

Evaluation of the ability of thermal and electrical tests to register pulp vitality

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Abstract – The aim of the present study was to evaluate the ability of thermal and electrical tests to register pulp vitality. Sensitivity, specificity, negative predictive value and positive predictive value were calculated by comparing the test results with a “gold standard”. The thermal tests studied were a cold test (ethyl chloride) and a heat test (hot gutta-percha). For the electrical test, the Analytic Technology Pulp Tester® was used. The examined teeth were 59 teeth with unknown pulpal status in need of endodontic treatment and 16 intact teeth, all with radiographically normal periapical bone structures. In total 46 teeth with vital pulps and 29 teeth with necrotic pulps were tested. This gave a disease prevalence of 39%. The gold standard was established by direct pulp inspection of the 59 teeth in need of endodontic treatment. In the 16 intact teeth the pulp was judged as vital. The number of true positive (TP), false positive (FP), true negative (TN) and false negative (FN) test results was calculated for each method as compared to the gold standard. Based on this, the sensitivity, specificity, positive predictive value and negative predictive value were calculated for each method. The sensitivity was 0.83 for the cold test, 0.86 for the heat test and 0.72 for the electrical test. The specificity was 0.93 for the cold test, 0.41 for the heat test and 0.93 for the electrical test. The positive predictive value was 0.89 for the cold test, 0.48 for the heat test and 0.88 for the electrical test, and the negative predictive value was 0.90 for the cold test, 0.83 for the heat test and 0.84 for the electrical test. This indicated that the probability of a non-sensitive reaction representing a necrotic pulp was 89% with the cold test, 48% with the heat test and 88% with the electrical test. It also indicated that the probability of a sensitive reaction representing a vital pulp was 90% with the cold test, 83% with the heat test and 84% with the electrical test.

An important part of the oral diagnostic procedure is to identify pulp necrosis when it is suspected. Radiographically detectable periapical bone destruction often indicates that a tooth has a necrotic pulp. However, periapical bone destruction is not always present or radiographically visible (1, 2). The identification of necrotic pulp in teeth with radiographically normal periapical bone structure is especially important in the follow-up of traumatised teeth and in the diagnos-

tic procedure prior to crown and bridge therapy. Under-diagnosis and under-treatment may in these cases lead to severe and expensive complications such as inflammatory root resorption in traumatised teeth (3) and the development of apical periodontitis in abutment teeth (4).

Since the pulp tissue cannot be directly inspected, the dentist has to use indirect methods like tests to register the sensitivity of the pulpal nerves. The most

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commonly used tests in general practice are thermal tests and electrical tests that stimulate the pulpal nerves either by the flow of dentine liquor at temperature changes, which leads to movement of the odontoblast processes and subsequent mechanical stimulation of the pulpal nerves (5), or by an electrical current conducted through the tooth, giving an electrical stimulation of the pulpal nerves.

Even when functioning at the greatest possible level of precision, every diagnostic test will misclassify a certain percentage of patients; that is, some disease-positive patients will have a negative test result, and some disease-free patients will have a positive result. In pulp vitality testing, for example, multi-rooted teeth with vital pulp in at least one canal and necrotic pulp in the rest of the root canal system may give a sensitive reaction on sensitivity testing, while teeth with a vital pulp in an obliterated pulp chamber often do not react to the stimulus given. The extent to which a test correctly classifies patients defines its accuracy. The concepts of sensitivity, specificity, positive and negative predictive value have been developed to characterise test accuracy and to compute the benefits of test usage (6).

Very few studies on the accuracy of pulp vitality test devices are found in the literature. Hyman & Cohen (7) used previously published results on the histological status of the pulp to calculate the predictive value of some common endodontic diagnostic tests. They estimated the sensitivity, specificity and predictive values for cold tests and electrical tests using information on cold tests and electrical tests found in the literature, which they compared with published histological findings. Fuss et al. (8) studied the accuracy of electrical pulp testing, CO₂ snow, dichlorodifluoromethane, ethyl chloride and ice. They compared the specificity of the different tests, mentioned the sensitivity but did not calculate the predictive values. Peters et al. (9) reported only on the sensitivity of different testing agents.

The aim of the present study was to evaluate the ability of thermal and electrical tests to register pulp vitality and then calculate the sensitivity, the specificity, the negative predictive value and the positive predictive value by comparing the test results with a gold standard.

Material and methods

Out of a total of 65 patients studied, 56 patients (36 men and 20 women) had 59 teeth with unknown pulpal status tested. All these patients were to receive endodontic treatment at the Centre for Oral Health Sciences, Malmö, Sweden. Another nine individuals (two men and seven women) among the undergraduate students had 16 intact teeth with radiographically normal periapical bone structures tested. The

age of the subjects ranged from 21 to 79 years. For the distribution by age groups see Table 1. The examined teeth represented all tooth groups. For the distribution by tooth groups see Table 2.

The examinations were performed by students and teachers at the student clinic. Before the tests were performed the subjects were informed of the procedures and aim of the experiment. For teeth in need of endodontic treatment, all tests were done prior to treatment.

The thermal tests studied were a cold test (ethyl chloride) and a heat test (hot gutta-percha). The cold test consisted of soaking a cotton pellet in ethyl chloride and immediately placing it on an intact tooth surface. In the heat test a heated gutta-percha rod was used. For the electrical test the Analytic Technology Pulp Tester® (Analytic Technology Redmond, WA, USA) was used. The electrical test was performed with an electrode gel used as the contact substance and only sensitive reactions at scale values under 50 were considered. All teeth were tested with the three test methods and the tests were performed after drying the tooth with air and isolating it with cotton rolls.

The gold standard (the facit of the pulp status) was dictated by the 59 teeth in need of endodontic treatment in connection with the endodontic treatment initiated immediately after the pulp testing procedure. In these teeth the pulp chamber was opened and the pulp status registered as either vital or necrotic by direct visual inspection. Partial necrosis was considered necrotic pulp. On opening the pulp chambers in the 59 tested teeth that were in need of endodontic treatment, it was observed that 29 pulps were necrotic (no bleeding, pulp tissue destruction) and 30 pulps were vital (bleeding from pulp tissue). In addition, the

Table 1. Distribution of the 65 subjects according to age and sex

Age group	Men	Women	Total
20-30	10	8	18
31-40	11	5	16
41-50	5	6	11
51-60	3	2	5
61-70	6	4	10
71-	3	2	5
Total	38	27	65

Table 2. The 75 examined teeth distributed by tooth group

Jaw	Tooth group		
	Molars	Premolars	Incisors and canines
Maxilla	14	10	4
Mandible	14	26	7

16 intact teeth were considered to have a vital pulp. This gave a disease prevalence of 39%.

The number of true positive (TP), false positive (FP), true negative (TN) and false negative (FN) test results was calculated for each method as compared to the gold standard. Based on this, the sensitivity, specificity, positive predictive value and negative predictive value were calculated for each method.

Sensitivity=the ability of a test to identify teeth that really are diseased. Diseased=teeth with necrotic pulp. The sensitivity was calculated according to the formula $TP/(TP+FN)$

Specificity =the ability of a test to identify teeth without disease. Without disease=teeth with vital pulp. The specificity was calculated according to the formula $TN/(TN+FP)$.

Positive predictive value=the probability that a positive test result really represents a diseased tooth=a tooth with necrotic pulp. The positive predictive value was calculated according to the formula $TP/(TP+FP)$.

Negative predictive value =the probability that a tooth with a negative test result really is free from disease. A tooth free from disease=a tooth with vital pulp. The negative predictive value was calculated according to the formula $TN/(TN+FN)$.

Accuracy=the overall rate of agreement between the diagnostic test and the gold standard. The accuracy is calculated according to the formula $(TP+TN)/(TP+FP+FN+TN)$.

Results

The cold test identified 24 of the 29 necrotic pulps as necrotic while five teeth with necrotic pulps gave a sensitive reaction. Out of the 30 teeth with vital pulp in need of endodontic treatment, the cold test identified 27, while three of the vital pulps did not react to cold. All of the 16 intact teeth gave a sensitive reaction when the cold test was used. For the distribution of test results when the cold test was used, see Table 3.

The heat test identified 25 of the 29 teeth with necrotic pulp as non-sensitive and four as sensitive. Out of the 30 teeth with vital pulp in need of endodontic treatment, the heat test identified 17 as sensitive, while 13 were identified as non-sensitive. In the 16 intact teeth, the heat test gave a sensitive reaction in two teeth and no reaction in 14 teeth. For the distribution of test results when the heat test was used, see Table 4.

The electrical test identified 21 of the 29 teeth with necrotic pulp as non-sensitive and 8 as sensitive. Out of the 30 teeth with vital pulp in need of endodontic treatment, 27 teeth were identified as sensitive and three as non-sensitive with the electrical test. All 16 intact teeth were identified as sensitive with the elec-

trical test. For the distribution of test results when the electric test was used, see Table 5.

On the basis of these findings, the sensitivity, specificity, positive predictive values and negative predictive values were calculated for each test method.

Sensitivity and specificity

For the cold test (ethyl chloride), the sensitivity was 0.83 and the specificity 0.93 (Table 6). This means that 83% of the teeth with a necrotic pulp were identified as necrotic by the cold test, while 93% of the teeth with vital pulp were identified as vital by the cold test.

For the heat test (hot gutta-percha rod), the sensitivity was 0.86 and the specificity 0.41 (Table 6). This means that 86% of the teeth with necrotic pulp were identified as necrotic by the heat test, while 41% of the vital teeth were identified as vital by the heat test.

For the electrical test, the sensitivity was 0.72 and the specificity 0.93 (Table 6). In other words, 72% of the teeth with necrotic pulp were identified as nec-

Table 3. Distribution of test results when the cold test was used. (TN=true negative, FN=false negative, FP=false positive, TP=true positive)

Pulp tissue	Sensitive result		Non-sensitive result	
Vital	43	TN	3	FP
Necrotic	5	FN	24	TP

Table 4. Distribution of test results when the heat test was used. (TN=true negative, FN=false negative, FP=false positive, TP=true positive)

Pulp tissue	Sensitive result		Non-sensitive result	
Vital	19	TN	27	FP
Necrotic	4	FN	25	TP

Table 5. Distribution of test results when the electrical test was used. (TN=true negative, FN=false negative, FP=false positive, TP=true positive)

Pulp tissue	Sensitive result		Non-sensitive result	
Vital	43	TN	3	FP
Necrotic	8	FN	21	TP

Table 6. Sensitivity, specificity, positive predictive value (PPV) and negative predictive value (NPV) for the cold test, heat test and electrical test

Test	Sensitivity	Specificity	PPV	NPV
Cold	0.83	0.93	0.89	0.90
Heat	0.86	0.41	0.48	0.83
Electrical	0.72	0.93	0.88	0.84

rotic by the electrical test, while 93% of the vital teeth were identified as vital.

Predictive values

For the cold test, the positive predictive value was 0.89 and the negative predictive value was 0.90. Thus, there was a probability of 89% that no sensitive reaction represented a necrotic pulp, and there was a probability of 90% that a sensitive reaction represented a vital pulp when the cold test was used.

For the heat test, the positive predictive value was 0.48 and the negative predictive value 0.83. Thus, the probability that no sensitive reaction represented a necrotic pulp was 48%, while the probability that a sensitive reaction represented a vital pulp was 83% with the heat test.

For the electrical test, the positive predictive value was 0.88 and the negative predictive value was 0.84. Thus, the probability that no sensitive reaction represented a necrotic pulp was 88%, while the probability that a sensitive reaction represented a vital pulp was 84% with the electrical test.

Accuracy

The accuracy was 86% for the cold test, 71% for the heat test and 81% for the electrical test.

Discussion

A perfect diagnostic test would always be positive in the presence of disease and negative in the absence of disease. However, false negative or false positive results disturb this perfection in a test's ability to achieve a clinician's two main diagnostic goals: to identify the presence or absence of disease. Some disease-positive patients will have a negative test result, and some disease-free patients will have a positive result. The extent to which a test correctly classifies patients defines its accuracy (10). The precision of a test refers to the tendency of repeated measurements on the same sample to yield the same result. The concepts of sensitivity, specificity, and positive and negative predictive value have been developed to characterise test accuracy and to compute the benefits of test usage. Since the calculations are based on a comparison of the test results and "true" disease status, identification of this "true" disease status becomes an important part of the evaluations. This so-called gold standard usually refers to a definitive diagnosis attained by biopsy, surgery, long-term follow-up or another acknowledged standard (7, 11). Many studies on pulp vitality (sensitivity) testing have dealt with the precision of the test (12–14). However, the extent to which a test correctly classifies conditions, the accuracy, has been incompletely studied.

Studies aiming to evaluate the accuracy of pulp vitality test methods have been performed by Hyman & Cohen (7), Fuss et al. (8) and Peters et al. (9). Hyman & Cohen (7) used data from five previously published studies in which endodontically tested teeth were examined histologically. Although valuable information was obtained on the importance of evaluating the accuracy of vitality testing agents, these studies were not designed for such an evaluation. Thus, the description of the test procedures and of the criteria used for determining the gold standard was unspecific or lacking, which might be detrimental to the results. Fuss et al. (8) studied the sensitivity and the specificity and Peters et al. (9) only the sensitivity. However, they made no evaluation of the predictive values.

The present study was designed to study the accuracy of three commonly used vitality test agents by calculating their sensitivity, specificity and predictive values. The gold standard chosen for three-quarters of the tested teeth was based on direct inspection of the pulp tissue after opening the pulp chamber. The pulp was considered vital when bleeding pulp tissue was present in the pulp chamber, and it was considered necrotic if the pulp chamber contained decomposed, non-bleeding tissue. In some of the teeth with necrotic tissue in the pulp chamber, vital tissue was observed more apically in the root canal system; thus, the condition was partial necrosis. Since the treatment is the same for teeth with partially necrotic pulp and teeth with necrotic pulp, the conditions were combined into one group.

We considered it important that three-quarters of the tested teeth in the present study had diseased pulps (vital and necrotic). The reason for suspecting pulp disease before the tests were performed was either deep carious lesions or symptoms from the tooth. By using pulp-diseased teeth in the evaluation of the pulp testing agents, we considered the conditions to resemble the clinical situation, where pulp vitality testing is a necessary diagnostic tool. A quarter of the tested teeth were intact with no periapical pathology. The tested individuals were all young students and we assumed their teeth had vital pulps.

In the evaluation of the predictive values of the different vitality test agents, it is important to consider the prevalence of the disease that the test is supposed to disclose since the predictive values change with the prevalence of the disease (6). The predictive values found in our study were based on a disease prevalence of 39%. The study by Hyman & Cohen (7), which also reports on predictive values, uses a disease prevalence of 18% for the calculations. Thus, the predictive values cannot be directly compared.

In the evaluation of the cold test, the negative predictive value (NPV) we obtained was 0.90. If we recalculate our values using the same disease prevalence

as Hyman & Cohen (7), our NPV would be 0.96 (for the formula, see Hyman & Cohen [7]). Both these values are similar to the NPVs (0.94 and 0.91) calculated by Hyman & Cohen (7). Thus, the results from both these studies indicated a probability of at least 90% that a sensitive reaction from a tooth tested with the cold test represents a vital pulp.

The positive predictive value (PPV) we obtained for the cold test was 0.89. If we calculate with a disease prevalence of 18%, we have a PPV of 0.72. Thus, in our experiment the PPV was considerably higher than the PPVs reported by Hyman & Cohen (7) (0.47 and 0.33), even when using their disease prevalence. Thus, we found a relatively high probability that teeth not reacting to cold would have a necrotic pulp compared to a less than fifty-fifty probability calculated by Hyman & Cohen (7). The explanation for the difference in PPVs of the cold test might be the relatively low number of teeth with extensive restorations and obliterated pulp chambers in our material. Testing vital teeth with extensive restorations and/or obliterated pulp chambers might render more false positive (false disease) reactions. The low specificity (0.81 and 0.70) reported by Hyman & Cohen (7) compared to the specificity we found (0.93) supports this assumption.

For the electrical test, the NPV we obtained was 0.84 while the NPVs calculated by Hyman & Cohen (7) were 0.94, 0.96 and 0.91. If we use the same disease prevalence as Hyman & Cohen (7), our NPV would be very similar (0.94). Thus, both in our experiment and in the study by Hyman & Cohen (7), it was probable that a sensitive reaction to electrical pulp testing represented a vital pulp.

Conclusions

The results from this study indicated that the probability that a non-sensitive reaction represented a necrotic pulp was 89% with the cold test, 48% with the heat test and 88% with the electrical test. The results

indicated that the probability that a sensitive reaction represented a vital pulp was 90% with the cold test, 83% with the heat test and 84% with the electrical test.

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