Original Article

Elemental Composition of Brazing Alloys in Metallic Orthodontic Brackets

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Abstract: The aim of this study was to assess the elemental composition of the brazing alloy of representative orthodontic brackets. The brackets examined were Gemini (3M, Unitec, Monrovia, Calif), MicroLoc (GAC, Bohemia, NY), OptiMESH^{xrt} (Ormco, Glendora, Calif), and Ultratrim (Dentarum, Ispringen, Germany). Four metallic brackets for each brand were embedded in epoxy resin and after metallographic grinding and polishing were cleaned in a water ultrasonic bath. Scanning electron microscopy and energy-dispersive x-ray microanalysis (EDS) were used to assess the quantitative composition of the brazing alloy. Four EDS spectra were collected for each brazing alloy, and the mean value and standard deviation for the concentration of each element were calculated. The elemental composition of the brazing alloys was determined as follows (percent weight): Gemini: Ni = 83.98 ± 1.02, Si = 6.46 ± 0.37, Fe = 5.90 ± 0.93, Cr = 3.52 ± 0.34; MicroLoc: Ag = 42.82 ± 0.18, Au = 32.14 ± 0.65, Cu = 24.53 ± 0.26, Mg = 1.12 ± 0.33; OptiMESH^{xrt}: Au = 67.79 ± 0.97, Fe = 15.69 ± 0.29, Ni = 13.01 ± 0.93, Cr = 4.01 ± 0.35; Ultratrim: Ag = 87.97 ± 0.33, Cu = 10.51 ± 0.45, Mg = 1.29 ± 0.63, Zn = 1.13 ± 0.24. The findings of this study showed that different brazing materials were used for the different brands, and thus different performances are expected during intraoral exposure; potential effects on the biological properties also are discussed. (*Angle Orthod* 2004;74:394–399.)

Key Words: Brazing filler alloy; Brackets

INTRODUCTION

Manufacturing of orthodontic brackets involves a wide array of raw materials (metal alloys, ceramic, plastic), various designs, and a variety of methods. Metallic brackets are the most commonly used appliances in orthodontic therapy, and they are fabricated by three main methods: casting, injection molding, and milling,[1] which may be used in combination. The materials used in the manufacturing of base and wing components of metallic brackets are mostly austenitic-type stainless steel alloys (303L, 304L, 316L, PH 17–4),[1,2] and Ti has recently been introduced for the same purpose.[3,4]

The attachment of the mesh to the base is achieved using brazing methods for stainless steel or laser welding for Ti brackets.[5] In the first case, special brazing filler alloys are applied between the bracket base and wing interface. In general, stainless steel alloys are relatively easy to braze, although some alloys that contain Ti or Al require additional precautions to avoid oxidation during the brazing cycle. The brazeability of these steels may change depending on alloy composition, whereas the quality of brazed joints depends on the selection of brazing process, temperature, filler metal, and the type of protective atmosphere or flux that is used. Most stainless steel alloys can be brazed with any one of several different filler metal families, including Ag, Ni, Cu, and Au.[6]

Initially, SS brackets were brazed with Ag-based filler alloys, which are also the most frequently used brazing filler metal for SS in industrial applications.[6] Unfortunately, the orthodontic silver brazing alloys suffered from the presence of Cd,[7] which was added to lower the melting temperature and to improve wetting.[6] Moreover, Ag-based brazing alloys introduce a galvanic couple with SS alloys, inducing release of metallic ions with Cu and Zn, the elements most easily leached out from Ag brazing alloys.[8,9]

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TABLE 1. Commercial Names, Lot Numbers and Manufacturers of Brackets that were Tested

Brand Name	Lot Number	Manufacturer
Gemini	N3752	3M Unitek, Monrovia, Calif
MicroLoc	11779	GAC, Bohemia NY
OptiMESH^{XRT}	00F660F	Ormco, Glendora, Calif
Ultratrim	148257	Dentaurum, Ispringen, Germany

Previous studies have demonstrated that brazing alloys that contained Cu and Zn had the highest cytotoxic effect among orthodontic metallic materials.[9–11] This galvanic corrosion is the main reason for the progressive dissolution of brazing filler metal, leading to detachment of the wing from the bracket base during orthodontic therapy or at the debonding stage.[1] Finally, almost all except the two Ag-based brazing alloys are used at brazing temperature within the range of sensitizing temperatures (540°C to 870°C) for austenitic stainless steels used for the manufacture of base and wing components. Chromium carbide precipitation occurs in the sensitizing temperature range, which impairs the corrosion resistance of the base metal.[6]

To overcome this problem, several manufacturers have introduced Au-based brazing materials. However, this may lead to dissolution of stainless steel, which is less noble than the gold alloys, and this may be the explanation for the in vivo corrosion of bracket bases[12,13] as well as for Ni leaching from SS alloys.[14] Metal ion release from brackets and orthodontic appliances,[15] in general, is of great concern because of the adverse effects of allergic reactions or because of cytotoxic effects.[16] The relevant literature shows a lack of evidence on this very important issue, which modulates the corrosion resistance and biological properties of orthodontic alloys.

The aim of this study was to assess the elemental composition and the microstructure of brazing filler metals of several commercially available orthodontic brackets.

MATERIALS AND METHODS

Four metallic orthodontic brackets from each of the brands listed in Table 1 were embedded in epoxy resin. Specimens were ground with water coolant SiC papers from 220 to 2000 grit until the cross-section of the base-wing interface was observed, polished up to 0.05 μm alumina suspension (Bueller, Lake Bluff, Ill) in a grinding-polishing machine (Ecomet III, Bueller), and cleaned in an ultrasonic water bath for five minutes.

The polished specimens were vacuum-coated with a thin layer of conductive carbon. The brazing zone was studied under a scanning electron microscope (Quanta 200, FEI, Hillsboro, Ore), whereas the elemental composition of brazing filler material was determined using a Si(Li) energy-dispersive x-ray microanalysis (EDS) detector (Sapphire, EDAX, Mahwah, NJ) with super ultrathin window (Be). Four EDS spectra were collected from each brazing alloy under a 25 kV accelerating voltage 100 μA beam current using an area analysis mode at 2000× magnification, a 64 × 64 μm sampling window, and 150 seconds of acquisition time. The quantitative analysis of the percent weight concentration was performed by nonstandard analysis using the atomic number, absorption and fluorescence correction method (ZAF).

RESULTS

Backscattered electron images demonstrated that all brackets tested consist of base and wings as separate components, joined together by the use of brazing fillers metals. The brazing zones for Gemini (Figure 1A), MicroLoc (Figure 1B), and Ultratrim (Figure 1D) can be clearly distinguished from their base and wing brackets components. However, for OptiMESH^{XRT} (Figure 1C), it seems that a transition zone connects the brazing alloy with base and wing components. Figure 2 demonstrates EDS spectra obtained from the surface of Gemini, MicroLoc, OptiMESH^{XRT}, and Ultratrim. The elemental composition of each brazed area as determined by EDS analysis is shown in Table 2.

DISCUSSION

The results of this study show that each manufacturer uses different alloys for brazing brackets components. A Ni-based alloy is used for the brazing of Gemini brackets composed of all elements of BNi-2 (Cr: 6.0–8.0, B: 2.75–3.5, Si: 4.0–5.0, Fe: 2.5–3.5, Ni: balance, other elements: $<$ 0.74),[6] which is a standard brazing filler alloy of the Ni family. The quantitative differences in elemental compositions and the results of Table 2 should be considered along with the fact that B cannot be detected by EDS analysis.

A predominantly ternary brazing alloy composed of Ag, Au, and Cu is used for brazing of MicroLoc brackets. The elemental composition of this two-phase alloy (Figure 1B) cannot be classified under Ag- or Au-based families.[6]

An Au-based alloy, containing Fe, Ni, and Cr, was chosen for OptiMESH^{XRT} brackets and is also a nonstandard brazing filler alloy for stainless steel brazing. Although the microstructure of this alloy resembles that of the eutectic with large preutectic grains and eutectic regions, it is not a eutectic one. The percentage of Fe is much less than that required for the eutectic reaction in Au–Fe binary-phase diagram. The eutectic-like phases are attributed to a significant mutual decrease in solid solution of these elements under 810.3°C, and thus, during cooling, plates rich in Au and Ni are developed by the decomposition of the Au–Ni solid solution.[17] Moreover, this is the only brazing joint that demonstrates a transition zone with bracket base and wing regions. This may be explained by the fact that when Au-based brazing alloys are used, there is a minimal alloying with stainless steel–alloys, and therefore joints exhibit good ductility, strength, and corrosion resistance.[6]

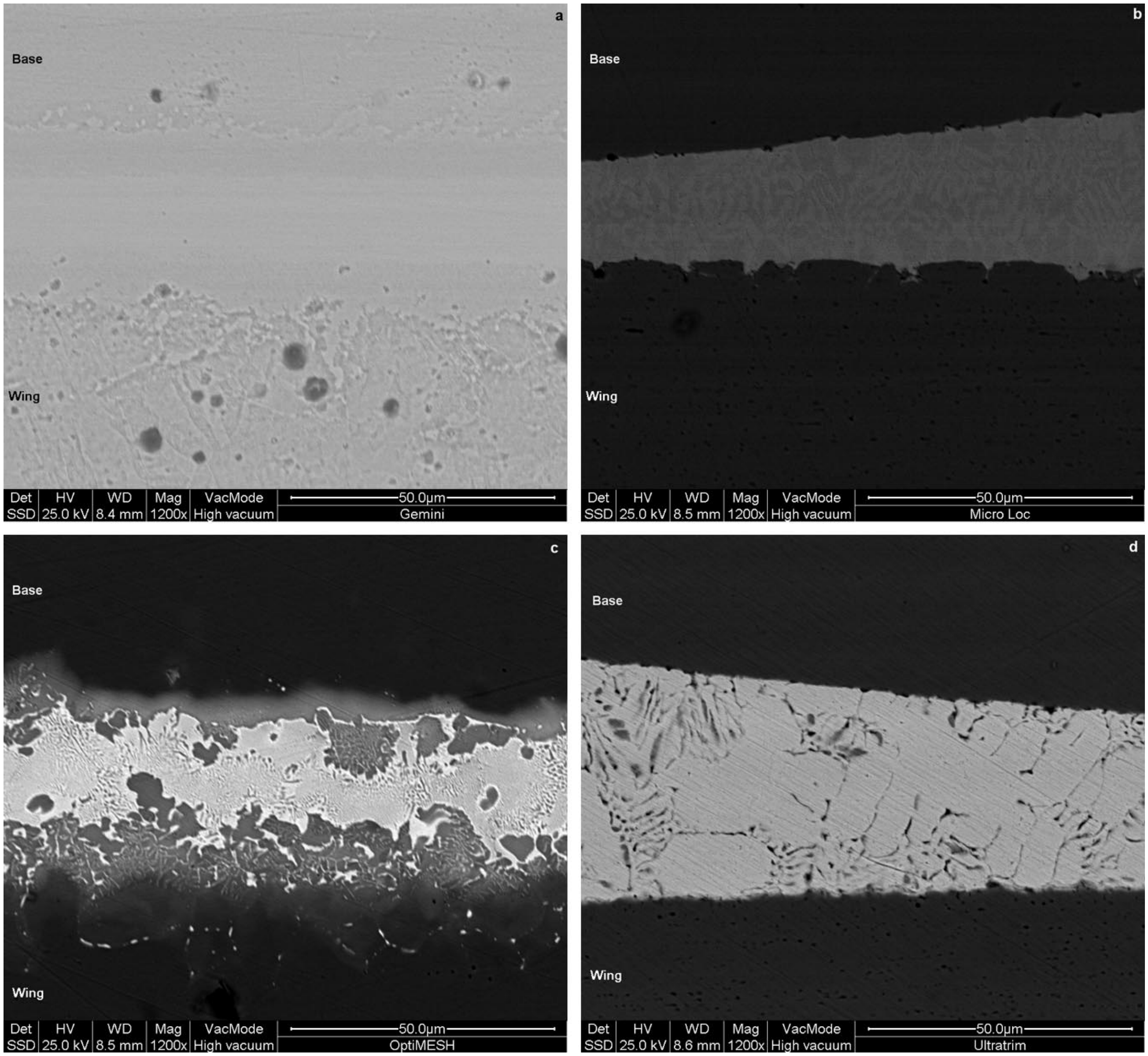

FIGURE 1. Backscattered electron images from the polished surfaces of brackets tested. (a) Gemini, (b) MicroLoc, (c) OptiMESH^{XRT}, and (d) Ultratrim. The brazing zones are clearly distinguished from the base and wing components for Gemini, MicroLoc, and Ultratrim brackets, whereas OptiMESH^{XRT} demonstrates a transition zone between brazing alloy and brackets components. Backscattered electron images demonstrate a single-phase brazing alloy for Gemini but two-phase alloys for the remaining ones. (Original Magnification 1200×.)

The elemental composition of brazing alloy used for the Ultratrim brackets is similar to the standard BAg-19 brazing alloy (Ag: 92–93, Cu: balance, other elements: 0.4).[6] The microstructure of this alloy clearly demonstrates the characteristic eutectic regions (lamellar black and white regions) and the presence of the preutectic large grains (white regions).

3M/Unitek uses an Ni-based alloy for the brazing area of Gemini brackets. The amount of Ni used in brazing fillers in Gemini brackets could generate questions about its biocompatibility, given that ion release can take place by in vivo corrosion of orthodontic appliances.[14,16,18] It is well known that allergic reactions[19–20] to this element has been an important concern among the manufacturers of biomaterials. For this reason, the new SS alloys with lower concentrations of Ni have been introduced for the manufacturing of base and wing components.[21] Ormco also uses an Au-based brazing alloy for OptiMESH^{XRT} brackets, with much lower Ni concentration (Table 2) compared with Gemini. However, it should be noted that the release rate of metallic ions is not proportional to their concentration[22] but depends mainly on the alloy's corrosion resistance during intraoral exposure. On the other hand, the presence of Cu in two brazing alloys (MicroLoc and Ultratrim) raises

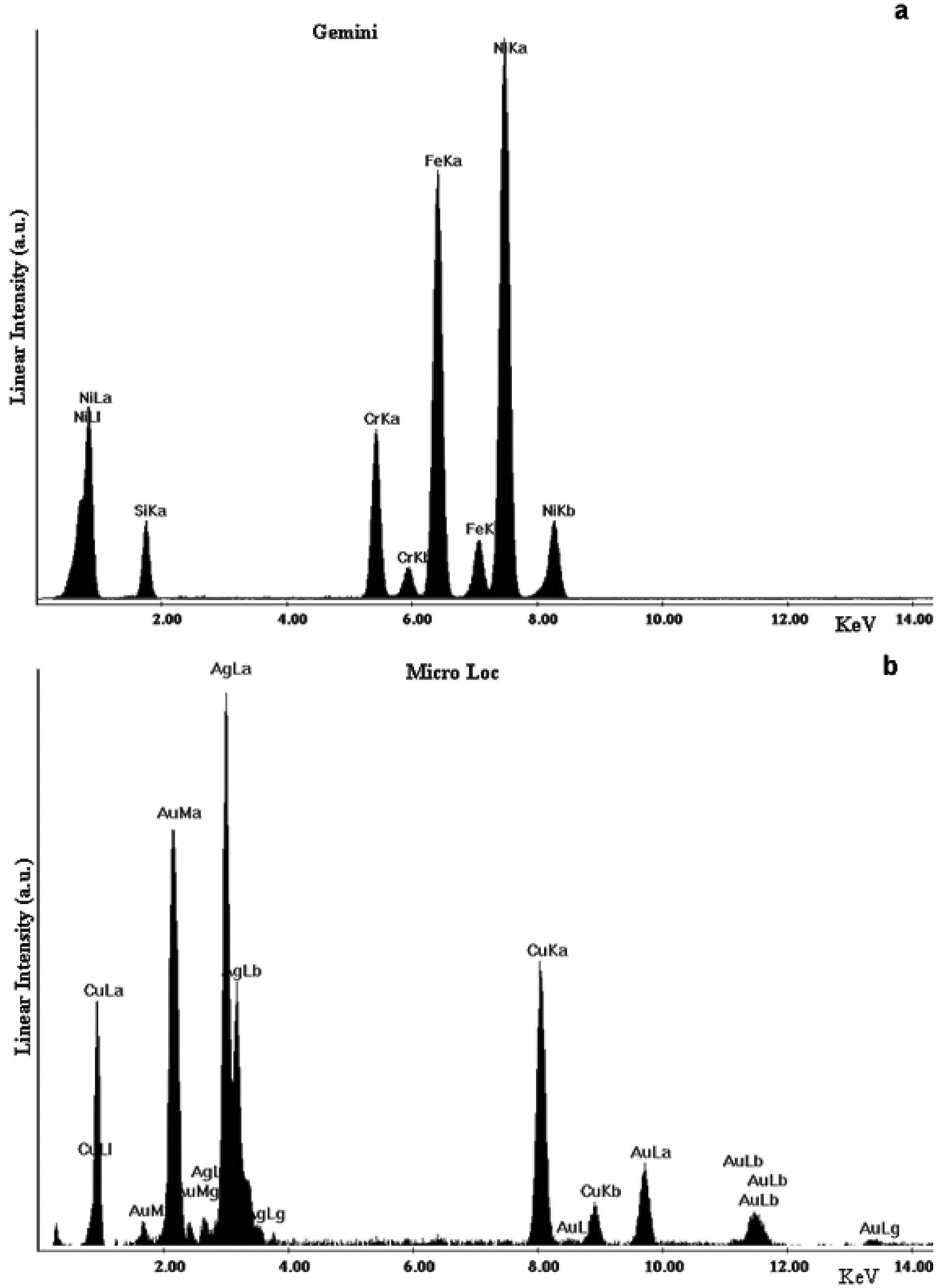

FIGURE 2. Spectra from energy-dispersive x-ray microanalysis analysis of brazing filler materials. (a) Gemini, (b) MicroLoc, (c) OptiMESH ^{XRT}, and (d) Ultratrim.

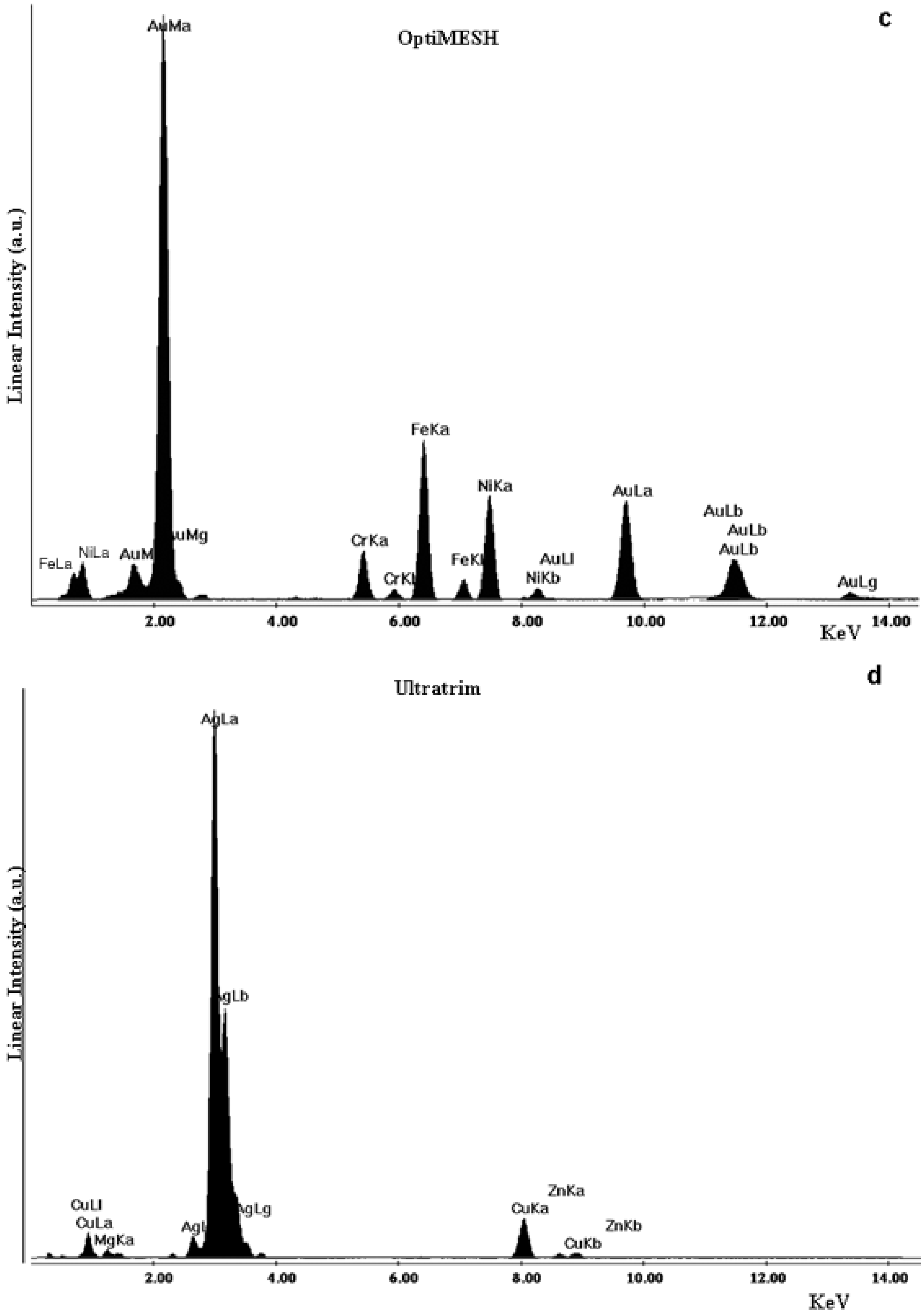

FIGURE 2. Continued.

TABLE 2. Elemental Composition (wt%) of Brazed Areas as Determined by energy-dispersive x-ray microanalysis (EDS) for All the Brackets Tested

Elements	Gemini	MicroLoc	OptiMESH^{XRT}	Ultratrim
Ag		42.82 ± 0.18		87.97 ± 0.33
Au		32.14 ± 0.65	67.79 ± 0.97	
Cr	3.52 ± 0.34		4.01 ± 0.35	
Cu		24.53 ± 0.26		10.51 ± 0.45
Fe	5.90 ± 0.93		15.69 ± 0.29	
Mg		1.12 ± 0.33		1.29 ± 0.63
Ni	83.98 ± 1.02		13.01 ± 0.93	
Si	6.46 ± 0.37			
Zn				1.13 ± 0.24

some concerns about the biocompatibility of these alloys, given that previous studies have shown that brazing alloys with Cu and Zn demonstrated higher cytotoxic effect.[9–11]

Apart from the concern about potential adverse biological effects of specific elements contained in brazing alloys, the electrochemical properties of the latter play a crucial role for the corrosion resistance of the bracket. The galvanic couple of a brazing alloy with SS may lead to the progressive dissolution of the less noble alloy. This may be the explanation for the Ni release in vivo[14] from the SS alloy, PH 17–4, used for the wing region of OptiMESH^{XRT} brackets.[21] In contrast, Ni did not dissolute from the 316 SS[14,21] used for the productions of base area, probably because of a higher corrosion resistance of this alloy. No information is currently available on the in vivo dissolution of the other brackets included in this study.

The large differences in the choice of brazing alloys imply that brazing technology has not attained a standard for bracket brazing. However, it must be noted that all the families of brazing alloys for SS have comparative disadvantages for bracket brazing technology. Ag-based alloys demonstrate severe limitations that are presented in the Discussion section, whereas Ni-based alloys raise serious concerns about their biocompatibility. Cu-based alloys have not been used, probably because of the high dissolution of Cu in biological environments.[8] Au-based brazing alloys are costly and have implications for the in vivo dissolution of SS alloys and for Ni release.[14] However, the selection of an optimum brazing alloy is a real challenge for the brazing technology because this material should fulfill a wide range of metallurgical, corrosion resistance, and biological criteria including (1) compatibility with SS, (2) brazing cycle outside the sensitizing temperatures of SS, (3) mechanical strength of jointed parts, (4) freedom from elements with adverse biological effects (Cd, Ni, Cu, Zn, etc), and (5) galvanic compatibility with SS alloys used for the base and wing components. It seems that there is no brazing material satisfying all the foregoing requirements, and thus, development of novel brazing alloys for orthodontic applications constitutes an important area for future research.

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