceramic brackets.[10,12] No study has compared the colour stability of plastic and ceramic brackets after aging and staining which has likely been due to the technical difficulty in quantifying bracket colour as well as defining their geometry.[4]

The aim of the present in vitro study was to assess the colour stability of commercially manufactured aesthetic (ceramic and plastic) brackets after aging and staining, using the colour change (ΔE_{ab}) formula and the National Bureau of Standards (NBS) System of Units.

Materials and methods

Eighty maxillary right central incisor brackets (0.022 inch slot, Roth prescription) were investigated during the study. Five brackets from each of twelve commercial brands of ceramic brackets and five brackets from each of four commercial brands of plastic brackets were assessed (Table I).

Colour evaluation

Colourimetric reading of the labial surface of the brackets was conducted before and after aging and staining. By means of a prefabricated positioner (Figure 1b) under the same room lighting conditions, recordings were generated by a portable digital spectrophotometer VITA Easyshade® Compact (Germany – Model DEASYC220) (Figure 1a) directed perpendicular to the bracket. The brackets were placed on a mirrored surface (Barasch – Barasch Sylmar – Indústria Metalúrgica LTDA), to avoid background effects[21] and an opaque black cardboard paper mask with a small central window was placed over the bracket[22] to diminish environmental factors (Figure 1c). The reflected colour was assessed in accordance with the Comission Internacional de I'Eclairage (CIE) colour scale, LAB,[23] relative to an illuminant standard D65. This divides colour by means of a mathematical colourimetric process into 3 fields: L* or ΔL*, representing luminosity or colour values (from black to white), a* or Δa* axis, which measures from green to red, and b* or Δb*, which measures the axis from yellow to blue.

Table I. Distribution of groups according to the type of bracket (material), code, brand, batch number and composition/manufacturer.

Type	Code	Brand	Batch number	Composition - manufacturer
Ceramic	RAD	Radiance	REF: 002-7221	Monocrystalline – American Orthodontics, Sheboygan, Wisconsin, USA
	PUR	Pure	LOT: 091211-05	Monocrystalline – Ortho Technology, Florida, USA
	CLY	Clarity	LOT: 013819	Polycrystalline injected, metal slot - 3M Unitek, California, USA
	INV	InVu	LOT: 2848c05	Injected polycrystalline, polymer mesh base – TP Orthod, La Porte, Indiana, USA
	SIG	Signature	LOT: 495-012	Machined polycrystalline – RMO, Denver, Colorado, USA
	TRL	Translux	LOT: 100205	Machined polycrystalline – Aditek lmta, São Paulo, Brazil
	ICR	Iceram	LOT: 0210	Machined polycrystalline – Orthometric, São Paulo, Brazil
	ILS	Illusion	LOT: 366927	Machined polycrystalline – Ortho Organizers, Australia and New Zealand
	MYS	Mystique	REF: 110-112-00	Machined polycrystalline – GAC, Central Islip, NY, USA
	ALR	Allure	REF: 101-112-14	Machined polycrystalline – GAC, Central Islip, NY, USA
	TEC	Tecnident	LOT: 168	Machined polycrystalline – Tecnident, San Carlos, SP, Brazil
	INO	In-ovation	REF: 100-212-00	Self-ligating machined polycrystalline – GAC, Central Islip, NY, USA
	SPR	Spirit MB	PART: 444-0110	Polycarbonate reinforced with ceramic – Ormco, Glendora, California, USA
Plastic	ELT	Elation	REF: 33-112-60	Polycarbonate, metal slot – GAC, Central Islip, NY, USA
	SIL	Silkin Plus	LOT: 002-950M	Filler reinforced plastic – AO Sheboygan, Wisconsin, USA
	COM	Composite	REF: 10.17.001	Composite – Morelli, São Paulo, Brazil

Table II. National Bureau of Standards (NBS) ratings.

NBS unit	Critical remarks of colour differences	
0.0 – 0.5	Trace	Extremely slight change
0.5 – 1.5	Slight	Slight change
1.5 – 3.0	Noticeable	Perceivable
3.0 – 6.0	Appreciable	Marked change
6.0 – 12.0	Much	Extremely marked change
12.0 or more	Very much	Change to other colour

Five measurements were conducted on each bracket after aging and staining. The mean value was subsequently obtained for each test specimen (L*, a* and b*). The colour changes after aging and staining were calculated by the following equation:

$$\Delta E^*_{ab} = [(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2]^{1/2}$$

in which ΔL, Δa and Δb are different from the value of L*, a* and b* before and after each time interval.

The limitation of clinical perception proposed for the colour variation was 3.7 ΔE^*_{ab}.[24] Colour change data (ΔE^*_{ab}) recorded by the spectrophotometer were converted into National Bureau of Standards (NBS) units by the equation: NBS units = ΔE* x 0.92. These values are shown in Table II.[25]

Aging

The test specimens were subjected to aging by irradiation with a Tungsten filament ultraviolet lamp in an atmosphere of mercury vapour[26] at a wavelength of 365 nm, a temperature of 45°C and a relative humidity of 65% (ADA Norm No 27). Aging occurred in a specific machine (Dark Chamber, Model SL-204, Solab, Piracicaba, Brazil) for 14.4 hours, which was equivalent to 3 years of average orthodontic treatment. Twenty-four hours of exposure is known to be the equivalent of 5 years of natural aging (ISO 3336-1977).

Staining

Bracket staining was achieved by the use of two solutions containing coffee (Pilão – Jundiaí/Brasil) and black tea (Leão – Curitiba/Brasil). The coffee solution

Table III. One-way analysis of variance for colour change among the types of materials.

	Sum of squares	df	Mean square	F-value	Significance*
Between groups	.21	1	.21	.02	.90
Within groups	917.32	78	11.76		
Total	917.53	79			

* not statistically significant ($p > 0.05$)

Table IV. One-way analysis of variance for colour change between the brands and brackets of the same crystalline composition/structure.

	Sum of squares	df	Mean square	F-value	Significance*
Between groups	937.49	15	62.50	781.25	.00
Within groups	5.12	64	.08		
Total	942.61	79			
Monocrystalline					
Between groups	215.30	1	215.30	12302.63	.00
Within groups	.14	8	.02		
Total	215.44	9			
Injected polycrystalline					
Between groups	128.16	1	128.16	2488.62	.00
Within groups	.42	8	.05		
Total	128.58	9			
Machined polycrystalline					
Between groups	282.13	6	47.02	1437.33	.00
Within groups	.92	28	.03		
Total	283.05	34			
Plastic					
Between groups	241.63	4	60.41	588.76	.00
Within groups	2.05	20	.10		
Total	243.68	24			

* statistically significant ($p < 0.01$)

was prepared by pouring 500 ml of boiling distilled water through 15 g of coffee placed in a paper filter. The tea solution was prepared by immersing 5 teabags in 500 ml of boiling distilled water for 10 minutes.[27,28] All the test specimens were immersed in the coffee and tea solutions, respectively, for 7 days at 37ºC.[29] After staining, the test specimens were washed with distilled water in an ultrasonic cleaner (Cristófile biosecurity of equipment LTDA; Campo Mourão, PR, Brazil) for 5 minutes and dried with paper towels.[28]

Statistical method

Statistical differences were investigated to assess colour change using the one-way analysis of variance (ANOVA) at a level of significance of 0.05 ($p \leq 0.05$). Furthermore, differences between the brands of brackets were investigated using the Tukey post-hoc multiple comparison test ($\alpha = 0.05$). For tabulation and data analysis, SPSS software version 16.0 was used (Statistical Package for Social Sciences; SPSS Inc., Chicago, IL, USA).

Results

Table III shows the result of the one-way analysis of variance (ANOVA), in which the mean colour changes between the type of materials (ceramic and plastic) were not significantly different ($p > 0.05$). Table IV shows that the colour change was statistically significant ($p < 0.001$) between the brands of brackets and among the brackets of the some composition/crystalline structure. Table V shows the results of colour change (ΔE_{ab}*) with their corresponding NBS units, and the Tukey multiple comparison test.

Table V. Colour change (ΔE_{ab}) and the corresponding NBS value after aging and staining ($\alpha = 0.05$).

	Code	ΔE_{ab}	NBS	Tukey grouping*
		Mean (SD)	unit	
Ceramic	RAD	1.5 (0.5)	1.3	A
	PUR	10.8 (0.8)	9.9	B
	CLY	3.3 (0.8)	3.0	C
	INV	10.6 (1.3)	9.7	B
	SIG	2.3 (0.2)	2.1	D C
	TRL	5.9 (0.7)	5.4	E
	ICR	12.0 (1.1)	11.0	B
	ILS	2.3 (0.9)	2.1	D C
	MYQ	3.3 (1.2)	3.0	C
	ALR	2.8 (0.9)	2.5	C D
	TEC	3.3 (0.6)	3.0	C
	INO	5.6 (1.9)	5.1	E
Plastic	ELT	4.1 (1.3)	3.7	E
	SPR	1.7 (0.6)	1.5	A
	COM	4.2 (0.9)	3.8	F
	SIL	11.1(0.8)	10.2	B

* The means with the same letter showed no significant difference with $\alpha = 0.05$

Discussion

In a survey of 27-year-old people in Sweden, 67% of the interviewees responded that they would accept orthodontic treatment with metal brackets if required, which infers that one third of young adults would refuse to wear non-aesthetic brackets.[30] However, this rate could be even higher in countries where aesthetics has a greater impact and considered desirable. Therefore, selecting brackets that blend with the teeth by approximating colours and translucence as well as colour stability, are prime factors determining aesthetics. Compatibilty may be distinguished visually or by a spectrophotometer; however, the sensitivity of the human eye is limited and interpretation is subjective.[10] The measurements using a spectrophotometer provide greater consistency and reproducibility in the evaluation and in the results.[31-33]

The technical difficulty associated with measuring the colour of aesthetic brackets may be the principal reason accounting for the lack of colour research. The difficulty has been caused by bracket geometry, their small and irregular morphology, as well as the disadvantage of using a spectrophotometer as it is designed to measure flat surfaces.[22,34,35] To avoid environmental factors, a black opaque cardboard mask with a bracket-sized central window was used,[21,22] and measurements were conducted under the same room lighting conditions.

Prosthetic and restorative dentistry have employed several techniques to study the discolouration of dental products. The method of accumulated discolouration by accelerated aging and staining by immersion in solutions such as coffee, tea, grape juice, wine, coca-cola and chlorhexidine have been used for in vitro simulations.[10,33,36,37] It has been shown that the type of solution and the exposure time significantly influence the level of colour change. Coffee, tea and wine are known to cause the greatest staining.[10,26,34] In the present study, the staining with coffee and tea for 7 days and 3-year artificial aging with UV light (ISO 3336-1977) were assumed and expected to produce bracket discolouration.

The present study noted colour change (ΔE_{ab}*) in ceramic as well as in plastic brackets (Figure 2) to the same level of statistical significance ($p > 0.05$). This

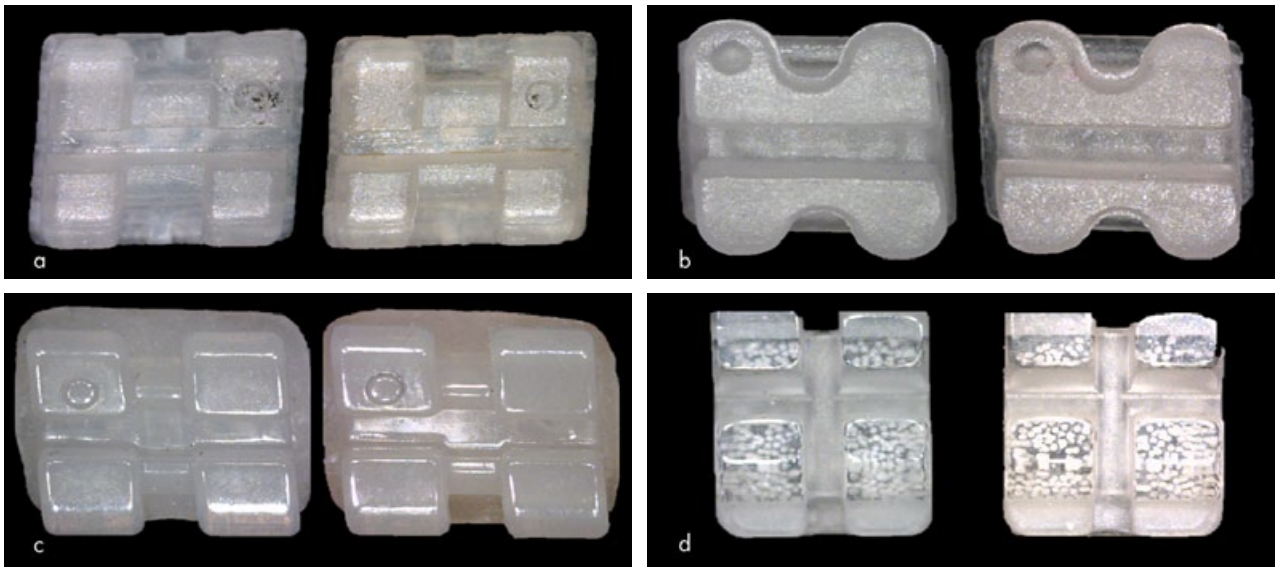

Figure 2. Brackets before and after staining and artificial aging. (a) plastic bracket, (b) machined polycrystalline ceramic brackets, (c) injection molded polycrystalline ceramic brackets and (d) monocrystalline ceramic bracket.

finding contradicts previous reports which indicated that ceramic brackets presented colour stability.[9] Additional studies confirmed that colour stability not only depended on the type of material (polycarbonate or ceramic) and crystalline structure (monocrystalline or polycrystalline),[12] but was also determined by bracket morphology (size and shape) and surface properties (roughness and surface energy).[11,12]

Generally, values of ΔE^* with a variation of 1 unit are considered a colour change. However, small changes of this order cannot be discerned by the human eye.[31] Although it has been suggested that differences of 2 units may indicate colour change,[38] most studies accept the colour limit equal to 3.7 units. Under these circumstances colour differences are clinically discernable.[28]

Dental materials literature has used ΔE_{ab} values to assess visually perceptible colour changes.[13-16,25,26,31] Unfortunately, the criteria for evaluating brackets have not yet been clearly defined. Due to the lack of clarity, the present study used the NBS System of Units to determine the degree of colour difference but ΔE_{ab} values may be converted for observations with clinical significance.[29] According to the current NBS calculations, it was found that bracket colour change ranged from slight to extremely accentuated (1.3 to 11.0 NBS units).

The clinically significant colour change ($\Delta E_{ab}^* > 10$) and extremely accentuated change (0.6 to 12.0 NBS units) was found for the plastic brackets (SIL) (Figure 2a) and the machined polycrystalline ceramic brackets (ICR) (Figure 2b), injection molded polycrystalline (INV) (Figure 2c) and monocrystalline (PUR) brackets (Figure 2d). The RAD and SPR brands showed the best results ($\Delta E_{ab}^* = 1.5$ and 1.7 respectively, $\alpha = 0.05$) and NBS unit values lower than 1.5, indicated a slight and visually imperceptible change. Due to their translucence, tooth colour was mimicked. However, when selecting brackets for clinical use, in addition to their optical properties, their physical and mechanical properties related to bonding, friction and fracture strength, must be taken into consideration. Therefore, further studies are required to evaluate these additional factors.

At present, machined polycrystalline ceramic brackets are more clinically popular due to their ready availability and competitive cost. According to the present results, ceramic brackets with $\Delta E_{ab}^* < 3.7$, and CLY injected molded polycrystalline brackets possessed good colour stability. TRL, ICR and INO ($\Delta E_{ab}^* > 3.7$) were the exception among the evaluated brands, as these brackets had a more milk-like colour and further clinical comparative studies are indicated.

It has been shown that the colour stability of plastic brackets increases as the filling level of UDMA

(Urethane dimethacrylate) increases.[5,10] The greater filler content reduces the susceptibility of discolouration caused by UV light. However, the colour stability of composite resins is also determined by chemical differences, polymer structure, residual monomers and the concentration of amines and diketones.[39] The oxidation of bonding agents that did not react in the polymer matrix and the subsequent formation of degradation products, due to the diffusion of water or polymer oxidation, are other factors responsible for the discolouration of plastic brackets.[40]

To reduce these undesirable effects of discolouration and improve optical properties and the cost/benefit ratio, the manufacturers tend to reinforce plastic with ceramic, as is the case with SPR, which provides acceptable aesthetics. However, further studies are required to evaluate long-term changes caused by the effects of polycarbonate degradation by microorganisms and oral fluids on the optical, physical and mechanical properties of materials.

Conclusion

From this in vitro study it was concluded that colour stability varied according to the manufacturer and that colour stability cannot be confirmed simply by knowing the type of material and crystalline composition/structure.

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Corresponding author

Professor Antonio Carlos de Oliveira Ruellas
Department of Orthodontics
Federal University of Rio de Janeiro – UFRJ
Av. Professor Rodolpho Paulo Rocco
Ilha do Fundão
Rio de Janeiro
Brazil

Email: antonioruellas@yahoo.com.br

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