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A comparison of the shear bond strength of metal orthodontic brackets that have been treated with various light-emitting diode intensities and curing times: *In-vitro* research

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Abstract: The study aims to test the effects of LED light at three different power settings (500mW/cm^2, 1000mW/cm^2& 1500m W/cm^2) and three different exposure times (5sec, 10sec & 20sec) adhesive composites for use with stainless steel orthodontic brackets, and their shear bond strengths. Current *In-vitro* work used 120 teeth, mostly premolars, separated into 10 equal groups of 12. After the crowns of the teeth were exposed by mounting them vertically into self-heal acrylics, the buccal-enamel exterior was prepared for bonding (PEA) 0.022"x 0.028" stainless steel premolar bracket using a thin layer of light cure adhesive primer and paste (Transbond-XT-3M Unitek Monrovia, Calif). Brackets in Group 1 comprising the Control group treated by usual halogen light source for forty sec, in remaining 9 groups (Experimental group) three commercially available LED curing light units i.e., Woodpecker, Guilin, Guangxi, China; Stealth Soft Equinox, Denmark, Holland; Radii plus, SDI, Australia, having three different light intensity 500mW/cm^2, 1000mW/cm^2, 1500mW/cm^2 respectively were used to bond the brackets at three contact time (5/10/20 sec). The universal testing equipment was used to determine the shear bond strength of each specimen. The uppermost average SBS was found in the group cured with LED of intensity 1500 mW/cm^2 for 20 sec (20.08 + 4.82 MPa) which was statistically significant compared the to control group (12.72 + 2.42 MPa). The lowest mean SBS values were obtained for groups cured with LED of intensity 500 mW/cm^2 even at different curing times of 5, 10 and 20 sec i.e., 5.46 + 1.99 MPa, 8.77 + 2.38 Mpa and 11.24 + 2.59 MPa, respectively. Increasing the intensity of the LED light curing unit provides a clinically acceptable SBS even after reducing the curing times, thereby reducing the chairside time for bonding of orthodontic brackets.

Introduction

Bonding of brackets is one of the most time-consuming processes in Orthodontics (Almeida et al., 2021). Therefore, there is an emphasis on reducing the chair side time during bonding to increase the treatment efficiency, reduce the cost and provide the patients with greater comfort (Alzainal et al., 2020). A desired result of bonding an attachment to a tooth surface is that it should withstand orthodontic and functional forces debonding without damage to the tooth surface and without risk of breaking (Hadole and Daokar 2019; Bhowmick et al., 2023). The degree of resin polymerization affects these

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Table 1. Description of various groups

Group	LCU	Cure time	Power Density (mW/cm^2)	Type
Control group (group1)	QHL75, Dentsply International, United States.	40 Seconds	$500mW/cm^2$	Halogen
Experimental group (group 2)	Woodpecker, Guilin, Guangxi, China.	05 Seconds	$500mW/cm^2$	Light-emitting diode
Experimental group (group 3)	Woodpecker, Guilin, Guangxi, China.	10 Seconds	$500mW/cm^2$	Light-emitting diode
Experimental group (group 4)	Woodpecker, Guilin, Guangxi, China.	20 Seconds	$500mW/cm^2$	Light-emitting diode
Experimental group (group 5)	Stealth Soft, Equinox, Denmark, Holland.	05 Seconds	$1000mW/cm^2$	Light-emitting diode
Experimental group (group 6)	Stealth Soft, Equinox, Denmark, Holland.	10 Seconds	$1000mW/cm^2$	Light-emitting diode
Experimental group (group 7)	Stealth Soft, Equinox, Denmark, Holland.	20 Seconds	$1000mW/cm^2$	Light-emitting diode
Experimental group (group 8)	Radii plus, SDI, Australia.	05 Seconds	$1500mW/cm^2$	Light-emitting diode
Experimental group (group 9)	Radii plus, SDI, Australia.	10 Seconds	$1500mW/cm^2$	Light-emitting diode
Experimental group (group 10)	Radii plus, SDI, Australia.	20 Seconds	$1500mW/cm^2$	Light-emitting diode

composites' strength, which is influenced by the radiation's duration, wavelength, strength, and other factors (Mathew, 2020).

The most popular curing devices are LED-based ones, which have been shown to produce good results with noticeably shorter light-curing periods of 10s (Erion and Banu, 2011; Mathew, 2020; Pettemerides et al., 2014) and 8s (Rueggeberg, 1996). It is based on the fundamental characteristics of a basic twin-element semiconductor diode enclosed in an optically clear epoxy dome which serves as a lens (Mavropoulos, 2005; Türkkahraman and Küçükeşmen, 2005). It needs sunlight electricity to run, is shocked and vibration-resistant, has a lifespan of over 10,000 hours with only a small amount of light output deterioration, and don't need filters to create blue light (Stahl et al., 2000; Huang et al., 2017). Recently, creators enlightened elevated power LED light sources (>$1000mW/cm^2$) (Abtahi and Khamverdy, 2006) to further reduce the irradiation time. Increased light intensity during resin polymerization might result in larger contraction strains, which may contribute to low clinical shear bond strength. The study's goal was to determine if the *In-vitro* adhesion strength of metal brackets and the adhesive residue of two orthodontic composites were affected by the reduced curing time of a high-power LED device.

Material & Methods

The 120 human pre-molar teeth were studied for the investigation, with each group consisting of 12 teeth. After receiving approval from the institution's Ethical committee, Dept. of Oral & Maxillofacial Surgery and private dental clinics were contacted to collect teeth taken for orthodontic indications from patients between the ages of 15 and 25. Extracted teeth were kept in room temperature formalin and saline water (Nawrocka and Łukomska-Szymańska, 2019).

Each tooth had its crown put vertically in self-curing acrylic to reveal the crown (Figure 1). The teeth's buccal enamel surfaces were refined by pumice & and rubber prophylaxis cups before the bonding technique. 120 pre-adjusted edgewise appliance (PEA) 0.022″ x 0.028″ stainless steel premolar brackets with an area of bracket base: 3.7mm x 3.81mm =$10.80mm^2$ (American Orthodontics, United States) were used in the study. Each tooth had a phosphoric acid gel (Scotchbond, 3M Unitek Monrovia, Calif.) rubbed into the enamel surface for 20 seconds to roughen it up, washed with water and air-dried.

Figure 1. Bonded premolar teeth

Light cure adhesive primer was pasted over the teeth's buccal surfaces after thorough cleaning and shaping. After that, we attached the brackets to premolars using a light cure adhesive paste, followed by curing with a halogen light source (QHL75, Dentsply International, United States) in Group 1 i.e., control group (Figure 2) and with three commercially available LED curing light units in remaining experimental groups, i.e. Woodpecker, Guilin, Guangxi, China; Stealth Soft Equinox, Denmark, Holland; Radii plus, SDI, Australia (Figure 3, 4, 5 respectively) having three different light intensity 500mW/cm^2, 1000mW/cm^2, 1500mW/cm^2 respectively, as shown in Table 1.

Figure 2. Halogen LCU (QHL75, Dentsply International, United States)

Figure 3. Led LCU (Woodpecker, Guilin, Guangxi, China)

Figure 4. Led LCU (Stealth soft, Equinox, Denmark, Holland)

Figure 5. Led LCU (Radii plus, SDI, Australia)

The intensity of all three LED units was measured with an intensity meter (Litex, Dentamerica Inc; Calif; Figure 6). All samples were carefully prepared before being stored in distilled water at 37 degrees Celsius for 24 hours. A universal testing machine (Fig. 7) was utilized to hold inserted specimens in place before the debonding technique was carried out (jig attached to the base plate of the machine). The testing device's chisel-edged plunger moved at a crosshead speed of 3mm/min towards the enamel-adhesive interface. Force values were divided by bracket base area to get the SBS. The force required to shift the brackets was determined to be 10.80 millinewtons.

Figure 6. Intensity meter (Litex, Dentamerica Inc. Calif)

Figure 7. Universal testing machine

Statistical Analysis

Data was tested with SPSS (IBM SPSS, IBM Corporation, New York, Version 20, 2011). Mean and standard deviation values, along with other descriptive statistics, were computed for both test and control groups. One-way ANOVA was applied to the comparison of the groups' relationship strengths and to identify any significant differences. All statistical tests have significance levels defined at or below a probability value of 05.

Results

Table 2 depicts average shear bond strengths and standard deviations in relation to curing time and light

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intensity. The mean SBS for conventional halogen curing light (group 1) was 12.72 + 2.42 MPa. Mean SBS of adhesives cured by LED light having an intensity 500 mW/cm^2 were 5.46 +1.99 MPa, 8.77 + 2.38 Mpa and 11.24 + 2.59 MPa in groups 2,3 and 4 respectively. In groups 8, 9 and 10, mean shear bond strengths were 11.63 + 5.87 MPa, 14.07 + 2.87 Mpa and 20.08 + 4.82 MPa respectively where adhesives treated by LED light having power of 1500 mW/cm^2.

exposure (P=0.164). For exposure times of 5 seconds (group 5) and 10 seconds (group 6), LEDs with an intensity of 1000 mW/cm^2 provided SBS values that were statistically analogous with those obtained for a contact time of 40 sec (group 1; P≥ 0.05) using a traditional halogen light. SBS values for the control set (group 1) were significantly less than those with an exposure time of 20 seconds with the same LED intensity (group 7; P=0.000).

Table 2. Standard deviations (SD) and mean shear bond strengths (MPa) in relation to cure time and light power

Type of Light	Group No.	No. of Sample	Curing Time (Sec.)	Mean SBS (MPa)	Standard Deviation (Mpa)
Halogen	1	12	40 sec.	12.7250	2.42883
LED 500mW/cm^2	2	12	5 Sec.	5.4675	1.99034
	3	12	10 Sec.	8.7783	2.38405
	4	12	20 Sec.	11.2475	2.59225
LED 1000mW/cm^2	5	12	5 Sec.	12.5458	4.94894
	6	12	10 Sec.	12.8733	1.99122
	7	12	20 Sec.	18.8833	2.06302
LED 1500mW/cm^2	8	12	5 Sec.	11.6367	5.87767
	9	12	10 Sec.	14.0700	2.87801
	10	12	20 Sec.	20.0808	4.82622

Table 3. One-way ANOVA comparing shear bond strengths

Comparison Between	Mean SBS (Mpa)	S.D. (MPa)	F-value	P-Value
Group 1 and Group 2	12.7250 5.4675	2.42883 1.99034	64.099	.000
Group 1 and Group 3	12.7250 8.7783	2.42883 2.38405	16.137	.001
Group 1 and Group 4	12.7250 11.2475	2.42883 2.59225	2.076	.164
Group 1 and Group 5	12.7250 12.5458	2.42883 4.94894	.013	.911
Group 1 and Group 6	12.7250 12.8733	2.42883 1.99122	0027	.872
Group 1 and Group 7	12.7250 18.8833	2.42883 2.06302	44.814	.000
Group 1 and Group 8	12.7250 11.6367	2.42883 5.87767	.351	.559
Group 1 and Group 9	12.7250 14.0700	2.42883 2.87801	1.531	.229
Group 1 and Group 10	12.7250 20.0808	2.42883 4.82622	22.243	.000

Shear bond strengths between the experimental and control groups were compared using a one-way ANOVA, with the results displayed in Table 3. An exposure time of 05 seconds (group 2) and 10 seconds (group-3) with LED of intensity 500mW/cm^2 attained SBS values which were *In-vitro*, were significantly lower in comparison to those found using a conventional halogen lamp for the time of 40 seconds (Group-1; P = 0.000 & 0.001 correspondingly). In group 4, 500mW/cm2 LEDs were used for 20 seconds to achieve SBS values similar to those discovered with a standard 40-second halogen lamp

SBS values in group 8 were equivalent to the control group's (group 1; P≥0.05) after being exposed to LEDs for 5 seconds at an intensity of 1500mW/cm^2. However, curing for 10 seconds (group 9) and 20 seconds (group 10) with the same LED intensity produced significantly higher SBS values compared to the control group (P = 0.229 &0.000 correspondingly).

Table 4 shows the effect of varying LED light intensity on shear bond strength in different experimental groups. LED of intensity 500mW/cm^2 used for 5 seconds (group 2) produced significantly lower SBS compared to

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Table 4. One-way ANOVA comparing shear bond strengths demonstrating the effects of light intensity of LED lights

Comparison Between	MEAN SBS (Mpa)	S.D. (MPa)	F value	P-Value
Group 2 and Group 5	5.4675 12.5458	1.99034 4.94894	21.130	.000
Group 2 and Group 8	5.4675 11.6367	1.99034 5.87767	11.860	.002
Group 5 and Group 8	12.5458 11.6367	4.94894 5.87767	.168	.686
Group 3 and Group 6	8.7783 12.8733	2.38405 1.99122	20.856	.000
Group 3 and Group 9	8.7783 14.0700	2.38405 2.87801	24.059	.000
Group 6 and Group 9	12.8733 14.0700	1.99122 2.87801	1.403	.249
Group 4 and Group 7	11.2475 18.8833	2.59225 2.06302	63.747	.000
Group 4 and Group 10	11.2475 20.0808	2.59225 4.82622	31.198	.000
Group 7 and Group 10	18.8833 20.0808	2.06302 4.82622	.625	.438

Table 5. Results of one-way ANOVA comparing shear bond strengths demonstrating the effects of curing time

Comparison Between	MEAN SBS (Mpa)	S.D. (MPa)	F value	P-Value
Group2 and group 3	5.4675 8.7783	1.99034 2.38405	13.638	.001
Group2 and group 4	5.4675 11.2475	1.99034 2.59225	37.533	.000
Group3 and group 4	8.7783 11.2475	2.38405 2.59225	5.898	.024
Group 5 and group 6	12.5458 12.8733	4.94894 1.99122	.045	.834
Group 5 and group 7	12.5458 18.8833	4.94894 2.06302	16.765	.000
Group 6 and group 7	12.8733 18.8833	1.99122 2.06302	52.724	.000
Group 8 and group 9	11.6367 14.0700	5.87767 2.87801	1.659	.211
Group 8 and group 10	11.6367 20.0808	5.87767 4.82622	14.794	.001
Group 9 and group 10	14.0700 20.0808	2.87801 4.82622	13.731	.001

LED of intensity 1000mW/cm^2 (group 5; P=0.000) and 1500mW/cm^2 (group 8; P=.002) used for a similar period. No significant variation in SBS was found between groups 5 and 8 (P≥0.05). The LED intensity of 1000mW/cm^2 (group 6) and 1500mW/cm^2 (group 9) used for 10 seconds produced significantly higher SBS compared to the LED of intensity 500mW/cm^2 used for similar time (P= 0.000 &0.000 correspondingly). Groups 6 & 9 did not significantly differ from one another (P≥0.05). LED of intensity 1000 mW/cm^2 (group 7) and 1500mW/cm^2 (group 10) at an exposure time of 20 seconds produced significantly higher SBS than LED of intensity 500mW/cm^2 (group 4) used for similar curing time (P=0.000 &0.000 correspondingly). Group 7 and Group 10 did not differ significantly from one another (P≥0.05).

Table 5 displays how shear bond strength in various experimental groups is affected by varied light-curing times. An exposure time of 05 seconds with LED of intensity 500mW/cm^2 (Group 2) obtained SBS values that were significantly lower than those found using an exposure of 10 seconds time (Group 3) and 20 seconds (group-4; P = 0.001 &0.000 correspondingly). An exposure time of 10 seconds (group 3) with LED having intensity 500mW/cm^2 produced SBS values that were significantly lower than those obtained using the same intensity light for 20 seconds (group 4; P=0.024).

SBS results were equivalent between a 5-second exposure to 1000mW/cm2 of LED light (group 5) and a

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10-second exposure to the same light (group 6; P= >0.05). However, the same LED light produced a statistically considerable increase in the SBS values compared to groups 5 & 6 at an exposure time of 20 seconds (P=0.000 &0.000 correspondingly). LED of intensity 1500 mW/cm^2 produced comparable SBS values at exposure times of 5 seconds (group 8) and 10 seconds (group-9). The same LED light produced significantly higher SBS values than group 8 and group 9 at an exposure time of 20 seconds. (P=0.001 &0.001 correspondingly).

Discussion and Conclusion

The most commonly used light curing methods in orthodontics are Halogen lamps and LED. Light power has a significant role in the polymerization process. One of the problems with halogen technology converts 1% energy it receives into light, the remaining released as heat (Buonocore, 1955; Fleming et al., 2013). Other downsides are the short halogen bulb life and the noisy cooling fan (Türkkahraman and Küçükeşmen, 2005; Verma, 2016).

According to Rueggeberg (1996), more photons will enter the resin at higher light intensities, which will result in more free radicals available for polymerization. Modern fast-curing devices have been created to enhance light power density and hence shorten exposure times without sacrificing bonding effectiveness, such as argon lasers and high-intensity light sources.

LEDs have some advantages over arc-curing lights composed of halogen or plasma. They don't require a noisy cooling fan, are cordless, smaller lifespan of over 10,000 h. (Haitz et al 1995). They therefore seem to be a better option than halogen sources. The best LED cure durations and whether they can cure all resins are currently unknown (Clinical Research Associates, 2001). A new series of high-intensity LED units, according to their manufacturer, combine all the benefits of their predecessors with a markedly decreased exposure time required to glue orthodontic attachments.

Consequently, the study's goal was to examine the impacts of LED light at three distinct power levels (500mW/cm^2, 1000mW/cm^2& 1500mW/cm^2) and three different exposure times (5sec, 10sec & 20sec) on the adhesive composites' shear bind strength to stainless steel orthodontic brackets.

According to the study's findings, all experimental groups, with the exception of group 2, had laboratory mean SBS values that were higher than the clinically acceptable bond strength of 6 to 8 Mpa (Reynolds, 1975; Udomthanaporn, 2017; Ganiger, 2017).

Orthodontic brackets cured with LED lights of intensity 500mW/cm^2 at exposure times of 5 & 10 seconds produced notably lower SBS values than the control group. However, SBS levels for a 20-second exposure time were comparable to the control. For photo-activation times of 10 seconds, Üşümez et al. (2004) discovered that LED devices with a light output of 400 mW/cm^2 had much lower values than halogen light units. However, they didn't report any significant difference at a curing time of 20 seconds. The result of our present study also corroborated with this study.

Additionally, SBS values of orthodontic adhesive obtained after brackets were exposed to 1000 mW/cm^2 and 1500 mW/cm^2 of usual halogen light for 5 & 10 seconds, respectively, were on par with or even exceeded those results. In addition, Tripathi et al. (2020) that those exposed to halogen LCU had a lower mean SBS value than those exposed to LEDs, according to the report. LEDs might potentially achieve SBS values (13.9 ± 4.8 MPa) in 20 seconds that are comparable to those achieved by halogen-based devices in 40 seconds (13.1 ± 3.1 MPa), as reported by Üşümez et al. (2004). In addition to these authors, Abdullah et al. (2019) and Palomares et al. (2008) all reached the same conclusion. However, Mavropoulos et al. (2005) reported significantly inferior SBS values compared to halogen light when intensive LED devices (>800 mW/cm^2 and 1000mW/cm^2) were used for 5 seconds. This difference may be attributed to high mean SBS values for the halogen lamp in their study.

In the present study, LEDs of intensity 1000mW/cm^2 and 1500mW/cm^2 at an exposure time of 20 seconds produced significantly higher SBS values compared to the control. Studies conducted by Teshima et al. (2003), Tsai et al. (2004), Rêgo EB and Romano (2007), Maruo et al. (2010), Silta et al. (2005), Artun and Bergland (1984) also recommended that light-curing devices, similar to LEDs, have performance for 40 seconds of photo-activation time at 20 seconds that is on par with or better than halogen light devices. Higher light power causes more photons to enter the orthodontic glue, increasing the number of free radicals produced during polymerization of the monomer into the polymer (Rueggeberg, 1996).

The orthodontic brackets cured with LED of intensity 500mW/cm^2 (group 2, 3 and 4) showed a significant increase in the SBS values as curing time increased from 5 to 20 seconds. However, this trend was not observed in the groups where LEDs of intensity 1000 mW/cm^2 and 1500 mW/cm^2 were used for curing. In these groups, no noteworthy difference in the SBS values was observed up to the curing time of 10 seconds. However, statistically significant increases in the SBS values were seen at an exposure time of 20 seconds.

Therefore, it may be inferred that LED light of intensity >1000mW/cm^2 may yield adequate SBS values when used for 5 to 10 seconds. A further increase in the exposure time up to 20 seconds, may lead to a significant increase in SBS value. Considering the significance of chairside time, it may be suggested that an exposure time of 5 seconds is sufficient to obtain adequate bond strength when LED light of intensity >1000mW/cm^2 is used for curing. However, an exposure time of at least 20 seconds will be required to achieve optimum SBS when LED of intensity 500mW/ cm^2 is used. This is comparable to findings obtained by Par et al. (2020) and Maliael and Saravana Dinesh (2021).

The outcomes of the current study also confirm the finding of the earlier *In-vitro* investigations on LED curing devices that have shown that LED devices outperform halogen light devices by an equal or greater margin. Erion and Banu (2011), used high-intensity LED (1200 +10% mW/cm^2) for 10 and 20 seconds and concluded that curing time can be reduced to 10 seconds with high-intensity LED without compromising *In vitro* SBS of metal brackets. Hakan and Kucukesmen (2005), used LED light of intensity of 1250 mW/cm^2 for 20 seconds and 40 seconds and concluded that Shear bond strength values achieved with a 20-second LED exposure in the fast mode were comparable to those produced with a 40-second halogen-based illumination.

The light emission spectrum's range of activity that can begin polymerization is constrained. Camphor quinone is the most widely used initiator for visible-light-curing adhesives because it reacts well to blue wavelengths in the visible light range (360-520 nm), with activity peaking at 465 nm (Nomoto, 1997). LEDs generate visible light through quantum mechanical processes. When two semi-conductors are used in concert, their combined spectral output (400-500 nm) nearly matches the absorption region of camphor quinones, the monomers responsible for initiating resin polymerization. High-intensity LED lighting generates more photons that are available for the photosensitizers to absorb, causing faster healing and a shorter chairside bonding time (Omidi et al., 2018).

In the present study, significantly higher SBS values were achieved when LEDs of intensity 1000mW/cm^2 and 1500 mW/cm^2 were used for 20 seconds. However, higher light intensity (>1000 mW/cm^2) may produce contraction stresses leading to insufficient clinical shear bond strength. Soft-start polymerization was developed as a solution to this issue; it involves initially exposing the material to weak light before finishing with a stronger beam (Nomoto 1997). Soft-start polymerization techniques have been shown by Yoshikawa et al. (2001) to dramatically lower polymerization stresses and enhance material characteristics.

In the present study, the effect of high-intensity LED light on the degree of cure (DC) of the resin phase was not studied. It is crucial because it controls the resin adhesive's mechanical, physical, and biological properties (Shen et al., 2021). Further, the rapid polymerization rate by LED may cause polymerization shrinkage leading to the development of high residual stresses. However, given the reduction of these stresses in the bracket-adhesive interface caused by the absence of cavity walls and borders, it seems that this should not be a cause for concern given the dearth of evidence on this topic for orthodontic bonding. Due to the different methods in which resin materials age in the oral environment and the unanticipated stress system that is formed during mastication40, the results of this investigation, which was conducted in a laboratory context, cannot be readily applied to clinical scenarios (Yadav et al., 2023). The study's findings support the use of LED-curing devices in orthodontics; nevertheless, further research into the physical properties of various orthodontic adhesives is required before certification.

In light of the study's limitations, it can be said that,

1. LED light at three different power settings (500mW/cm^2, 1000mW/cm^2 and 1500mW/cm^2) and three different exposure times (5sec, 10sec & 20sec) produced clinically acceptable bond strength except for 5 seconds of exposure with LED of intensity 500mW/cm^2.
2. LED light curing device using a combination of short exposure time i.e., 5 seconds and high-power light i.e.,1000mW/cm^2 and 1500mW/cm^2 produced shear bond strengths which were equivalent to those obtained using a conventional halogen lamp for 40 seconds. However, an exposure time of at least 20 seconds will be required to produce comparable bond strength when an LED of intensity 500mW/cm^2 is used for curing.

Conflict of interest

Nil

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