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SCIENTIFIC SECTION

Effects of different brazing and welding methods on the fracture load of various orthodontic joining configurations

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Purpose: The aim of this study was to compare the fracture load of different joints made by conventional brazing, tungston inert gas (TIG) and laser welding.

Materials and methods: Six standardized joining configurations of spring hard quality orthodontic wire were investigated: end-to-end, round, cross, 3 mm length, 9 mm length and 6.5 mm to orthodontic band. The joints were made by five different methods: brazing with universal silver solder, two TIG and two laser welding devices. The fracture loads were measured with a universal testing machine (Zwick 005). Data were analysed with the Mann–Whitney–Wilcoxon and Kruskal–Wallis tests. The significance level was set at $P<0.05$).

Results: In all cases brazed joints were ruptured at a low level of fracture load (186–407 N). Significant differences between brazing and TIG or laser welding ($P<0.05$) were found. The highest mean fracture loads were observed for laser welding (826 N). No differences between the various TIG or laser welding devices were demonstrated, although it was not possible to join an orthodontic wire to an orthodontic band using TIG welding.

Conclusion: For orthodontic purposes laser and TIG welding are solder free alternatives. TIG welding and laser welding showed similar results. The laser technique is an expensive, but sophisticated and simple method.

Key words: Brazing, soldering, tungsten inert gas welding, laser welding, fracture load, orthodontic wire

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Introduction

Brazing, defined as soldering over a temperature of 450°C, is the conventional method of joining orthodontic wires in different clinical situations.[1–5] Beside the problems of galvanic corrosion and possibly biocompatibility, brazed joints show a low mechanical strength with high failure rates.[6–16] The strength of silver soldered joints used to fabricate space maintainers and orthodontic appliances is critical to their success.[2] Broken appliances complicate the orthodontic treatment including the danger of soft tissue irritation, lost orthodontic anchorage or aspiration of broken parts.

Another method employed for joining metal frameworks is laser welding.[17–27] To weld dental alloys, crystals of yttrium, aluminium and garnet (YAG) doped with neodymium (Nd) are mainly used to emit laser beams (Nd:YAG laser).[28–34] In 2005 an interesting alternative with lower investment costs was introduced in orthodontics. Based on the technique of tungsten inert gas (TIG) welding two different devices for orthodontic purposes were developed. The welding heat is produced with the help of a light bow between tungsten anode and metal. The advantages of laser and TIG welding systems is that there is no solder and thus no galvanic corrosion in the joint; however it requires a small focus to perform the weld and a stereomicroscope is desirable for efficient working, as well as an Argon shielding atmosphere to stop the oxidation process around the welding zone.[7,12–14]

The aim of this study was to compare the mechanical strength of joints made by conventional brazing, TIG and laser welding.

Materials and methods

To simulate typical clinical situations when fabricating individual orthodontic appliances six standardized joint configurations of the stainless steel wire Forestanit (DIN 14310, chemical composition in wt-%: Cr 16.0–18.0; Ni 6.0–9.0, Fe rest; LOT: 272; Forestadent, Pforzheim, Germany) in spring hard quality (diameter 0.9 mm for all joints except for end-to-end joints with diameter

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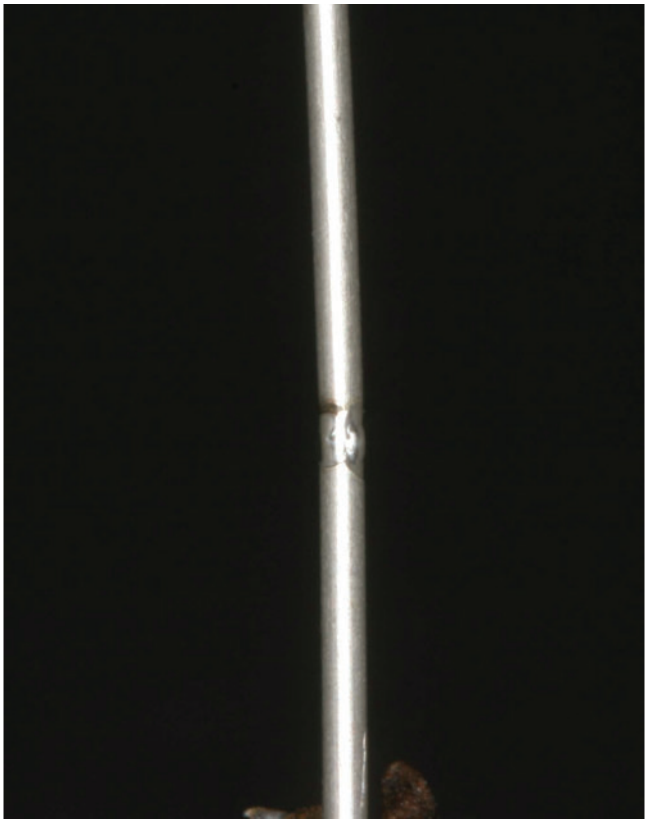

Figure 1 End-to-end joints

Figure 2 Round joints

Figure 3 Cross-joints

1.2 mm) was used (Figures 1–6, Table 1). With the help of pre-tests the number of specimens was calculated and estimated at 10. Before brazing or welding the joining lengths were determined and marked stereo microscopically at ×12 magnification.

The joints were made by five different methods: brazing with universal silver solder, Orthophaser (Dentaurum, Ispringen, Germany), Welder (Schütz Dental, Rosbach, Germany), DL 2002 (Dentaurum), LWI (Schütz Dental).

The specimens to be brazed or welded were placed in a specially designed stainless steel jig for stabilization (Figure 7). Prior to brazing the joint sites were heated with the reducing zone of the flame (gas burner YG9000 ST, Schifftner, Düsseldorf, Germany) and as soon as the sites reached a braze flow temperature of approximately

Table 1 Length of the used brazed and welded specimens.

Joining configuration		Dimension	
End-to-end	(Figure 1)	Diameter	1.20 mm
Round	(Figure 2)	Length	2.50 mm
Cross	(Figure 3)	Length	0.90 mm
3 mm	(Figure 4)	Length	3.00 mm
9 mm	(Figure 5)	Length	9.00 mm
Band	(Figure 5)	Length	6.50 mm

Figure 4 Joints with 3 mm length

Figure 5 Joints with 9 mm length

Figure 6 Band-to-wire joints. Band material: Dura-Fit (Forestadent, Pforzheim, Germany)

700°C, sufficient length of braze was held in a tweezer and introduced at the joint site.

Laser parameters and welding conditions were used in accordance to manufacturer's guidance (Table 2). According to the manufacturer's guidance TIG welding of orthodontic wire to an orthodontic band could not carried out with the two devices used for this experiment. The tensile strength of the original wire material with the diameters of 0.9 mm (n=10) and 1.2 mm (n=10) were also measured.

Following joining, the gap sizes were controlled with the help of a computer supported video inspection system VMZM/40 at ×34 magnification (Jena Engineering, Jena, Germany). The fracture load measurement was carried out with the use of a universal testing machine (Zwick 005; Zwick/Roell, Ulm, Germany). The wire length between the cross-heads of the machine was standardized at 5 mm. The full scale load was set at 2000 N with a cross-head speed of 10 mm/minute.

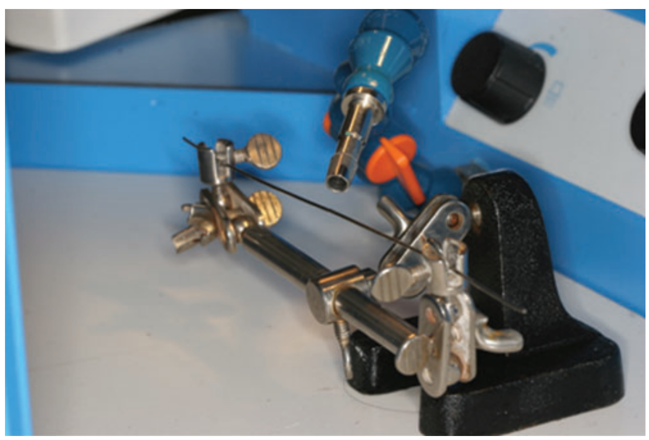

Figure 7 Standardized stabilization for brazing or welding

According to the study of Baba *et al.*[17] fracture load was determined in Newtons because the calculation of the real contact area of each joint without destruction was not available.

Data were analysed with help of the statistical software package SPSS 12.0. The statistical comparisons of the different specimens groups were made with the Kruskal-Wallis one-way analysis of variance by ranks (KW test) and Mann–Whitney–Wilcoxon test (MWW test). The level of significance was set at 5%.

Results

Means, minima, maxima and standard deviations of the fracture load of the different joining methods are given in Table 3 and Figure 8. Mean tensile strengths of the original orthodontic wire (n=10, diameter 0.9 mm: 1492$\pm$55 N, diameter 1.2 mm: 1689$\pm$39 N) were found in accordance with manufacturer's guidance. Compared to these findings welding and brazing had significantly decreased fracture loads (KW test, P<0.001).

For brazing the highest mean fracture loads were observed in the band-to-wire configuration (407$\pm$116 N). The lowest mean fracture loads for brazing were found in the cross-joints (186$\pm$36 N). For TIG welding the highest means were observed in the end-to-end configuration (TIG 1: 819$\pm$70 N; TIG 2: 790$\pm$94 N) on low levels of standard deviations. The lowest mean fracture loads were in the joints of 9 mm length (TIG 1: 555$\pm$35 N; TIG 2: 549$\pm$105 N). No significant differences between the various joint configurations, except the connections of band to orthodontic wire were found. In this configuration the mean joint length made by brazing was between 0.5 and 1.0 mm longer than when using Laser 1 or Laser 2.

In our study the highest mean fracture loads were found in laser welding when joining orthodontic wire of 3 mm length (Laser 1: 826$\pm$109 N; Laser 2: 826$\pm$168 N). The lowest mean laser welding values were found in the configuration orthodontic wire to band (Laser 1: 354$\pm$55 N; Laser 2: 329$\pm$32 N).

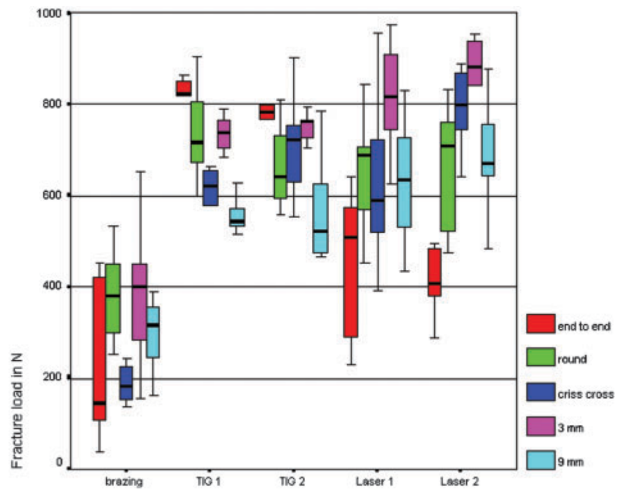

Figure 8 Graphical analysis of the fracture loads in N

In general significant differences were found between the various joining methods except in the when connecting an orthodontic wire to a band (MWW test, Table 4). The statistical comparison of single groups demonstrated significantly decreased mean fracture loads in brazing compared with TIG or laser welding, except the band-to-wire joints (MWW test, Table 4).

No significant differences were found between the two different TIG welding devices (MWW test, Table 4) and TIG welding mean fracture loads of TIG welding were significantly greater in the end-to-end configuration compared with the laser welding, whereas joints of 9 mm with TIG welding demonstrated lower mean fracture loads compared with laser welding (MWW test, Table 4).

No significant differences between Laser 1 and Laser 2 were found, except in the cross configuration (MWW

Table 2 The used brazing and welding conditions (TIG=tungsten inert gas welding; Laser=laser welding).

Brazing	Silver solder (LOT: 47160)		Dentaurum (Ispringen, Germany)
TIG 1	OrthoPhaser		Dentaurum (Ispringen, Germany)
	Figures 1–5	70%, 21 ms	
TIG 2	Welder		Schütz Dental (Rosbach, Germany)
	Figures 1–5	50 W, 30 ms	
Laser 1	Desktop Power Laser		Dentaurum (Ispringen, Germany)
	Figures 1–4	265 V, 3 ms, 0.4 mm	
	Figure 5	265 V, 3 ms, 0.8 mm	
	Figure 6	225 V, 2 ms, 0.8 mm	
Laser 2	LWI		Schütz Dental (Rosbach, Germany)
	Figures 1–5	2 kW, 5 ms, 0.9 mm	
	Figure 6	1 kW, 1 ms, 0.4 mm	

Table 3 Fracture load in N (n=number of specimens; SD=standard deviation; SE=standard error; TIG=Tungsten inert gas welding; Laser=laser welding).

Joining configuration		n	Means	SD	SE	Minimum	Maximum
End-to-end	Brazing	10	223.6	165.0	52.2	37.3	451.5
	TIG 1	10	819.3	69.6	22.0	668.1	936.9
	TIG 2	10	790.1	94.4	31.5	672.2	1015.6
	Laser 1	10	454.7	145.0	45.8	229.0	640.7
	Laser 2	10	417.8	67.1	21.2	288.7	495.1
Round	brazing	10	384.0	98.0	31.0	252.4	533.9
	TIG 1	10	743.4	92.7	29.3	598.9	903.7
	TIG 2	10	651.3	86.6	27.3	557.5	810.2
	Laser 1	10	646.6	114.9	36.3	453.2	842.3
	Laser 2	10	655.2	136.9	43.3	474.5	830.4
Cross	brazing	10	185.9	35.9	11.4	139.2	242.9
	TIG 1	10	608.0	143.9	45.5	351.8	801.1
	TIG 2	10	712.8	115.1	36.4	551.7	901.8
	Laser 1	10	622.2	160.9	50.9	390.0	954.8
	Laser 2	10	791.6	79.8	25.2	641.1	887.7
3 mm	brazing	10	382.7	134.9	42.6	154.7	652.9
	TIG 1	10	739.8	38.3	12.1	683.3	790.1
	TIG 2	10	725.0	104.2	32.9	488.2	867.7
	Laser 1	10	825.7	108.6	34.3	626.4	975.2
	Laser 2	10	825.8	167.6	53.0	469.9	952.4
9 mm	brazing	10	297.0	73.6	23.3	161.5	389.7
	TIG 1	10	555.4	34.5	11.5	516.2	626.9
	TIG 2	10	548.9	105.3	33.3	461.3	783.4
	Laser 1	10	629.9	122.6	38.8	434.2	829.9
	Laser 2	10	687.6	112.8	35.7	484.1	878.1
Band	brazing	10	406.6	116.1	38.7	210.0	595.6
	Laser 1	10	354.4	55.0	17.4	314.9	491.4
	Laser 2	10	328.8	31.7	10.0	294.4	397.1

test, $P=0.008$, Table 4). There were no significant differences between the mean fracture loads for the band-to-wire joints between laser welding and brazing (MWW test, $P=0.072/P=0.800$, Table 4), although there was less variability with the laser welding (Laser 1: 55 N; Laser 2: 32 N compared to brazing: 116 N).

Discussion

In our study a direct comparison between brazing, TIG and laser welding was carried out for the first time. We found that brazing joints lead to the lowest mean fracture loads. TIG and laser welding showed significantly

Table 4 Results of Mann–Whitney–Wilcoxon test (ns=non-significant; level of significance $P<0.05$ *).

		End-to-end	Round	Cross	3 mm	9 mm	Band
		P	*P*	*P*	*P*	*P*	*P*
Brazing	TIG 1	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	–
	TIG 2	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	–
	Laser 1	0.007*	0.010*	<0.001*	<0.001*	<0.001*	0.072 ns
	Laser 2	0.016*	0.021*	<0.001*	<0.001*	<0.001*	0.180 ns
TIG 1	TIG 2	0.121 ns	0.340 ns	0.199 ns	0.880 ns	0.191 ns	–
	Laser 1	<0.001*	0.059 ns	0.880 ns	0.023*	0.191 ns	–
	Laser 2	<0.001*	0.199 ns	0.004*	0.023*	0.006*	–
TIG 2	Laser 1	<0.001*	0.880 ns	0.151 ns	0.051 ns	0.076 ns	–
	Laser 2	<0.001*	0.940 ns	0.082 ns	0.380 ns	0.010*	–
Laser1	Laser 2	0.199 ns	0.705 ns	0.008*	0.545 ns	0.364 ns	0.151 ns

higher mean fracture loads; however the tensile strength of the original wire was not achievable. Therefore, welding changes the properties of spring hard quality orthodontic wire, which needs to be taken into consideration when designing orthodontic appliances. The high standard deviations for the mean fracture loads in our study suggest that the optimal joins were not always achieved and the reason for this should be the subject of future studies.

One proposed advantage of laser or TIG welding is superior biocompatibility,[9,12,13] therefore the finding that these techniques lead to higher mean fracture loads is noteworthy. Studies concerning the mechanical behaviour of welded or soldered orthodontic wires are rare and up to the present time the authors are not aware of any comparison of different brazing and welding methods and the use of different TIG or laser welding devices in orthodontics has not been investigated.[26]

The outcome of fracture load measurements of welded precious and non-precious cast alloys used in fixed or removable prosthodontics are not easily applied to orthodontics[3,9,22] and the results have been variable.[6,16–21,27,31–38] Chai and Chou[21] showed that welded sites of different Ti alloys had equal or superior mechanical strength compared to the parent metal.[21] In contrast Watanbe and Topham[33] could not achieve the fracture load of unwelded Ti, gold or Co–Cr alloys in different configurations of laser welding.[33]

Rocha *et al.*[39] compared laser and TIG welding of non-precious alloys. TIG welding increased the flexural strength of Ti, Co–Cr and Ni–Cr.[39] By contrast, laser welding achieved only 17.5% of the flexural strength of Co–Cr alloy.

Uysal *et al.*,[25] Roggensach *et al.*[40] and Bertrand *et al.*[20] demonstrated various changes in the welding area and the so called heat affected zone in Ni–Cr–Mo, Co–Cr–Mo or Titanium alloys depending on welding conditions.

To-date only one published study has investigated laser welded orthodontic materials.[22] Krishnan *et al.*[22] evaluated the laser characteristics of three orthodontic arch wire alloy materials—stainless steel and two different Beta titanium alloys. Fracture load differed significantly between the three materials (stainless steel 363 ± 22 MPa, Beta titanium 463 ± 27 MPa and 344 ± 25 MPa). Although a comparison with the original wires was missing from this study, it could be assumed that laser welded specimens showed significantly lower fracture loads than pure metals (approximately 1500–1800 MPa). These findings were in accordance with our results.

Conclusions

- Brazing showed a low mechanical strength.
- There were no statistical differences in the fracture loads between joins constructed using TIG and laser welding, although it was not possible to join a wire to an orthodontic band using TIG welding.
- TIG and laser welding are solder free alternatives for orthodontic purposes and produce high mechanical stability.

Contributor statement

Jens J. Bock is the guarantor, and was responsible for the whole work and the coordinating of experimental and statistic solutions. Jacqueline Bailly was responsible for the experimental work. Robert Fuhrman was responsible for the final manuscript.

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