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Evaluation of Ultrasound for Measuring Remaining Dentin Thickness: *In Vitro* Study

Kalan Dentin Kalınlığının Ölçülmesinde Ultrason Yönteminin Değerlendirilmesi: *İn Vitro* Çalışma

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This study was presented as a summary orally in IV. Prevent from Caries Symposium in May 8-9, 2023, İstanbul.

ABSTRACT Objective: To determine the remaining dentin thickness between the cavity floor and pulp tissue at 3 levels: dentino-enamel junction, 0.5 mm coronal, and 1 mm coronal to the pulp horn using ultrasonic measurement compared with digital caliper. **Material and Methods:** Twenty-one sound human molars, free of caries and restorations, were disinfected in 0.1% thymol solution for 1 week, cleaned of tissue, and examined under 2.5x magnification microscope. The teeth were randomly divided into 3 groups (n=7). Vertical sections were obtained using a diamond-separating disc in the mesiodistal direction. Horizontal sections were taken from the apical of the dentino-enamel junction in group 1, 1 mm coronal of the pulp horn in group 2, and 0.5 mm coronal of the pulp horn in group 3. Measurements were taken using an ultrasonic system (Novascope 4500, NDT, Waltham, Mass., USA; 11 MHz frekans, 1,5 mm prob, Harisonic, Staveley NDT, Wash., USA) with glycerin coupling gel and a digital caliper (Dasqua 1804-1065, Italy). Three measurements were obtained between the pulp horns of each sample. Paired t-tests were used for analysis. **Results:** No statistically significant differences were found between the mean values of 2 methods at any level ($p>0.05$). A strong positive correlation was demonstrated between ultrasonic and caliper measurements ($r=0.872$, $p<0.001$), with high reliability (Cronbach's alpha=0.91). **Conclusion:** Using an ultrasonic system to measure dentin thickness at different levels appears promising. Accurate measurement of remaining dentin thickness during cavity preparation is critical for preventing pulp exposure and preserving vitality. The findings suggest ultrasonic systems may provide a reliable, non-invasive method for real-time monitoring of dentin thickness.

Keywords: Ultrasonography; dentin; dental pulp; tooth preparation

ÖZET Amaç: Bu çalışmanın amacı, kavite tabanı ile pulpa dokusu arasındaki kalan dentin kalınlığını; mine-dentin birleşiminde, pulpa boynuzunun 0,5 mm ve 1 mm koronalinde olmak üzere 3 farklı düzeyde ultrasonik ölçüm yöntemi ile dijital kumpas kullanılarak karşılaştırmalı olarak belirlemektir. **Gereç ve Yöntemler:** Çürüksüz ve restorasyonsuz, sağlam 21 insan molar dişi %0,1 timol çözeltisinde bir hafta süreyle dezenfekte edildi, dokulardan temizlendi ve 2,5x büyütmeli mikroskop altında incelendi. Dişler, rastgele 3 gruba ayrıldı (n=7). Mezio-distal yönde elmas ayırıcı disk kullanılarak dikey kesitler elde edildi. Grup 1'de mine-dentin birleşiminin apikalinden, grup 2'de pulpa boynuzunun 1 mm koronalinden, grup 3'te ise pulpa boynuzunun 0,5 mm koronalinden yatay kesitler alındı. Ölçümler, gliserinli ara jel kullanılarak ultrasonik sistem (Novascope 4500, NDT, Waltham, Mass., ABD; 11 MHz frekans, 1,5 mm prob, Harisonic, Staveley NDT, Wash., ABD) ve dijital kumpas (Dasqua 1804-1065, İtalya) ile gerçekleştirildi. Her örnekte, pulpa boynuzları arasında 3 ölçüm yapıldı. Verilerin analizinde eşleştirilmiş t-testi kullanıldı. **Bulgular:** Hiçbir düzeyde 2 yöntem arasındaki ortalama değerler açısından istatistiksel olarak anlamlı bir fark bulunmadı ($p>0,05$). Ultrasonik ve kumpas ölçümleri arasında güçlü pozitif bir korelasyon gösterildi ($r=0,872$, $p<0,001$) ve yüksek güvenilirlik saptandı (Cronbach alfa=0,91). **Sonuç:** Ultrasonik sistem ile dentin kalınlığının ölçülmesi umut verici görünmektedir. Kavite preparasyonu sırasında kalan dentin kalınlığının doğru bir şekilde belirlenmesi, pulpa ekspozunu önlemek ve dişin canlılığını korumak açısından büyük önem taşımaktadır. Bulgular, ultrasonik sistemlerin dentin kalınlığının ölçümünde güvenilir ve noninvaziv bir yöntem sağlayabileceğini düşündürmektedir.

Anahtar Kelimeler: Ultrasonografi; dentin; diş pulpası; diş hazırlama

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The ultrasonic method seems a promising technique to use in clinical routine in dentistry due to its advantages, such as ease of use, painlessness, non-invasive nature, and the absence of ionizing radiation.[1] Small or medium cavities may not be important from the pulp's vitality point of view. However, extensive caries might lead to pulpal exposure during cavity preparation procedures. During cavity preparation, accurate determination of residual dentin thickness is a clinically important requirement that is quite difficult due to differences in individual tooth anatomy, pulp chamber calcification, and reparative dentin formation.

Although radiographs can be helpful in this regard, they can cause interruptions and exposure to X-rays during treatment and are generally not definitive due to their limitations. However, the non-destructive and quantitative results obtained with ultrasound can provide the opportunity to determine the remaining dentin thickness. Especially in cases where selective caries removal and indirect pulp capping are performed, the use of ultrasound might be very important for ensuring the protection of the pulp.[2] In addition, ultrasonic systems do not involve ionizing radiation and are capable of making fast, repeatable, and numerical measurements, providing significant advantages during treatment.[3,4]

Ultrasound systems transmit high-frequency sound waves through a probe with a coupling medium such as glycerin, and the reflected signals are converted into numerical values.[5,6] Previous studies applied ultrasound for detecting enamel demineralization, proximal caries, enamel thickness, and for evaluating the sound velocity in dentin sections.[7-13] While these investigations confirmed the diagnostic potential of ultrasound, they were primarily limited to the detection of enamel and proximal caries. The ability of ultrasound to accurately determine the residual dentin thickness between the cavity floor and the pulp chamber remains underexplored, representing a key clinical need during cavity preparation.

Therefore, this study aimed to determine the remaining dentin thickness between the cavity floor and pulp tissue at three levels: dentino-enamel junction, 0.5 mm coronal, and 1 mm coronal to the pulp horn using ultrasonic measurement compared with a digital caliper. The null hypothesis was that there would be no statistically significant difference between the remaining dentin thickness values measured by the ultrasonic system and those measured by the digital caliper.

MATERIAL AND METHODS

COLLECTION AND STORAGE OF TEETH

Ethical approval was obtained from İstanbul Kent University Health Sciences Research Ethics Committee (date: March 7, 2025; no: E-10420511-051-42545). This study was conducted in accordance with the ethical principles of the Declaration of Helsinki. The extracted human teeth used in the study were obtained anonymously and without being associated with patient identification information. Teeth were extracted due to clinical necessity, and informed consent was obtained from the individuals involved.

This *in vitro* study was performed on 21 extracted human molars. Before extractions, all patients were informed about the study and provided their written consent to participate. Teeth were preserved in a 0.1% thymol solution. Before the study, the extracted teeth were cleaned of any blood and soft tissue residues. Only teeth with no cracks or caries were included, verified under a 2.5x magnification light microscope.

PREPARATION OF SAMPLE GROUPS

Twenty-one teeth were randomly selected and divided into 3 different dentin thicknesses: thick dentin, medium dentin, and thin dentin. The teeth were sectioned in the mesiodistal direction using a fine-grit diamond separator to expose the dentino-enamel junction and pulp chambers, resulting in vertical sections. Horizontal sections were then obtained as follows: from the apical part of the dentino-enamel junction pulp horn in Group 1, from 0.5 mm coronal to the highest pulp horn in Group 2, and from 1 mm coronal to the highest pulp horn in Group 3 (Figure 1, Figure 2, Figure 3). Subsequently, a digital caliper (Dasqua 1804-1065, Italy) and ultrasonic system (Novascope 4500, Harisonic, Staveley NDT, Kennewick, Wash, USA) were used to measure the dis-

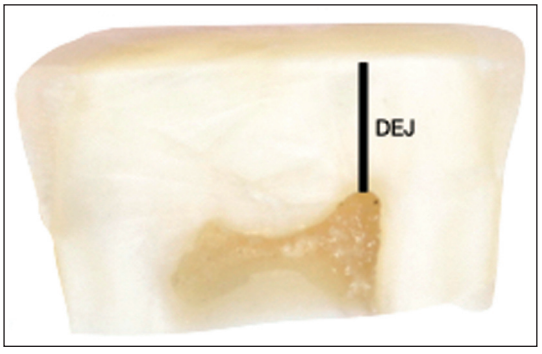


FIGURE 1: Sample in the group where the distance is from the pulp chamber ceiling to the DEJ
DEJ: Dentino-enamel junction

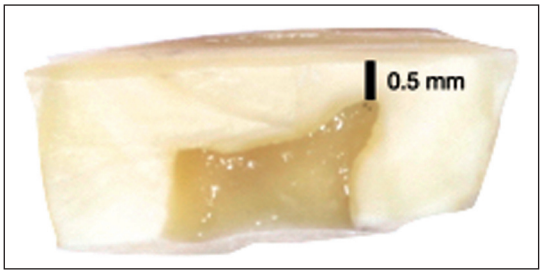


FIGURE 2: Sample in the group where the closest distance to the pulp chamber ceiling is 0.5 mm

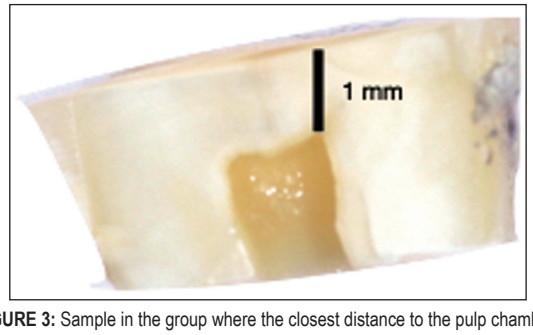


FIGURE 3: Sample in the group where the closest distance to the pulp chamber ceiling is 1 mm

tances between the marked points and determine their proximity to the pulp chamber.

CALIBRATING THE ULTRASOUND DEVICE

The ultrasonic system was primarily calibrated with aluminium measurement blocks of 0.025 and 0.035 inches (0.635 and 0.889 mm) thickness. To ensure accurate measurements, the device was also calibrated with dentin sections representing the lowest and highest values within the measurement range. Therefore, dentin sections with thicknesses of 0.5, 1, 2, and 3 mm were prepared using a diamond separator and utilized for calibration (Figure 4).

ULTRASONIC AND DIGITAL CALIPER MEASUREMENTS

The ultrasonic system used in this study was the Novascope 4500 (NDT, Waltham, Mass., USA), capable of measurements with 1 μm precision. The frequency range of the device is 0.3-20 MHz and the pulse range is 50-3450 Hz. The device was equipped with a right-angle contact transducer (11 MHz nominal center frequency, 1.5 mm tip contact diameter) with a removable Plexiglas delay tip (Harisonic, Staveley NDT, Wash., USA). Ultrasonic systems operate by generating high-frequency longitudinal pressure waves, in which particle motion is parallel to the sound beam propagation. Using the pulse-echo technique, these waves are transmitted from the transducer through a coupling medium, reflected from tissue interfaces, and reconverted into electrical signals displayed as numerical thickness values. In this study, glycerin gel (Fisher Scientific, Hampton, NH, USA) was applied as the coupling medium to ensure

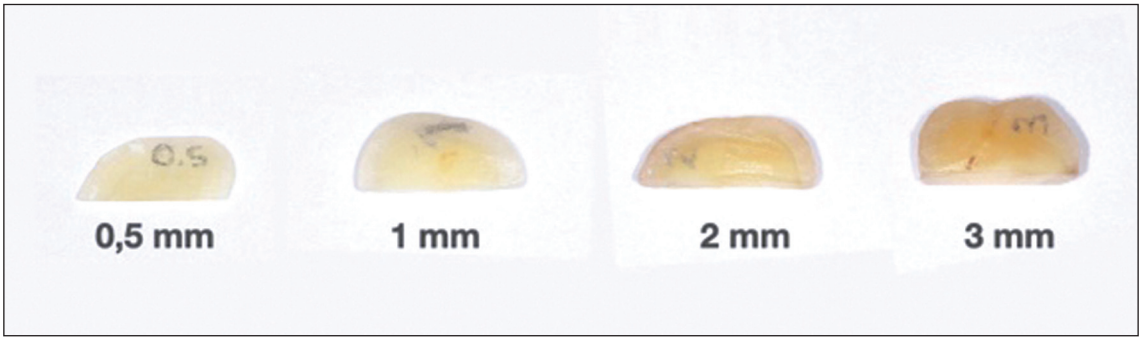


FIGURE 4: Created dentin sections in 0.5, 1, 2 and 3 mm thickness for calibration

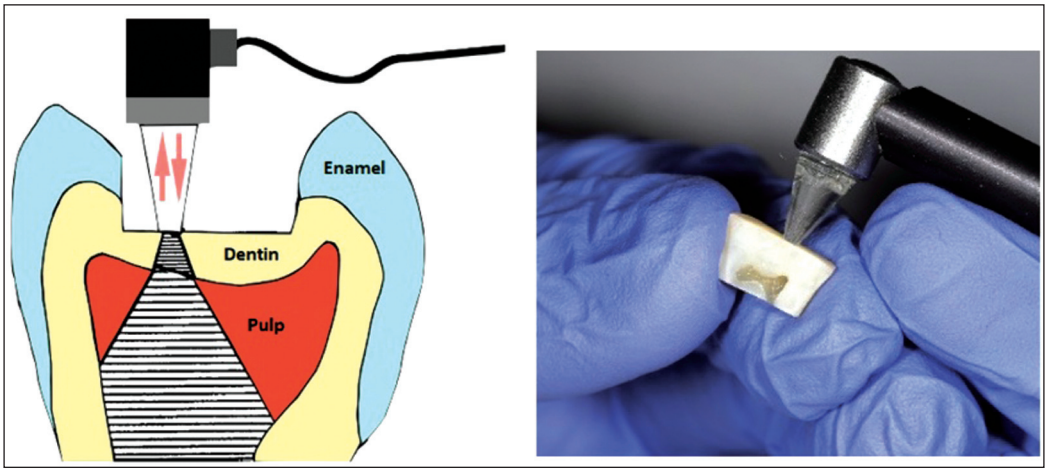


FIGURE 5: Determination of dentin thickness using ultrasonic measurement.[14]

effective sound wave transmission.[12] The tip of the probe is larger than the pulp horn, so measurements were made in flat areas between the pulp horns.

The samples were stored in distilled water until the measurement, removed immediately before the measurement, and gently dried. Measurements were made approximately in 30 seconds, recorded with the ultrasound device and the digital caliper at 3 different points between pulp horns in each sample (Figure 5, Figure 6).

These 3 measurements were then averaged. The error for thickness measurements was 1/1,000.[12]

The same operator performed all ultrasonic measurements to ensure consistency. The probe was positioned perpendicular to the sectioned dentin surface, with minimal and constant pressure applied to avoid deformation. The bottle of glycerin gel was applied with only one drop over each surface.



FIGURE 6: Determination of dentin thickness using ultrasonic measurement digital caliper

STATISTICAL ANALYSES

The statistical analyses were performed using SPSS software (version 21.0; IBM Corp., Armonk, NY, USA). The Shapiro-Wilk test was used to evaluate the normality of paired differences between ultrasonic and caliper measurements. As the data showed normal distribution, comparisons between the 2 methods were conducted using paired t-tests at each measurement level. Additionally, Wilcoxon signed-rank tests were used as a sensitivity analysis. The internal consistency of ultrasound and digital caliper was assessed using Cronbach's alpha. Correlation analyses were also conducted to determine the relationships between relevant variables. A significance level of $p<0.05$ was considered statistically significant.

RESULTS

The differences between ultrasound and caliper measurement averages are shown in Table 1.

The paired t-test results indicated no statistically significant differences within group 1 (dentino-enamel junction to pulp) ($p=0.935$), group 2 (0.5 mm coronal to the pulp horn) ($p=0.272$), and group 3 (1 mm coronal to the pulp horn) ($p=0.589$) for measurements obtained using the ultrasonic system and the digital caliper ($p>0.05$).

TABLE 1: Differences and error percentages between ultrasound and caliper measurement (mm) averages

Group	Sample	Ultrasound (mm)	Caliper (mm)	Difference
Group 1	1	2.22	2.17	**+0.05**
	2	2.79	2.86	**-0.07**
	3	2.41	2.4	**+0.01**
	4	2.69	2.63	**+0.06**
	5	3.34	3.47	**-0.13**
	6	2.97	2.63	**+0.34**
	7	2.38	2.6	**-0.22**
$\bar{X}$±SD		2.69±0.41	2.68±0.41	**0.006±0.18**
Group	1	1.47	1.49	**-0.02**
	2	1.49	1.63	**-0.14**
	3	1.77	1.64	**+0.13**
	4	1.92	1.82	**+0.1**
	5	1.99	1.47	**+0.52**
	6	1.99	2.05	**-0.06**
	7	1.58	1.42	**+0.16**
$\bar{X}$±SD		1.74±0.23	1.65±0.22	**0.10±0.22**
Group 3	1	1.78	1.79	**-0.01**
	2	1.71	1.75	**-0.04**
	3	2.19	2.12	**+0.07**
	4	1.93	2.13	**-0.2**
	5	1.79	1.85	**-0.06**
	6	1.42	1.80	**-0.38**
	7	1.91	1.61	**+0.3**
$\bar{X}$±SD		**1.82±0.24**	**1.86±0.19**	**-0.046±0.21**

SD: Standard deviation

TABLE 2: Reliability (Cronbach's alpha) and correlation analysis between caliper and ultrasound measurements

Device	$\bar{X}$±SD	Cronbach's alpha	Pearson correlation
Caliper	2.02±0.58	0.929	0.872 (p<0.001)
Ultrasound	2.08±0.52		

SD: Standard deviation

Reliability (Cronbach's alpha) and correlation analysis between caliper and ultrasound measurements are shown in Table 2.

The mean values obtained by caliper and ultrasound methods were 2.02±0.58 and 2.08±0.52, respectively. A strong and statistically significant positive correlation was found between the 2 measurement methods (Pearson r=0.872, p<0.001).

DISCUSSION

Based on the results of this study, our null hypothesis was accepted, as no statistically significant difference was observed between the ultrasound and the digital caliper.

During cavity preparation, there is no reference to the dentist on how much being away from the pulpal floor of the cavity, except for constantly checking the initial radiograph of the related tooth. It is known that caries is progressive 30% more in clinics than what was observed in radiographs.[15] It was possible with a digital caliper, which was used as a control method for measurement in this *in vitro* study, since the samples could be held in hands. However, in clinics, it is not possible to measure the samples this way. There is a need for a nondestructive and accurate measurement during cavity preparation to prevent any pulpal exposure. For this purpose, an ultrasound device was used to determine the dentin thickness between the cavity floor and the pulp chamber in this study. It was observed that there was no significant difference in statistics between the measurements of ultrasound device and digital caliper in all three groups. This shows that it is possible to use an ultrasonic system to measure the distance of dentin tissue of different thicknesses and different locations from the pulp chamber.

Recently ultrasonic systems have been used to measure the thickness of tooth tissue.[16] Several studies investigated the reliability of ultrasonic measurements compared to other methods.[17-20] Ślak et al. reported that the use of a high-frequency ultrasound device to measure the enamel thickness was similar to the data obtained with the direct cross-sectional measurements (with a 12% difference) and the acoustic microscope (with a 10% difference).[17] Hughes et al. stated that a high-frequency ultrasonic system was able to measure enamel thickness with an accuracy of 10% compared to the sequential grinding and imaging method.[20] Huysmans and Thijssen found a Pearson correlation value of 0.9 between the ultrasonic system and the histological gold standard method for enamel thickness measurement.[21] In the current study, the dentin thickness values measured by the ultrasound device were similar to the values obtained by the digital caliper.

By determining the sound velocity in the dentin tissue and measuring the time interval between the transmission of the ultrasonic pulse and the echo pro-

duced by the pulp chamber the thickness of dentin can be measured.[5,21] Since the sound velocity transmitting through the tissue is generally assumed to be constant, the time measurement can be easily converted into distance.

In optical methods such as optical coherence tomography, light may not propagate well through dark affected dentin. Therefore, ultrasound, which uses sound waves instead of light, offers a promising alternative, especially in deep lesions. However, ultrasonography has some disadvantages. The need for flat surfaces to make accurate measurements in the dental tissue and the probe design may be considered among these. In addition, since hard tissues (enamel, dentin and cementum) are anisotropic, the sound velocity in these tissues is not constant and may not give a uniform thickness measurement because of this. Another important disadvantage is that the probe tip used in ultrasonic system is too large to fit into the cavities that may be prepared in the tooth. Ng et al. made measurements on enamel surfaces using an ultrasound device and indicated that the probe is difficult to apply due to its large size, and requires application of a gel between the tested surface and the probe as an intermediate medium.[22] Although the angulation of the probe, being contra-angled, resembles handpieces used in dentistry, an appropriate size allowing for easy measurement of the cavity and shape may be developed for this purpose.

Considering the limitations of this study, it was observed that the cavity floor and the pulp chamber are not parallel to each other, which causes echo loss in the return of sound waves, sometimes prevents obtaining accurate measurements, and sometimes results in no measurement at all. In addition, it was observed that the probe tip is not linear, and its width only allows measurement between the pulpal horns.

On the other side, non-radiation is worth studying further. Measuring the thickness of the dentin with ultrasonography may provide important benefits in determining the treatment to be applied and the material to be chosen by the clinicians. However, the awareness of this technology is still low in dentistry. The findings indicate that ultrasound may be useful in estimating dentin thickness and avoiding pulp exposure. This *in vitro* study shows great promise in determining the distance to the pulp chamber. Therefore, further studies are required to validate these findings under clinical conditions, to evaluate factors influencing reproducibility (e.g., probe repositioning, pressure standardization), to investigate sound velocity variations in dentin, and to develop some applicable protocols, perhaps in clinics.

CONCLUSION

The use of an ultrasonic system to measure the distance of dentin tissue of different thicknesses and at different locations from the pulp chamber seems a promising non-destructive and non-ionizing method. In order to benefit from these positive properties of ultrasound method, additional research, both laboratory and clinical, may contribute to dentistry.

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Conflict of Interest

No conflicts of interest between the authors and / or family members of the scientific and medical committee members or members of the potential conflicts of interest, counseling, expertise, working conditions, share holding and similar situations in any firm.

Authorship Contributions

Idea/Concept: *Funda Yanıkoğlu, Ezgi Erden Kayalıdere;* ***Design:*** *Funda Yanıkoğlu, Maxim Lagerweij;* ***Control/Supervision:*** *Funda Yanıkoğlu, Ezgi Erden Kayalıdere;* ***Data Collection and/or Processing:*** *Ezgi Erden Kayalıdere, Kaan Aka;* ***Analysis and/or Interpretation:*** *Elif Alkan, Merve Şahin;* ***Literature Review:*** *Ezgi Erden Kayalıdere, Kaan Aka;* ***Writing the Article:*** *Ezgi Erden Kayalıdere, Kaan Aka, Funda Yanıkoğlu;* ***Critical Review:*** *Funda Yanıkoğlu, Dilek Tağtekin, Maxim Lagerweij;* ***References and Fundings:*** *Funda Yanıkoğlu, Merve Şahin;* ***Materials:*** *Ezgi Erden Kayalıdere, Merve Şahin, Kaan Aka.*

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