Distortion of cobalt-chromium frameworks induced by laser-welding

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Purpose: This study examined the amount of distortion of prosthetic metal frameworks caused by laser welding when the welding pattern and the method of fixing the ends of the specimens in the jig were varied during the welding process.
Materials and Methods: Wax plate patterns (0.5x3.0x10 mm) were prepared to cast the Co-Cr plates. After the welded surfaces (3.0x0.5 mm) were polished with No. 600 SiC paper, the two plates were matched and welded with a Nd:YAG laser at constant welding parameters. The specimens were welded unilaterally or bilaterally with either three or five spots as follows: two ends fixed unilaterally (A) or bilaterally (AA), one end fixed unilaterally on one surface (B), two ends fixed on one surface with the opposite surface fixed at one end (AB), or one end fixed bilaterally on two surfaces (BB). The bilateral specimens were made by inverting the unilateral specimens and welding them on the other side opposite the first weld. Distortion was determined by measuring the gap from the jig base at one end of the plate after each welding application. The results (n=3) were analyzed using a two-way ANOVA and Tukey's HSD ($p<0.05$).
Results: Compared to the two-end fixed specimens (A and AA), the specimens fixed at only one end on either surface (B, AB, and BB) had significantly more distortion. When both ends were fixed (A and AA), more distortion appeared to occur for three-spot welding compared with five-spot welding.
Conclusion: The method of fixing the ends of the specimens in the jig significantly affected the amount of distortion for both the three- and five-spot welding patterns. **(Int Chin J Dent 2005; 5: 47-51.)**

Key Words: cobalt-chromium, distortion, laser welding, metal framework.

Introduction

Due to its convenience, laser welding has gained popularity in the past decade for connecting metal prosthetic frameworks. Since the laser energy is concentrated on a small area, the effect of heating around the weld is reduced. Thus, broken metal frameworks that include combustible acrylic can be repaired using laser welding, preserving any denture base resin already affixed to the framework. Other advantages of laser welding are: 1) Oxidation on the area surrounding the welding spot can be minimized because of the argon shielding capability of the welding machine; 2) any type of dental alloys, including titanium, can be welded, and 3) there is no need for extra materials and equipment such as investment, flux, a furnace or a gas torch, as needed for conventional soldering. The disadvantage of laser welding is that it is troublesome to fill the large space left after cutting the framework because of the small welding area (adjustable spot diameter: 0.2-2.0 mm).

There have been numerous studies on laser welding, most of them dealing with the mechanical strength of welded joints.[1-9] In our previous studies using titanium[7,9] and Co-Cr alloy,[8] laser welding was proven to produce joint strength equivalent to that of the non-welded parent alloys. One of the focuses of research connecting the parts of frameworks is distortion, which directly affects the dimensional integrity of prostheses. Although conventional soldering is known to create distortion,[10-13] there is little information about distortion induced by laser welding.[14,15] Huling and Clark[14] evaluated three different joint-forming procedures: laser welding, soldering, and one-piece casting. They reported that there is significantly less post-joining distortion for laser-welded and one-piece castings than for soldering, and significantly greater reliability (the least error variance) for joining with the laser than either one-piece casting or soldering. Iwasaki et al.[15] investigated the distortion of laser-welded titanium, and reported smaller distortion for two-side welding compared to one-side welding and that pre-welding significantly reduced the distortion by stabilizing the welding assembly. In clinical practice, laser welding is always performed on the master cast as shown in Fig. 1. Note that the metal framework is tightly screwed onto implant analogs on the master cast. After the top is welded, the metal framework sometimes distorts when the bottom is welded after the framework is unscrewed and removed from the implant analogs.

This study examined the distortion of metal frameworks caused by laser welding when the welding pattern and the method of fixing the ends of the specimens in the jig were varied during the welding process.

Materials and Methods

The alloy used in this study was a Co-Cr alloy (60.6% Co, 31.5% Cr, 6.0% Mo; Vitallium, Austenal, Chicago, IL, USA).

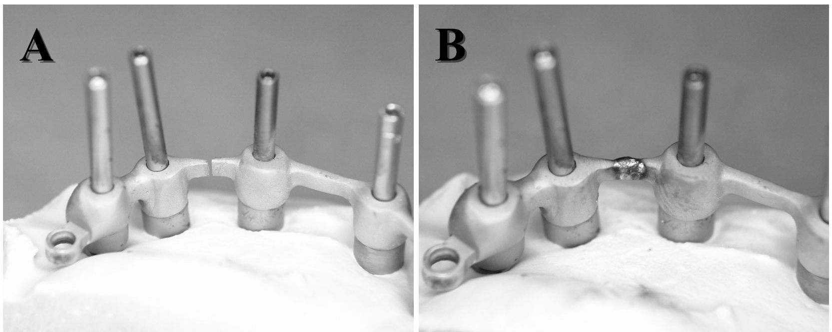

Fig. 1. Metal framework for implant supported superstructure screwed onto implant analogs of the master cast before (A) and after (B) laser welding.

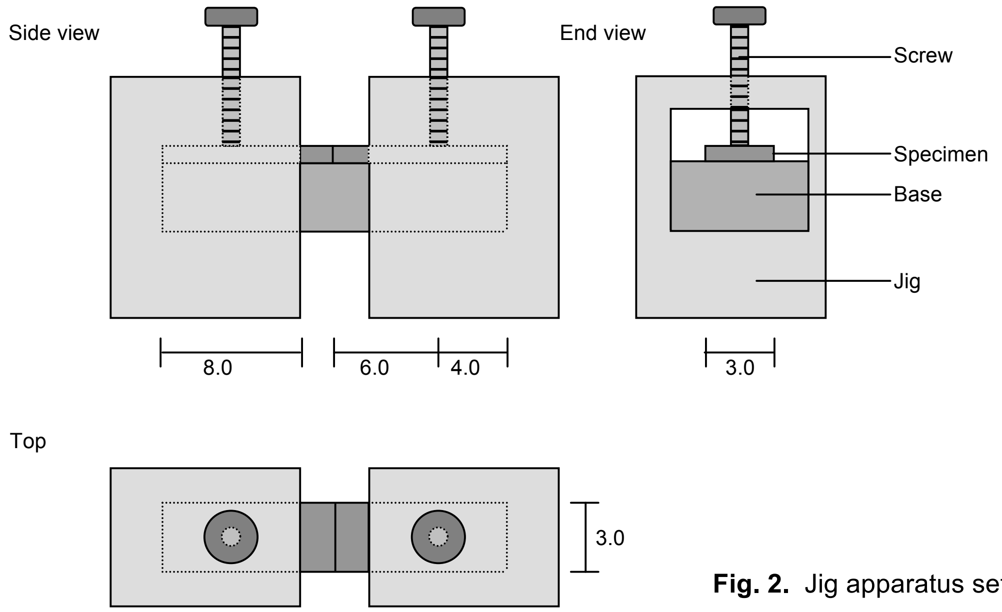

Fig. 2. Jig apparatus setup (unit: mm).

To prepare the cast Co-Cr plates, wax plate patterns (0.5x3.0x10 mm) were invested in mold rings using a phosphate investment (V.R. Investment, Austenal). The Co-Cr alloy ingots were then cast using an induction-melting centrifugal casting machine (Modular 4, CMP Industries Inc., Albany, NY, USA). After the cast surfaces were air-abraded with 50 µm Al_2O_3 particles, the welded surfaces (3.0x0.5 mm) were polished with No. 600 SiC paper, and the two plates were matched and butted together.

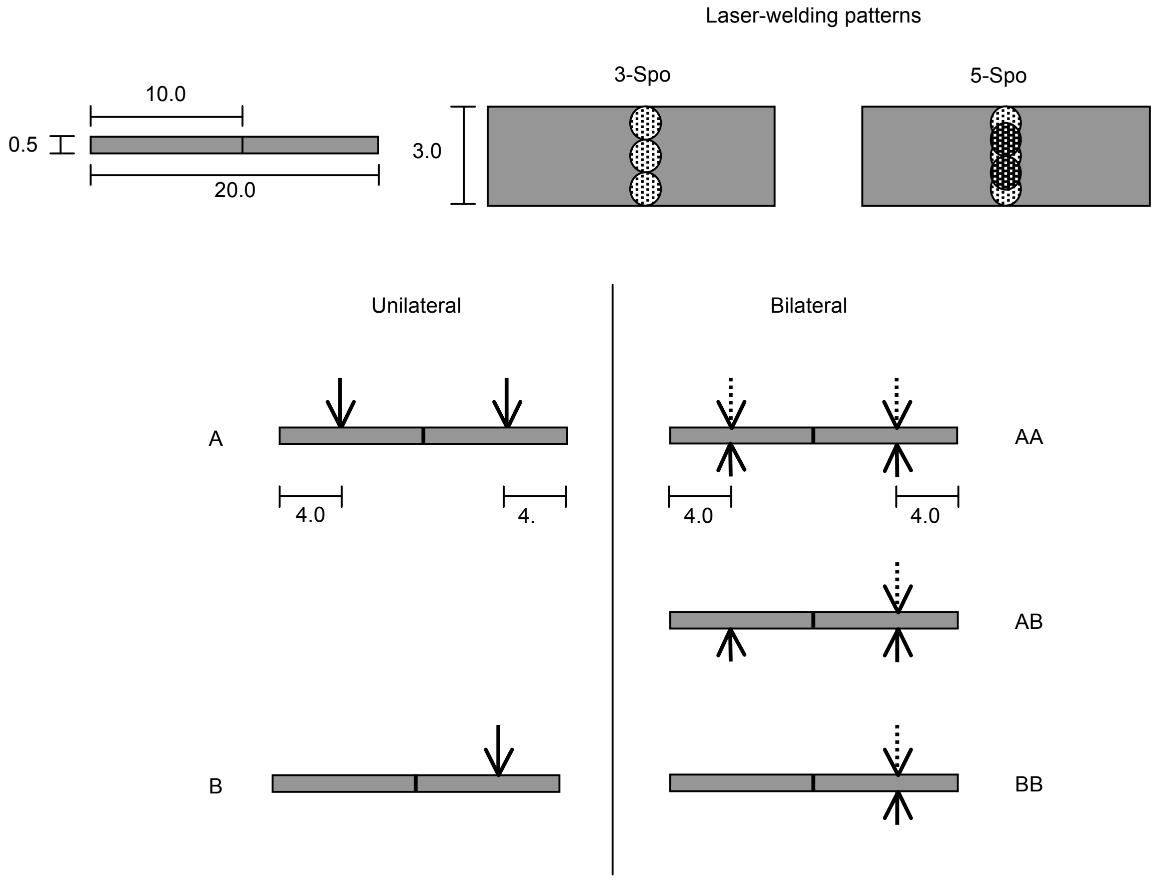

Fig. 3. Experimental patterns for laser welding and fixing the ends of specimens (unit: mm).

Welding was performed with a Nd:YAG laser (Neolaser L, Girrbach Dental Systems, Pforzheim, Germany) at a constant voltage of 200 V, pulse duration of 10 ms, and spot diameter of 1 mm. The specimens were welded using a jig apparatus (Fig. 2). Methods of laser welding and fixing the specimens in the jig are shown in Fig. 3. Either three or five spots were applied unilaterally or bilaterally. Specimens welded with two ends fixed unilaterally (A) or bilaterally (AA) in the jig served as controls. The non-control group specimens had one end fixed unilaterally on one surface (B), two ends fixed on one surface with the opposite surface fixed at one end (AB), or one end fixed bilaterally on two surfaces (BB). Bilateral specimens were made after inverting the unilateral specimens (AA from A, AB from A, BB from B). Distortion was determined by measuring the gap from the jig base at one end of the plate after each welding application. Three specimens were evaluated for each experimental condition. The results (n=3) were analyzed using a two-way ANOVA and Tukey's HSD ($p<0.05$).

Results

Distortions (mm) induced by laser-welding for each experimental condition are summarized in Fig. 4. Statistical significance was found in the fixed condition factor ($F=49.965$, $p<0.001$). Compared to the two ends-fixed specimens (A and AA), the specimens fixed at only one end on either surface (B, AB, and BB) were significantly more distorted. When both ends were fixed (A and AA), there appeared to be more distortion for three-spot welding compared with five-spot welding.

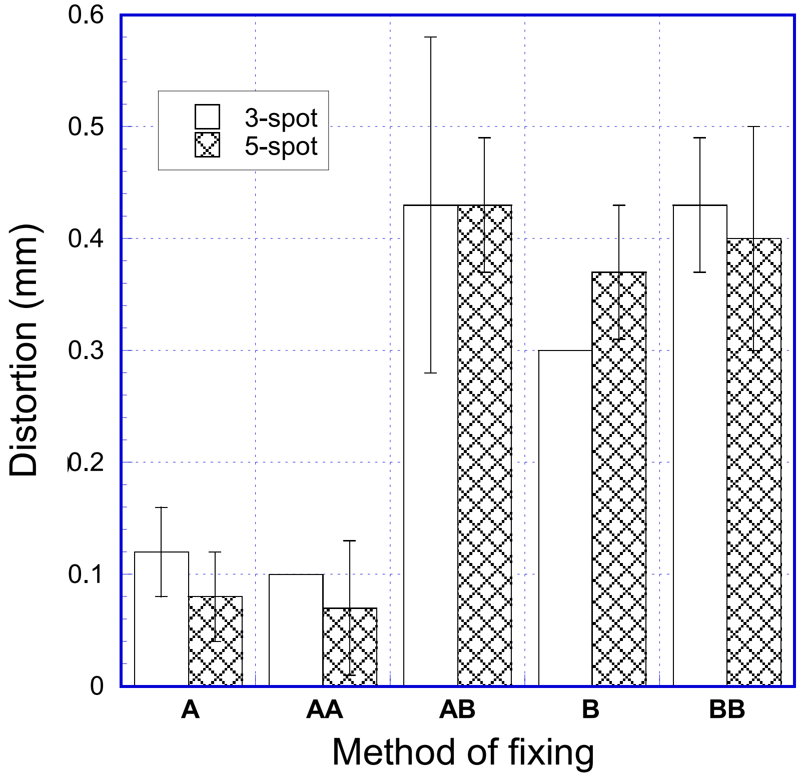

Fig. 4. Distortion induced by laser welding.

Discussion

Compared to groups A and AA in which both ends were fixed (for both the three-spot and five-spot welding methods), distortion of the Co-Cr metal specimens increased significantly for those experimental groups with only one end fixed (AB, B, and BB) (Fig. 4) because the other end of these specimens was free to distort. When both ends were fixed either unilaterally (A) or bilaterally (AA), more distortion was found using the three-spot welding pattern compared with the five-spot welding pattern. Since the welded area covering the joint width was smaller with three spots compared to the area covered by five spots, the weld joint strength of the Co-Cr plates was stronger with five spots. The stronger joint produced by five spots might reduce the residual stress induced by laser welding when the specimens are tightly fixed at both ends. The relief of residual stress was also compared in the specimens welded unilaterally and bilaterally. Bilaterally welded specimens (AA) should have a larger welded area and higher strength compared with the unilaterally welded specimens (A). As a result, there was less distortion of the bilaterally welded specimens compared to the unilaterally welded specimens for both three-spot and five-spot welds. Distortion takes place in the direction of the welded side because of the melting-solidification process that causes metal shrinkage and induces residual stress on the welded side of the two plates.

When the specimens were fixed at one end (AB, B, and BB), the one fixed end and unilaterally welded (B) specimens had the least distortion compared with the two ends fixed on one surface with the opposite surface fixed at one end (AB) and one end fixed bilaterally on two surfaces (BB) (Figs. 3 and 4). This finding can also be attributed to the difference in the number of laser shots. Under these conditions, since the specimens were fixed at only one end, the residual stress at the welded region was freed. Consequently, increasing the number of laser shots (AB and BB > B) increased the amount of residual stress and resulted the increase of distortion. From the results obtained in this study, it is suggested that the metal framework should be tightly fixed at a certain position to prevent the distortion during the laser welding. In the clinical case shown in Fig. 1, making an access hole in the casting beneath the framework enabled us to weld the bottom of the framework without removing it from the implant analog on the cast and minimizes the occurrence of distortion on the welded metal framework.

Conclusion

The method of fixing the ends of the specimens in the jig significantly affected the amount of distortion for both the three- and five-spot welding patterns. To minimize the occurrence of distortion on the welded specimens, both ends should be fixed in the jig. Once they are tightly fixed, the distortion may decrease with a greater number of bilaterally-applied laser spots.

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References

1. Yamagishi T, Ito M, Fujimura Y. Mechanical properties of laser welding of titanium in dentistry by pulsed Nd: YAG laser apparatus. J Prosthet Dent 1993; 70: 264-72.
2. Berg E, Wangner WC, Davik G, Dootz ER. Mechanical properties of laser-welded cast and wrought titanium. J Prosthet Dent 1995; 74: 250-7.
3. Wang RR, Welsch GE. Joining titanium materials with tungsten inert gas, laser welding and infrared brazing. J Prosthet Dent 1995; 74: 521-30.
4. Neo TK, Chai J, Gibert JL, Wozniak WT, Engelman MJ. Mechanical properties of titanium connectors. Int J Prosthodont 1996; 9: 379-93.
5. Chai T, Chou CK. Mechanical properties of laser-welded cast titanium joints under different conditions. J Prosthet Dent 1998; 79: 477-83.
6. Watanabe I, Liu J, Atsuta M. Effect of heat treatment on mechanical strength of laser welded equi-atomic AuCu-6at%Ga alloy. J Dent Res 2001; 80: 1813-7.
7. Liu J, Watanabe I, Yoshida K, Atsuta M. Joint strength of laser welded titanium. Dent Mater 2002; 18:143-8.
8. Baba N, Watanabe I, Liu J, Atsuta M. Mechanical strength of laser-welded cobalt-chromium alloy. J Biomed Mater Res 2004: 69B: 121-4.
9. Watanabe I, Topham DS. Tensile strength and elongation of laser-welded Ti and Ti-6Al-7Nb. J Biomed Mater Res 2004; 71B: 46-51.
10. Willis LM, Nicholls JI. Distortion in dental soldering as affected by gap distance. J Prosthet Dent 1980; 43: 272-8.
11. Sarfati E, Harter JC. Comparative accuracy of fixed partial dentures made as one-piece castings or joined by solder. Int J Prosthodont 1992; 5: 377-83.
12. Zoidis PC, Winkler S, Karellos ND. The effect of soldering, electrowelding, and cast-to procedures on the accuracy of fit of cast implant bars. Implant Dent 1996; 5: 163-8.
13. Zervas PJ, Papazoglou E, Beck FM, Carr AB. Distortion of three-unit implant frameworks during casting, soldering, and simulated porcelain firings. J Prosthodont 1999; 8: 171-9.
14. Huling JS. Clark RE. Comparative distortion in three-unit fixed prostheses joined by laser welding, conventional soldering, or casting in one piece. J Dent Res 1977; 56: 128-34.
15. Iwasaki K, Ohkawa S, Rosca ID, Uo M, Akasaka T, Watari F. Distortion of laser welded titanium plates. Dent Mater J 2004; 23: 593-9.

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