Original Article

Comparative evaluation of push-out bond strength and mode of failure of three different obturating materials: An *in vitro* study

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Abstract

Aim: This research aimed to assess the push-out bond strength (PBS) to dentin of three distinct obturation materials inside the root canal and identify the failure mechanism.

Materials and Methods: The research used 30 undamaged human mandibular premolars. The specimens were randomly assigned to three groups, each employing a different sealer ($n = 10$). Group 1 used AH Plus sealer, Group 2 used GuttaFlow-2 sealer, and Group 3 used bioceramic sealer (CeraSeal). The obturation procedure was performed utilizing the single-cone method with gutta-percha. The specimens were divided into sections and loaded using a universal testing machine. Following PBS testing, every sample underwent a stereomicroscope examination, and the specific failure mechanism was documented.

Results: The average PBS was greatest for AH Plus, followed by CeraSeal and Guttaflow-2. Notable disparities existed between the coronal and apical levels.

Conclusion: AH Plus exhibited superior PBS qualities to root dentin compared to other sealers.

Keywords: AH Plus; bond strength; CeraSeal; Guttaflow-2

INTRODUCTION

The key indicator of successful endodontic therapy is the complete removal of symptoms and the restoration of the affected tooth to its original shape, function, and appearance.[1] This is accomplished by thoroughly eliminating microbes, inflammatory pulp tissue, and diseased dentin. It is performed by cleaning and shaping the root canal system using rotary and manual files to provide mechanical and chemical action. Traditional methods often cause substantial loss of dental structure, leading to a reduction in the tooth's ability to withstand fractures. Hence, there has been a recent focus on minimizing the use of instruments in the root canal space while preserving the remaining root dentin as much as possible. The introduction of rotary files with greater taper has made it possible to use a single master cone that matches the size of the master apical file.[2]

The single-cone obturation method involves the precise placement of a cone that is appropriately sized and sealed using a root canal sealer. This combination is used to fully fill and create an airtight closure in the whole canal.[2] Hence, the quality of a sealer is of utmost significance. Achieving a complete root canal sealing after cleaning and shaping is crucial to avoid the infiltration of oral pathogens into the root canal space and surrounding periapical tissue. Ensuring a thorough and effective three-dimensional

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obturation, which creates a tight seal, is crucial to avoid potential endodontic treatment failure.

Sealers are mainly used in endodontic treatment to cover the imperfections of the root canal system, such as connecting voids or lateral canals, which cannot be filled by gutta-percha (GP) points. Many different types of sealers are available, each with different qualities, which are utilized to create a tight barrier between the GP and dentinal wall.

The bond strength between the sealer and dentin is regarded as the primary component in preserving the integrity of the root canal.[3] Under static conditions, it is necessary to minimize any gaps that allow the ingress of fluids between the dentinal wall and the obturating material.

AH Plus, manufactured by Dentsply, is a root canal sealer made from a hydrophobic epoxy resin. It is regarded as the "gold standard" because of its long-term dimensional stability and lower shrinkage.[4]

GuttaFlow2 (Coltene) is a root canal sealer made of silicone. It is a combination of GP and sealer in powder form, with each particle size being <30 μm. The composition comprises a blend of GP powder, zirconium dioxide, platinum catalyst, polydimethylsiloxane, and microsilver. Guttaflow2 is a dental sealer that has the ability to flow easily at room temperature and slightly expand as it sets. This makes it particularly suitable for use in narrow and curved root canals. Recent literature has shown that the GP powder in the sealer forms a strong bond with the master GP cone, ensuring a fluid and hermetic seal.[5]

CeraSeal, developed by Meta Biomed, is a root canal sealer made from calcium silicate. It has gained significant interest because of its notable physicochemical and biological characteristics. Calcium silicate absorbs moisture from the surrounding tissues in the root canal and undergoes crystallization, producing calcium silicate hydrate gel. This material has adequate radiopacity, convenient handling characteristics, perfect biocompatibility, a lower setting time, dimensional stability, and exceptional sealing capability.[5]

The purpose of this research is to assess and compare the push-out bond strength (PBS) of three root canal sealers that are currently available: AH Plus, Guttaflow2, and Meta CeraSeal. The current research also focuses on their ability to adhere to the dentin within the root canal and identify the specific way, in which the bond failure occurs.

MATERIALS AND METHODS

A total of 30 undamaged human premolar teeth, each with a single straight canal, were taken. These teeth were then cleaned using an ultrasonic scaler and kept in distilled water, following the rules set by OSHA and the Centers for Disease Control and Prevention.

All the crowns of the teeth were sectioned at the cementoenamel junction by diamond discs while constantly irrigating with water until they reached a consistent length of 12 mm. The working length was calculated by inserting a #10K file into the root canal. The whole canal system was shaped with Protaper next files up to a size ×3. After using each file, the canals were irrigated with a 5.25% sodium hypochlorite solution. Following the process of cleaning and shaping, the canals were thoroughly dried using 30-size paper points.

The samples were categorized into three groups ($n = 10$):
- Group 1: The root canals were filled with traditional GP and AH Plus sealer
- Group 2: The root canals were filled with traditional GP and GuttaFlow 2 sealer
- Group 3: The root canals were filled with traditional GP and CeraSeal sealant.

Following obturation, a temporary filling material (Cavit, 3M ESPE) was used to seal the root canal orifices with a thickness of 3 mm. In addition, the apical region was sealed using a flowable composite.

The teeth were placed in an incubator set at a temperature of 37°C and a humidity level of 100% for the duration of 7 days to facilitate the solidification of the sealers. Following the storage time, the samples were placed in transparent acrylic resin blocks that were appropriately sized.

Calculation of push-out bond strength

The specimens were divided horizontally into sections at the apical and coronal thirds. The thickness of each segment was 2 mm. The specimens were divided into sections and exposed to loading using the universal testing machine. The punch pin was inserted in the apical-coronal direction with a crosshead speed of 0.5 mm/min till the initial dislodgment of the obturating material was detected. The magnitude of the force (F) was measured in newton (N) units.

The PBS was then determined using the following formula:

The formula for calculating the pressure between two surfaces in megapascals (MPa) was obtained by dividing the applied force in newtons (N) by the area of adhesion in square millimeters (mm^2).

Failure mode analysis was conducted by inspecting each sample under a stereomicroscope at a magnification of ×40 after PBS testing to ascertain the specific failure mechanism. The images were documented, and each specimen was evaluated and classified into one of three categories: Type 1: Adhesive failure (AF), Type 2: Cohesive failure (CF), and Type 3: Mixed failure (MF).

Sample size calculation

Based on previous study means (Sundus H. Naser *et al*.),[6] the effect size calculated was 0.634 with α err probability of 0.05 and power (1-β err prob) of the study 0.8 (80%), the total sample size obtained was 30 (10 per group) [Table 1].

F tests – ANOVA: Fixed effects, omnibus, one-way.

Table 1: Sample size calculation

Parameter	Values
Input	
Effect size (*F*)	0.6344445
α error probability	0.05
Power (1−β error probability)	0.8
Number of groups	3
Output	
Noncentrality parameter (λ)	12.0755947
Critical (*F*)	3.3541308
Numerator (df)	2
Denominator (df)	27
Total sample size	30
Actual power	0.8450596

Statistical analysis

The statistical analysis was performed using SPSS statistical software (IBM Corp., Armonk, USA, version 22). Descriptive statistics were represented using mean, standard deviation, frequency, and percentage distribution. The normality of the data distribution pertaining to the assessed variables was verified using the Shapiro–Wilk test on residuals and Q-Q plot. The equality of variances between the compared groups was verified using Levene's test. Since the results of the Shapiro–Wilk test on residuals revealed that data pertaining to the PBS was normally distributed, parametric tests were performed for testing the level of significance between the compared groups. Levene's test revealed that the compared groups presented with equal variances for PBS at the apical region and unequal variances at the coronal region. Intergroup comparison was performed using one-way ANOVA followed by *post hoc* Tukey honest significant difference test for PBS at apical level (due to equality of variances). *Post hoc* tests for PBS at the coronal level were performed using the Games-Howell test (due to unequal variances).

RESULTS

The results of the Shapiro–Wilk test for normality and Levene's test were represented in the Supplementary File. Q-Q plots for the assessed variables for verifying the normality of the data distribution are also presented in the Supplementary File. AH Plus group had the highest mean PBS values at coronal and apical levels followed by CeraSeal group. There was a statistically highly significant difference between PBS at the coronal and the apical level ($P < 0.001$) [Tables 2 and 3]. The coronal level in all groups has the highest mean PBS than the apical level [Figure 1]. Gutta-flow 2 exhibited the least PBS [Table 2].

Analysis of failure mode

The analysis of the failure mode for PBS showed that the predominant mode of failure in the AH-Plus group was AF occurring at sealer-GP interface (S/G) [Figure 2]. In the CeraSeal group, the failure mode was predominantly adhesive (S/G) and MF [Figure 2]. The failure mode in the GuttaFlow2 group was an AF, mainly at S/G, with some failure at the sealer-dentin interface [Figure 2].

DISCUSSION

Endodontic treatment should ideally achieve a condition where the tooth is free of microbes as well as there is improvement of function and esthetics. An essential criterion for a restored tooth is its capacity to endure the forces exerted during mastication. The insertion of an appropriate prosthesis ensures the integrity of the coronal portion, whereas the obturating material is responsible for the stress-bearing ability of the radicular portion. GP is the primary core material utilized; however, there is a diverse range of sealers with different compositions.

Table 2: ANOVA test for mean push-out bond strength among groups at the coronal level and apical level

	ANOVA			
	n	Mean	SD	*P*
Coronal				
Group 1 (AH plus)	10	7.2460	0.52629	<0.001**
Group 2 (GuttaFlow2)	10	1.5170	0.34811	
Group 3 (Ceraseal)	10	6.2000	0.21602	
Total	30	4.9877	2.56069	
Apical				
Group 1 (AH plus)	10	3.4480	0.41593	<0.001**
Group 2 (GuttaFlow2)	10	1.2500	0.32745	
Group 3 (Ceraseal)	10	3.2530	0.28064	
Total	30	2.6503	1.06407	

*$P<0.05$ is statistically significant, **$P<0.01$ is statistically highly significant. SD: Standard deviation[16]

Table 3: *Post hoc* test for mean push-out bond strength among groups at coronal level and apical level

	Group (I)	Group (J)	Mean difference	*P*
Coronal	Group 1 (AH Plus)	Group 2	5.729	<0.001**
		Group 3 (Ceraseal)	1.046	0.452
	Group 2 (GuttaFlow 2)	Group 3	−4.683	<0.001**
Apical	Group 1 (AH plus)	Group 2	2.198	<0.001**
		Group 3 (Ceraseal)	0.195	0.356
	Group 2 (GuttaFlow 2)	Group 3	−2.003	<0.001**

*$P<0.05$ is statistically significant, **$P<0.01$ is statistically highly significant[16]

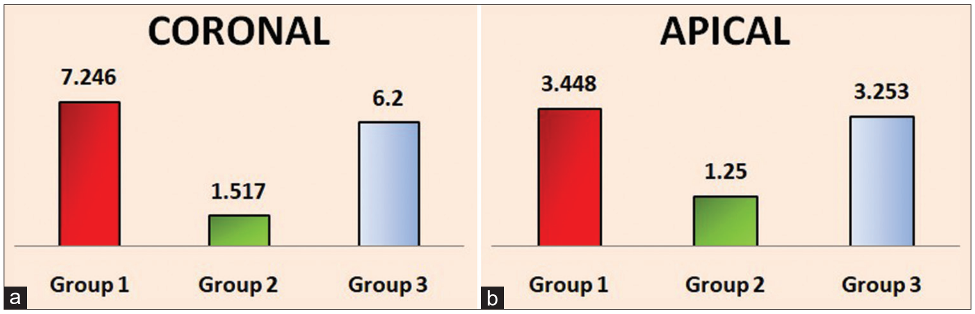

Figure 1: Bar graph for mean push-out bond strength at coronal and apical levels of different groups (a) coronal (b) apical

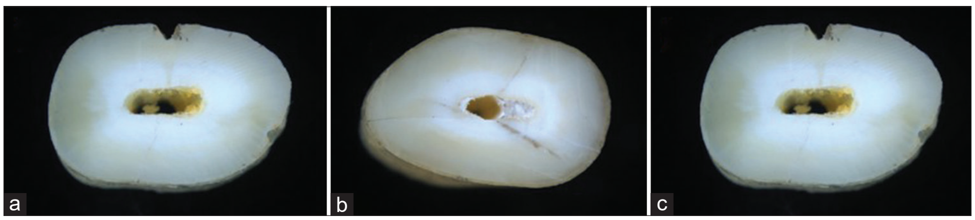

Figure 2: Failure mode analysis. (a) AH Plus sealer, (b) CeraSeal, (c) GuttaFlow 2

The adhesion strength of root canal sealers to dentin is crucial for preserving the integrity of the seal between the restoration material and the canal wall. GP is used with root canal sealers since it is incapable of adhering to the canal wall. The adhesive characteristics of endodontic sealers are said to enhance their resistance to dislodgment.[7] The current research assessed and compared the PBS of three distinct root canal sealers to root canal dentin.

The AH Plus sealer had the greatest average PBS. The PBS values align with the findings of Nagas *et al*.[8] The elevated pH of AH Plus may be attributed to the fact that a covalent link is established between an unreacted epoxide ring in the sealer and any accessible amino groups in the collagen of the dentinal wall. The sealer's enhanced PBS values are attributed to its prolonged dimensional stability, reduced shrinkage, and improved ability to penetrate root canal surface imperfections.[9]

The GuttaFlow 2 group exhibited a notable disparity compared to the AH Plus and bioceramic sealer (BC sealer) groups. Tummala *et al*. (2012) found that the porosity of the root canal sealer affects its ability to bond to the dentin.[10] The inclusion of silicone in GuttaFlow 2 raises its surface tension, resulting in porosity on the root dentin surface and restricting the dispersion of the substance.

CeraSeal had moderate PBS values compared to the other two sealers and was shown to be less effective than AH Plus. There was no statistically significant difference in PBS between AH Plus and BC sealer group.[11] These findings agree with the research conducted by Shokouhinejad *et al.*, which concluded that resin and BC sealers had almost identical PBS values.[12] CeraSeal outperforms Guttaflow 2 because it combines the chemical and mechanical bonding of the BC sealer to the dentin wall, which is further enhanced by the production of hydroxyapatite during the setting reaction.

The PBS values exhibited a decline in the corona-apical direction and demonstrated a notable disparity between the coronal and apical levels. This is because the apical dentin has fewer open tubules than the coronal dentin. The intricate composition of tubular dentin in the upper third of the tooth seems to provide superior sealer penetration compared to the hardened apical portion. Similar conclusions were observed in the studies done by Nagas *et al*. and Al Hamed *et al*.[8,13]

The primary cause of failure for the AH Plus group was AF occurring at the interface between the sealer and core material. Elsheikh *et al*. demonstrated that the primary failure mechanism of AH Plus was adhesive, which mainly occurred between the sealer and the main cone and, to a lesser extent, between the sealer and the dentin.[14] In addition, Nagas *et al*. concluded in their study that the cause of this kind of failure was due to the chemical bonding between AH Plus and the dentin of the canal.[8]

Within the BC group, CFs were seen in the sealer itself, and AFs occurred at the interface between the sealer and the core material. The absence of failure at the dentin-sealer interface may be attributed to the hygroscopic expansion, which is accompanied by the formation of hydroxyapatite during solidification.[15]

The primary cause of failure in the GuttaFlow 2 group was AF, particularly at the interface between the GP and the sealer. Signs of AF were seen at the interface between the dentin and sealer, which may be due to the absence of chemical bonding between the GP and the sealer or between the dentin and the sealer.[8]

Limitations of the current study

The *in vitro* nature of the current study could not mimic the routine clinical settings. *In vitro* studies have controlled situations, whereas it is impossible in routine clinical settings. Bond strength also varies at different sections of the teeth and also varies for different teeth. Bond strength also has a strong temporal association (i.e.,) it varies relatively with time.

CONCLUSION

There was no statistically significant difference in the PBS between AH Plus and CeraSeal. Gutta-flow2 exhibited the least PBS among the compared groups.

Clinical implications

The results of the current study regarding the PBS of different root canal sealers could provide valuable insights regarding their clinical implications.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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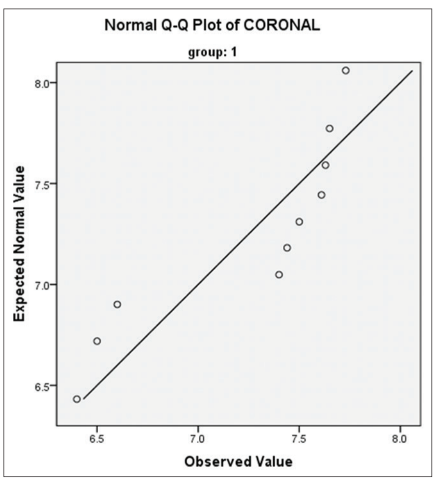
SUPPLEMENTARY FILE

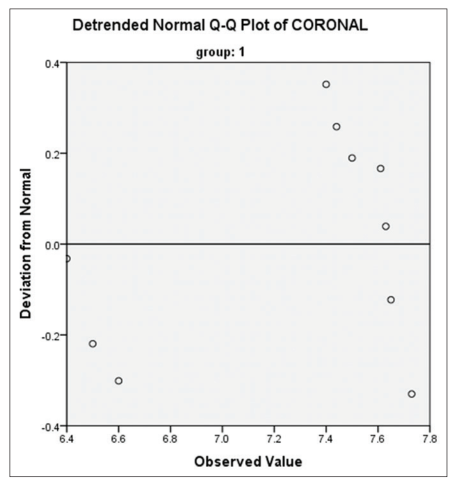
Tests of normality						
Group=1	Kolmogorov–Smirnov[b]			Shapiro–Wilk		
	Statistic	Df	Significant	Statistic	Df	Significant
Coronal	0.315	10	0.006	0.775	10	0.007
Apical	0.201	10	0.200*	0.901	10	0.226
Group=2	Kolmogorov–Smirnov			Shapiro–Wilk		
	Statistic	Df	Significant	Statistic	Df	Significant
Coronal	0.204	10	0.200*	0.916	10	0.323
Apical	0.361	10	0.001	0.729	10	0.002
Group=3	Kolmogorov–Smirnov			Shapiro–Wilk		
	Statistic	df	Significant	Statistic	df	Significant
Coronal	0.178	10	0.200*	0.924	10	0.393
Apical	0.200	10	0.200*	0.886	10	0.152

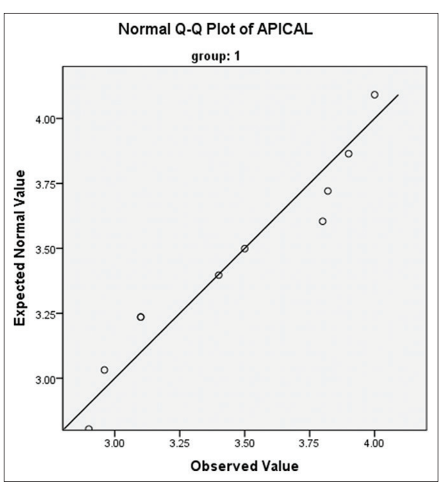
*Indicates deviation from normality

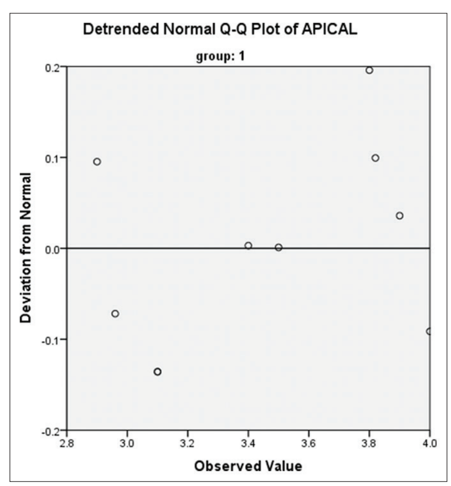
Test of homogeneity of variances				
	Levene's statistic	df1	df2	Significant
Coronal	6.821	2	27	0.004
Apical	1.873	2	27	0.173

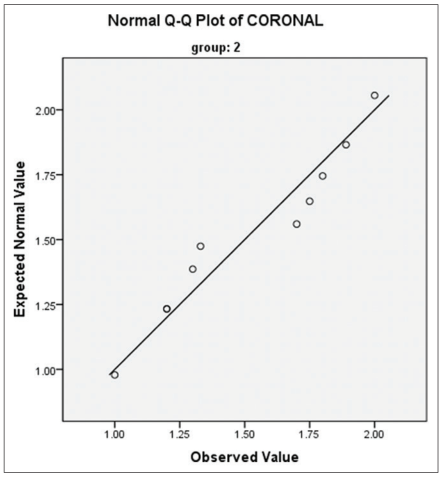
*Indicates unequal variances between the compared groups







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Expected Normal Value
Observed Value
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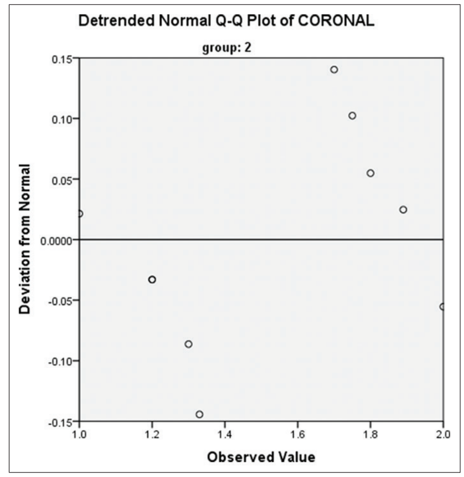
1.50
1.75
2.00


Detrended Normal Q-Q Plot of CORONAL
group: 2
Deviation from Normal
Observed Value
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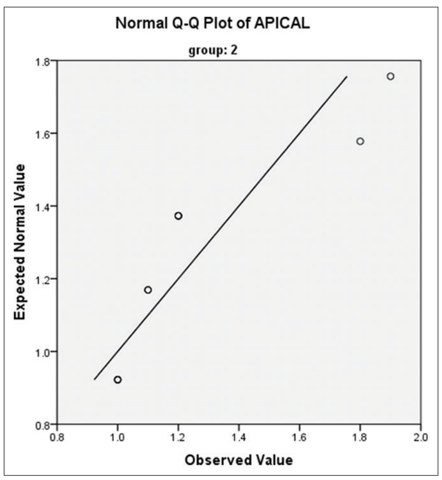
0.10
0.05
0.0000
-0.05
-0.10
-0.15
1.0
1.2
1.4
1.6
1.8
2.0


Normal Q-Q Plot of APICAL
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Expected Normal Value
Observed Value
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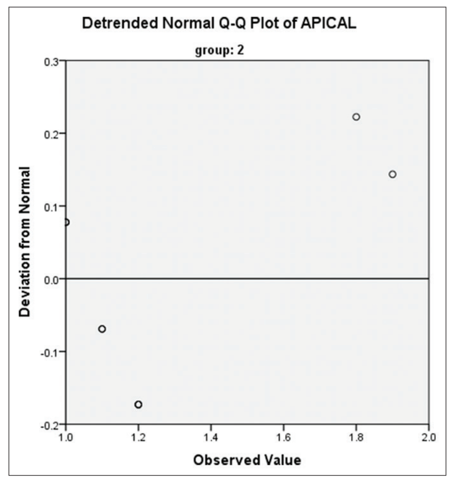
1.2
1.4
1.6
1.8
2.0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Deviation from Normal
Observed Value
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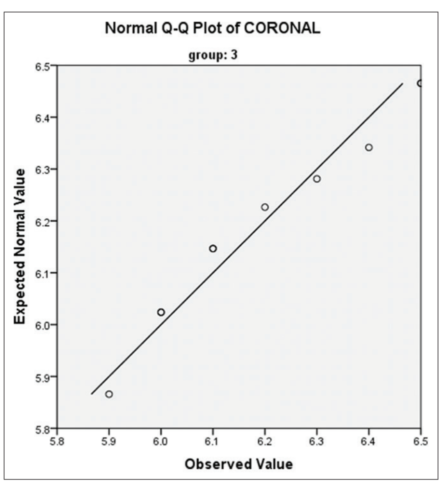
1.2
1.4
1.6
1.8
2.0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Expected Normal Value
Observed Value
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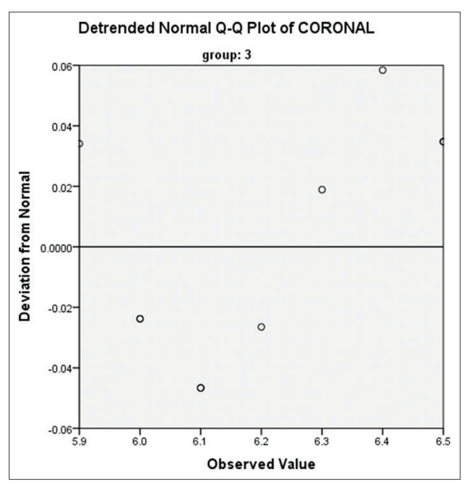
6.1
6.2
6.3
6.4
6.5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Deviation from Normal
Observed Value
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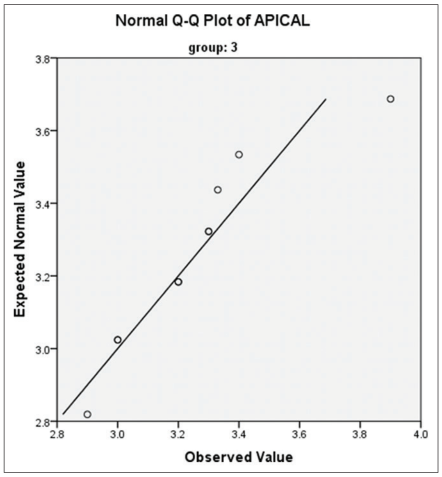
6.5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Expected Normal Value
Observed Value
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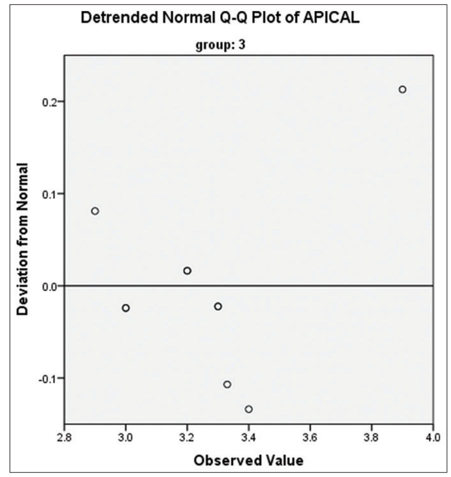
3.8
4.0


Detrended Normal Q-Q Plot of APICAL
group: 3
Deviation from Normal
Observed Value
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0.0
-0.1
2.8
3.0
3.2
3.4
3.6
3.8
4.0