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# Diagnosis of ankylosis in permanent incisors by expert ratings, Periotest® and digital sound wave analysis

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Abstract – The objectives of this investigation were to: (i) assess the reliability of expert raters to detect ankylosis from recordings of percussion sounds, (ii) measure differences in Periotest® values (PTV) between ankylosed and non-ankylosed incisors and (iii) identify characteristic differences in recorded percussion sounds from ankylosed and non-ankylosed incisors using digital sound wave analysis. A convenience sample of healthy children (age range 7–18 years) was invited to participate. Ankylosis group children had one or more documented ankylosed maxillary incisors. Control group children had intact, non-ankylosed incisors. Digital recordings of percussion sounds and PTV were acquired for each incisor of interest. Four experienced pediatric dentists rated the randomized percussion sound pairs for the presence of ankylosis. Percussion sounds were also subjected to digital sound wave analysis. Overall agreement for the expert raters was substantial ($K = 0.7$). Intra-rater agreement was substantial to almost perfect ($K = 0.6$–$0.9$). Diagnosis of ankylosis demonstrated sensitivity of 76–92% and specificity of 74–100%. PTV from ankylosed incisors were statistically lower than PTV from non-ankylosed incisors. Ankylosed incisor digital sound wave signals exhibited significantly more energy in high-frequency bands than non-ankylosed incisors. This investigation demonstrated that: (i) experienced pediatric dentists reliably detected ankylosis by percussion sound alone; (ii) PTV for ankylosed incisors were statistically lower than PTV from non-ankylosed incisors; and (iii) ankylosed incisors exhibited a higher proportion of their signal energy in high-frequency bands.

Key words: ankylosis; diagnosis; Periotest®; dental trauma

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Ankylosis of tooth root to alveolar bone is based on the clinical assessment of mobility and percussion sound combined with a radiographic assessment of the associated periodontium. The diagnosis of ankylosis by percussion sound relies on the clinician's judgment of the quality of sounds made by tapping a suspect tooth with a dental mirror handle. The sound produced by this tapping was described as 'high' or 'sharp' (1–3) when compared with adjacent non-ankylosed teeth. 'High' or 'sharp' percussion sounds and decreased tooth mobility were determined to be more sensitive and accurate signs of ankylosis than radiographic examination (4, 5) if 20% or more of the root surface was ankylosed (1, 2).

The Periotest® (Siemens/Medizintechnik-Gulden, Bensheim, Germany), a commercially available device for assessment of tooth mobility, produces a quantitative measure of the damping properties of the periodontal ligament. Within its 4-s measurement cycle, the retractable metal rod within the unit handpiece delivers 16 taps of a preset percussion force to the tooth. Rod-to-tooth contact time of each tap is detected by a chronometer and deceleration time of the rod converted to a numeric value ranging from −8 to +50. Lower Periotest® values (PTV) indicate faster deceleration and shorter rod-to-tooth contact times; hence lower mobility and higher damping properties of the periodontal ligament. The Periotest® has been used for the objective diagnosis of ankylosis (6).

Sound frequency analyses have been employed to differentiate healthy and periodontally involved adult teeth (7, 8) and to correlate mobility of healthy teeth with percussion sounds (3). To date, no study has been undertaken specifically using sound wave analysis of percussion sounds from ankylosed incisors.

The objectives of this investigation were to: (i) determine whether experienced clinicians could reliably detect ankylosis from digitally recorded percussion sounds; (ii) determine whether PTV differed significantly between ankylosed and non-ankylosed incisors in a pre- and adolescent population; and (iii) identify characteristic differences between the digitally recorded percussion sounds of ankylosed and non-ankylosed incisors, using digital sound wave analysis.

## Method

### Subjects

A convenience sample of children was invited to participate in the investigation. Two groups of subjects participated: (i) children who had experienced a luxation injury that produced ankylosis of one or more permanent maxillary incisors (ankylosis group) and (ii) children who had intact, non-ankylosed permanent maxillary incisors (control group).

Subjects were 7–18 years of age with no potentially complicating medical conditions (e.g. connective tissue disorders) and had the ability to cooperate with data collection procedures. Subjects in the ankylosis group were invited to participate in the study while attending routine trauma follow-up at The Hospital for Sick Children and Bloorview MacMillan Children's Centre. They all had previously documented clinical or radiographic signs of ankylosis in their treatment record. Subjects in the control group were invited to participate while attending orthodontic screening. Subjects with prior traumatic dental injuries, orthodontic or restorative treatment of the incisor teeth were excluded from the control group. The Research Ethics Board of The Hospital for Sick Children and the University of Toronto Health Sciences I Ethics Review Committee granted ethical clearance for the investigation.

One investigator (KMC) performed all data collection. Consent and assent were obtained before proceeding. Subjects were semi-reclined in the dental chair for the entire data collection session, which began with a cursory oral examination. For each incisor of interest, percussion sounds were recorded; clinical photographs and PTV were acquired. Digital recordings of percussion sounds made by tapping the incisors with a metal dental mirror handle were captured using a USB microphone (Macally *i* voice, Model 000896, Macally, Irwindale, CA, USA) clipped to the left lab coat collar of the investigator to imitate a typical subject-to-ear distance for the recordings. This microphone was connected to a notebook computer (Dell PC, Model PP01L) equipped with digital sound recording software (Sonic Foundry Sound Forge Studio©, Version 6.0). For each incisor that was assessed, a series of three sets of three axial taps followed by three sets of three lateral taps were recorded. Each incisor was also assessed with the Periotest®. The handpiece of the unit was positioned according to the manufacturer's instructions and five consecutive PTV were documented for each incisor.

### Expert ratings of percussion sounds

The reliability of expert raters to detect ankylosis from paired ankylosed/non-ankylosed percussion sound files was assessed. Percussion sounds were extracted unaltered from the original sound files. Four types of sound pairs were produced: (i) three lateral percussion sounds from an ankylosed incisor were matched with three lateral percussion sounds from a non-ankylosed incisor from the same subject; (ii) three axial percussion sounds from an ankylosed incisor were matched with three axial percussion sounds from a non-ankylosed incisor from the same subject; (iii) three lateral percussion sounds from an ankylosed incisor were matched with three lateral percussion sounds from a non-ankylosed incisor of an age- and gender-matched subject from the control group; and (iv) three axial percussion sounds from an ankylosed incisor were matched with three axial percussion sounds from a non-ankylosed incisor of an age- and gender-matched subject from the control group. The order of presentation of percussion sounds from ankylosed and non-ankylosed incisors within each pair was randomized. Each pair of percussion sounds was presented a second time with the order of the sounds in each pair either presented in their original order or reverse order by random assignment to permit an assessment of intra-rater reliability. The rating exercise consisted of 96 sound pairs (48 pairs of three percussion sounds presented twice in random order with ankylosed and non-ankylosed percussion sounds presented in random order within each pair).

The principal investigator (KMC) presented the rating exercise to each of four experienced pediatric dentists in a standardized format as follows: the rater was seated at a desk, facing two tabletop speakers placed to their right and left connected to a notebook computer from which the percussion sound pairs, each of approximately 5 s in length, were played back by the principal investigator. Verbal pretest instructions included a statement of the purpose and format of the exercise and rating method to be used. The rater was advised that each sound pair consisted of one series of three percussion sounds from the first incisor, a pause, and another series of three percussion sounds from the second incisor and that one of the series of percussion sounds within each pair was from an ankylosed incisor. Three sample sound pairs were presented to adjust and confirm appropriate volume levels before beginning the actual exercise. The sound pairs of the exercise were offered to the rater one at a time and the rater indicated on a prepared score sheet whether the first or the second set of percussion sounds was from the ankylosed incisor. Each sound pair was repeated for the rater upon request, as many times as he or she required to make a determination of which set of percussion sounds was from the ankylosed incisor.

### Digital sound wave analysis

The same sound pairs developed for the expert rater reliability exercise were subjected to digital sound wave analysis. A systematic approach was used to identify fundamental differences in the signal characteristics between ankylosed and non-ankylosed incisors. First, because of the random nature of the data, the sound waves were assessed to determine whether stationarity (i.e. the mean and variance of the data remain constant over time) and normality (i.e. the amplitude distribution of the data follows a normal distribution) were present. This initial determination provided the basis for appropriate application of temporal and spectral analyses such as measures of decay times, frequency bandwidths and time frequency analyses.

### Statistical methods

The mean and age range, gender proportion of the ankylosis and control groups were calculated.

The expert rater reliabilities from the assessment exercise were reported as kappa values for inter-rater, intra-rater and overall agreement. Sensitivity and specificity values were also calculated for the individual raters.

The mean and standard deviation of the five consecutive PTV readings were calculated for each incisor. All observations were graphically represented in a scatter plot, and best-fit trend lines were calculated for descriptive purposes. Further analysis included comparisons of mean PTV of all ankylosed and non-ankylosed incisors using ANOVA, weighted by variance. To ensure statistical independence in the case of multiple ankylosed incisors within one subject, the ankylosed incisor with highest PTV was selected for both within-subject and between-subject comparisons with the non-ankylosed incisor having the lowest PTV.

The digital sound wave analysis data included all ankylosed and non-ankylosed incisors represented by the percussion sound pairs used in the expert rater reliability exercise. Statistical analysis included comparisons between ankylosed and non-ankylosed incisors in both axial and lateral percussion direction. Nonparametric Wilcoxon rank sum tests were used for the comparisons.

## Results

### Sample

Sample demographic information is displayed in Table 1. The sample of 12 ankylosed incisors from the nine patients included 10 avulsions with delayed replantation and two severe intrusions. All except one were central incisors.

### Expert rater reliability

The kappa statistic for intra-rater agreement ranged from 0.6 to 0.9, which indicated 'substantial' to 'almost perfect' agreement (9) in the diagnosis of ankylosis by percussion sound. Inter-rater agreement kappa ranged from 0.5 to 0.9, which indicated 'moderate' to 'almost perfect' agreement. The overall kappa was 0.7, which indicated 'substantial' agreement. Diagnosis of ankylosis by percussion

Table 1. Sample demographics

| | Ankylosis group | Control group |
|---|---|---|
| $n$ (incisor) | 12 ankylosed, 17 non-ankylosed | 50 |
| Age range (years) | 9.6–18.5 | 9.7–17.8 |
| Mean age (years ± SD) | 13.8 (±3.8) | 13.3 (±2.2) |
| Male:female | 4:5 | 7:12 |

sound demonstrated sensitivity of 76–92% and specificity of 74–100%.

### Periotest®

The sample of 12 mean PTV from the ankylosis group was plotted against the 67 mean PTV that included all non-ankylosed incisors from the ankylosis and control groups (Fig. 1). The trend line for the non-ankylosed observations demonstrated a decrease in mean PTV with increasing age, which was consistent with results from previous studies (6, 10, 11). The decreasing trend also appeared to exist with the ankylosis group sample, and its trend line demonstrated a consistent downward shift from the non-ankylosed line.

Mean PTV for ankylosed and non-ankylosed incisors were compared using ANOVA, weighted by variance. An initial overall analysis comparing all ankylosed and non-ankylosed incisor observations in this sample demonstrated that ankylosed incisors had a significantly lower PTV ($P < 0.0001$). Additionally, within-subject and between-subject comparisons were performed as follows: for those subjects with more than one ankylosed incisor, the incisor with the highest PTV was selected for comparison with the non-ankylosed incisor having the lowest PTV within the same subject. This yielded nine possible 'worst outcome' within-subject comparisons. Between-subject comparisons included the selection of the highest PTV for an ankylosed incisor per subject to be paired with the lowest PTV from an age- and gender-matched control group subject incisor. This again yielded nine possible 'worst outcome' between-subject comparisons. The results of these comparisons determined that the mean PTV for ankylosed incisors was statistically lower (Table 2).

Table 2. Mean PTV comparison by ANOVA

| | Mean PTV ankylosed incisors | Mean PTV non-ankylosed incisors | P-value (weighted ANOVA) |
|---|---|---|---|
| Within-subjects | 5.508 | 8.446 | 0.004 |
| Between-subjects | 5.463 | 8.949 | 0.011 |

### Digital sound wave analysis

Ankylosed and non-ankylosed incisor percussion sounds generated in both axial and lateral directions were investigated in this analysis. Initial assessment of the wave patterns determined that neither stationarity nor normality were characteristics of percussion sounds, as has been noted previously with other physiologic signals [e.g. electromyographic (EMG) signals (12) and swallowing sounds (13)]. Simple analytical testing, such as temporal analysis that examined the rate of decay of the sound signal, did not reveal consistent differences. The 'impulse' nature of the sound waves suggested a spectral analysis might also be appropriate. Specifically, examination of the collection of frequencies that contained 95% of the signal energy showed that ankylosed incisors had bandwidths that generally extended to higher frequencies. To investigate further, a combined time frequency analysis of each sound signal by 7-level Daubechies wavelet decomposition (14) was then undertaken. This provided a relative distribution of the total energy of the sound

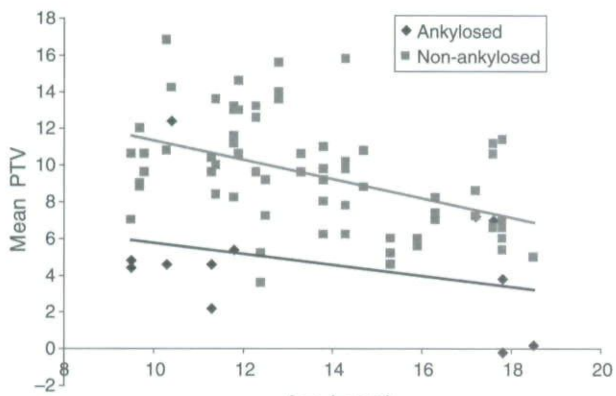


*Fig. 1.* Mean PTV vs. age. Scatter plot representing all ankylosed and non-ankylosed observations with trend lines. Note the similar decrease in PTV with age for both groups of observations.

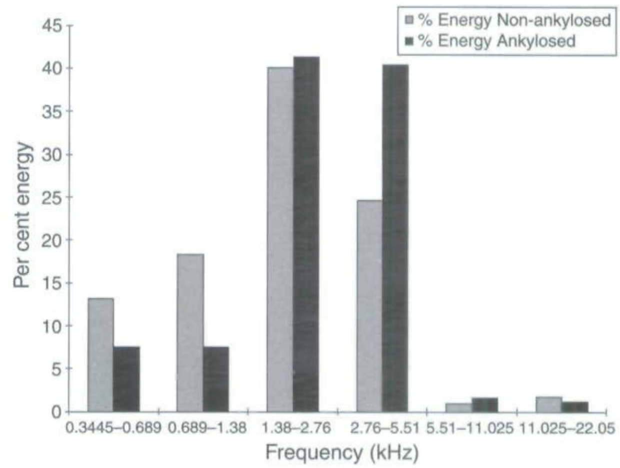


*Fig. 2.* Time frequency analysis for lateral percussion sounds – non-ankylosed vs. ankylosed incisors. Note the majority of frequency energy for both groups is contained in the 1.38–2.76 and 2.76–5.51 kHz bands but with non-ankylosed signals demonstrating more low frequency energy components. Compare with Fig. 3.

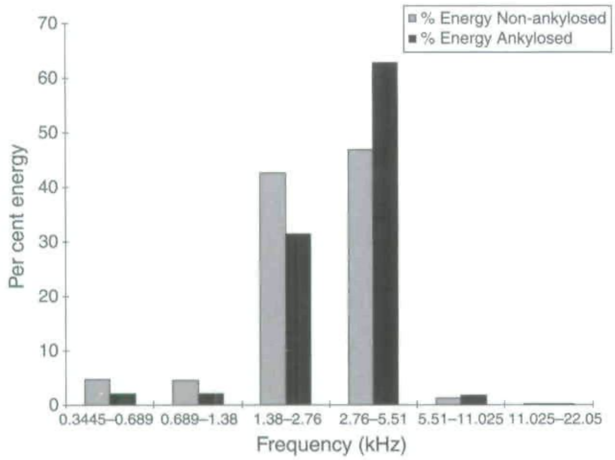


*Fig. 3.* Time frequency analysis for axial percussion sounds – non-ankylosed vs. ankylosed incisors. Again, the majority of frequency energy for both groups is contained in the 1.38–2.76 and 2.76–5.51 kHz bands. However, in contrast to Fig. 2, a higher percentage of the overall signal energy is concentrated in these two bands.

Table 3. Digital sound analysis: Wilcoxon rank sum test

| Frequency band (kHz) | Lateral taps: non-ankylosed (N) vs. ankylosed (A) | Axial taps: non-ankylosed (N) vs. ankylosed (A) |
|---|---|---|
| 0.3445–0.689 | N > A* | N > A* |
| 0.689–1.38 | N > A** | N > A** |
| 1.38–2.76 | n.s. | N > A** |
| 2.76–5.51 | A > N* | A > N** |
| 5.51–11.025 | n.s. | A > N** |
| 11.025–22.05 | N > A* | n.s. |

*Significant at <0.05.
**Significant at <0.005.

signal across the decomposition levels that corresponded to the different frequency bands (Figs 2 and 3). It was then revealed that the majority of the energy in all signals resided in two frequency bands, namely 1.38–2.76 kHz and 2.76–5.51 kHz. Specifically, for lateral percussion sounds, non-ankylosed incisor signals demonstrated more energy in the two lowest frequency bands or, alternately, had stronger low-frequency components. For the axial percussion sounds, ankylosed incisor signals exhibited more energy in the high-frequency bands. With the exception of the highest frequency band, high frequency energy was overall significantly greater in the ankylosed than in the non-ankylosed percussion sound signals (Table 3).

## Discussion

Experienced pediatric dentists were chosen as expert raters as management of dentoalveolar trauma is a usual and customary part of their practice. The 'paired' presentation format best simulated the technique of incisor-to-incisor comparison used clinically for subjective detection of ankylosis. Unlike the clinical situation, raters were unbiased by historical, clinical or radiographic information and lacked the tactile feedback of percussion testing, which would further improve identification of ankylosis. Ratings were based solely on percussion sounds. Sound files were modified only in length, with no digital sound wave modifications applied. The consistent high reliability within and among these expert raters, despite ambient noise on the recording and the lack of visual information, supports the contention that ankylosed incisors produce a recognizable percussion sound. Furthermore, this sound was differentiated with a high degree of reliability regardless of the direction the tooth was percussed. The protocol used in this investigation did not impair the rater's ability to detect the differences between ankylosed and non-ankylosed incisors.

The Periotest® was chosen for this clinical investigation because it offered a method for objective assessment of ankylosis. In all cases, the Periotest® was introduced to the subject before use, with a tell-show-do approach that subjectively appeared to allay any initial apprehension; however, it is worthy to note that one parent refused to give consent for her daughter to participate as a control subject for fear that the Periotest® method would be traumatic. Handpiece placement was critical, especially in the horizontal direction, to enable error-free readings. Readings were taken consecutively for each tooth before moving on to the next to simulate practical clinical use, unlike other studies in which a 10–15-min waiting time lapsed between individual readings (10, 11). The retractable rod mechanism within the handpiece was noted occasionally to 'fatigue' or 'stutter' in its cycle of 16 taps. This would most often occur during periods of extended use, regardless of AC adaptor or battery power usage. It was not unusual to require more than five attempts to achieve five PTV readings. Nevertheless, the results indicated that the mean PTV for this group of ankylosed incisors was significantly lower than the non-ankylosed incisors, which verifies that the Periotest® can identify ankylosis in a relative manner. However, its usefulness may be limited in that it is only able to confirm what the clinician has already detected with a high degree of accuracy by tapping the tooth with a mirror handle. A diagnosis of ankylosis cannot be made strictly on the basis of a low PTV. This study confirms the findings of past studies that a range of physiologic mobility can be expected as part of normal variation among individuals (3, 6, 10, 11, 15). It may be more meaningful to use the Periotest® to assess one patient's traumatized tooth longitudinally, where a decrease in PTV may be potentially diagnostic when compared with a contralateral unaffected tooth. Even so, because of the firm tapping action of the Periotest®, its use in the early post-trauma period may not be well accepted by younger or sensitive patients.

The time frequency sound wave analysis illustrated differences in the signal energy of ankylosed and non-ankylosed incisors. Signals from ankylosed incisors demonstrated significantly more energy in the high-frequency bands, which corroborates reports of the 'high' percussion sound for ankylosed teeth. The majority of the signal energy of both ankylosed and non-ankylosed percussion sounds, whether generated in the lateral or axial direction, resides within a relatively narrow range of frequencies. It seems quite likely that these frequency bands play a key role in auditory differentiation of percussion sounds from ankylosed and non-ankylosed incisors. This investigation has shown that quantitative examination of signal energy within these frequency bands, particularly for percussion sounds generated in the axial direction, can be used to differentiate between ankylosed and non-ankylosed incisors. Sound signal energy analysis may provide a novel approach to development of an instrument for clinical detection of ankylosis.

Despite efforts toward trauma prevention and improvement of treatment protocols, there will always be a need for an accurate and reliable method to diagnose ankylosis. Clinicians will continue to be confronted with delayed replantation due to a lack of knowledge or unwillingness of laypersons to provide immediate replantation (16). When the decision has been made to proceed with treatment of a severe injury, the clinician is obligated to perform therapies based on the best evidence available. Currently, treatments are designed to eliminate inflammatory resorption but they promote replacement resorption. With short-term repair, the tooth becomes stable, and the patient is encouraged by the look and feel of stability. However, the preadolescent with ankylosis will experience progressive infraocclusion with loss of alveolar bone height, distortion of the gingival margin and space loss (17, 18). Replacement resorption of the root occurs more rapidly in the preadolescents and adolescents (2) with an increased risk of secondary crown loss. This emphasizes the need for close monitoring and timely management. Alterations to the alveolar bone associated with previous trauma may compromise the site for future bone grafts and implants (19). Early detection of ankylosis would allow intervention before the full scope of negative consequences of ankylosis complicated by growth arises.

## Conclusions

1. Experienced pediatric dentists can reliably detect ankylosis by percussion sound alone.
2. PTV for ankylosed incisors are statistically lower than non-ankylosed incisors.
3. The digital percussion sound waves of ankylosed incisors examined by time frequency analysis exhibit a higher proportion of their signal energy in the high frequency bands than non-ankylosed incisors.

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