

On cantilever loading of vital and non-vital teeth

An experimental clinical study

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Three healthy subjects with neighboring or contralateral vital and root-filled teeth requiring crown therapy were selected as test persons. All teeth had optimal alveolar bone support. The root-filled teeth were furnished with individual cast posts and cores, and veneer crowns were made on both the vital and non-vital teeth. Buccal extension bars were then soldered to the occlusal surfaces of these crowns, and weights were applied in different positions along the bars until the test persons experienced pain. The experiments were repeated under local anesthesia. The results showed that non-vital teeth had mean pain threshold levels that, on cantilever loading, were more than twice as high as those of their neighboring or contralateral vital teeth. The positions of the centers of rotational deformations of the loaded teeth, which were assumed to be mainly rotational, were calculated and found to be located inside the peripheries of the crowns for the vital teeth but extracoronally in markedly more peripheral positions for the non-vital teeth. □ *Biomedical engineering; dental prostheses design; endodontics; tooth movements*

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During mastication, teeth and periodontal membranes undergo deformation (1-5). In periodontal membranes, strain is monitored by mechanoreceptors that reflexly modulate muscular activity (6). No such mechanisms have yet been reported to be present in the teeth themselves. However, an autoradiographic study of dental pulpal tissue has shown structures resembling corpuscular receptors, which may be responsive to stimuli other than pain, such as touch and pressure (7).

A study of the pressoreceptive sensibility of human teeth has also suggested the existence of intradental pressoreceptors and shown that the thresholds for pressoreceptive sensibility are higher in pulpless teeth than in vital ones (8).

It has been shown in an epidemiologic study that root-filled teeth used as abutments for extensive bridgework have a higher tendency to mechanical failure than vital teeth (9). Similar observations have been reported in non-systematic evaluations of the outcome

of various types of restorative treatment (10).

It has also been shown that non-axial strain frequently appears distally in extensive fixed reconstructions such as cantilever bridges (20). The high failure rate of root-filled distal abutment teeth could be due to a) differences in the mechanical properties of vital and non-vital dentin, b) undermining or dimensional reduction of dentin during endodontic treatment or the incorporation of restorations in root-filled teeth, c) destruction of dentin by breakdown processes such as corrosion, or d) the absence, in non-vital dentin, of certain strain-monitoring properties in pulp or dentin.

Whereas the first three factors above have been studied (12-15), no completely satisfactory explanation has yet been given for the high frequency of fracture observed in root-filled abutment teeth.

The loading that teeth are subjected to in function would make it reasonable to assume that some kind of protective mechanism

mediated by mechanoreceptors may be present, not only in the tooth-supporting structures but also in the teeth themselves. Since a better understanding of the biomechanical principles governing abutment teeth in function is necessary to improve further oral restorative treatments, it was considered appropriate to investigate the reaction patterns to cantilever loading in vital and non-vital teeth.

Materials and methods

Three healthy dentate subjects were selected as test persons. Their informed consent and the approval of the local ethical committee were obtained. Clinical examination showed good oral health. No periodontal disease resulting in radiographically detectable reduction of alveolar bone level was found. Their intermaxillary relations were in neutral occlusion. The age, sex, and dental state of the subjects are shown in Table 1.

The test subjects had contralateral or neighboring vital and non-vital teeth requiring crown therapy. The non-vital teeth were treated endodontically with standardized clinical procedures (16). The canals were filled with guttapercha-chloropercha, after which posts and cores were cast and fitted. The vital teeth were prepared for veneer crowns (17). Radiographs of the selected teeth are shown in Fig. 1.

Veneer crowns were cast in Type III dental gold alloy (Sjöding-C gold, J. Sjöding AB, Solna, Sweden). Horizontal buccal extension bars, measuring $50 \times 4 \times 3$ mm, were

cast in the same alloy and marked at 1-mm intervals along their upper surfaces before being soldered to the occlusal surfaces of the crowns (Fig. 2). These crowns were tried in place, adjusted as necessary, and luted in place with temporary cement (Nobotec, Astra, Södertälje).

The clinical experiments were conducted in two parts. In the first part, 1-N weights were applied from various positions along the bars, using loops made from 200 mm of 0.3-mm stainless steel wire (SIS 2330, Sandvik 12 R10, Sandviken, Sweden), until pain or a pain-like sensation was elicited (18, 19). The weights were applied in random positions along the bars at distances from the occlusal centers of the veneer crowns as shown in Table 2. All the selected teeth were tested in random order with relaxation periods of 5 to 7 min between each individual loading experiment.

In the second part the test teeth were anesthetized. Up to 3×1.8 ml of lidocaine (Xylocaine®), 20 mg/ml, with epinephrine (Adrenalin®), 12.5 µg/ml (Astra), was injected in the buccal and palatal regions of the test teeth. Anesthesia was considered to be effective when neither the tested vital teeth nor the neighboring mesial and distal teeth of the test teeth responded to electrostimulation from a pulp tester (Type 2001, Analytic Technology, Redmond, Wash., USA). Immediately after this verification of anesthesia, the described loading experiments were repeated.

Studies on some possible errors in the method

The physical properties and dimensions of

Table 1. Age, sex, and dental state of test subjects and teeth selected for biomechanical studies

Test subject	Age, years	Sex	Dental state	Experimental teeth
1	47	Male	<u>18,17,16,15,14,13,12,11,21,22,23,24,25,26,27</u> 48,47,46,45,44,43,42,41,31,32,33,34,35,36,37,38	14/24*
2	70	Male	<u>complete denture</u> 44,43,42,33,34,37	34*/44
3	40	Female	<u>17,16,15,14,13,12,11,21,22,23,24,25,26,27</u> 47,46,45,44,43,42,41,31,32,33,34,35,36	45/44*

* Non-vital experimental tooth.

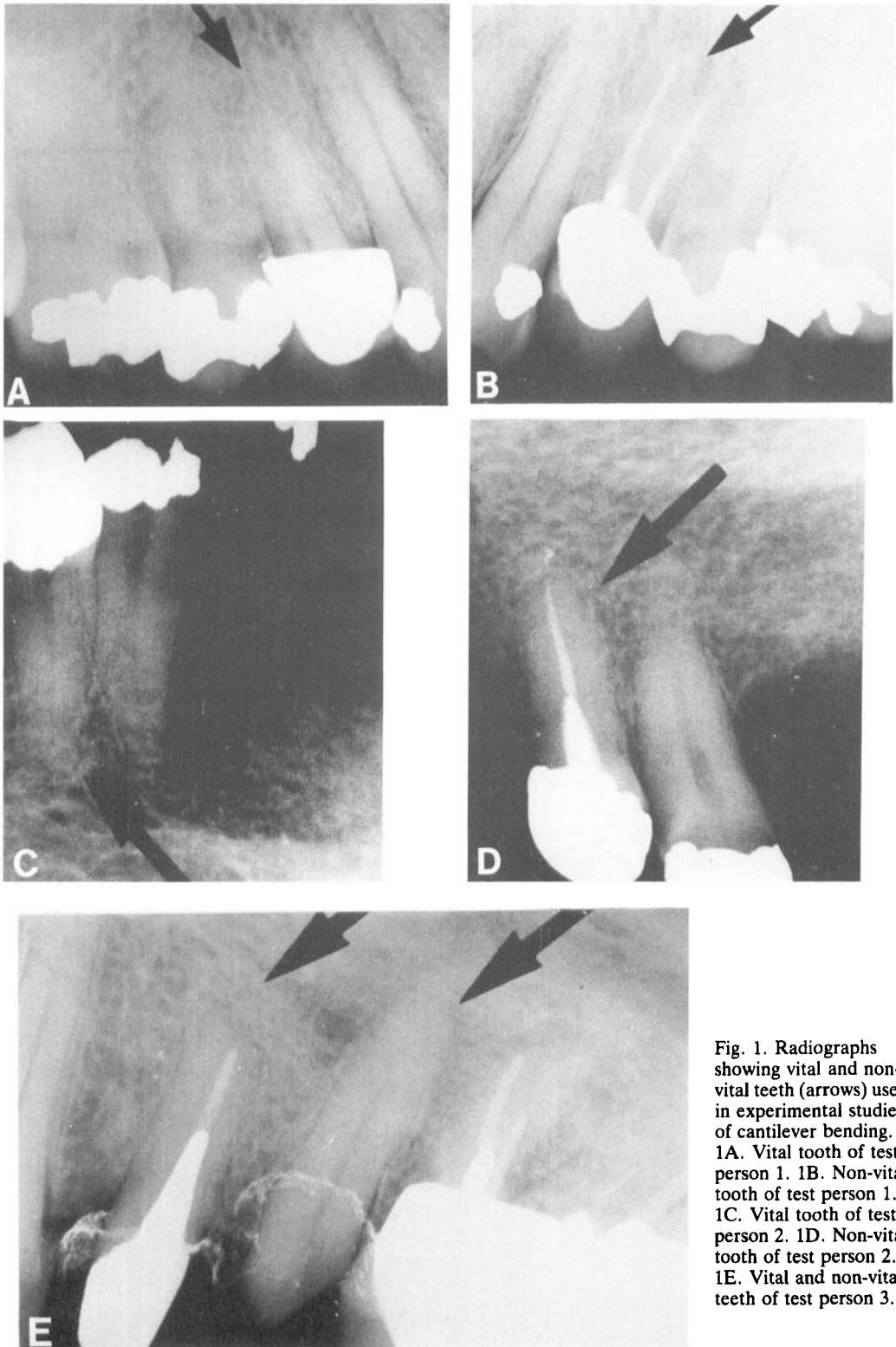


Fig. 1. Radiographs showing vital and non-vital teeth (arrows) used in experimental studies of cantilever bending. 1A. Vital tooth of test person 1. 1B. Non-vital tooth of test person 1. 1C. Vital tooth of test person 2. 1D. Non-vital tooth of test person 2. 1E. Vital and non-vital teeth of test person 3.

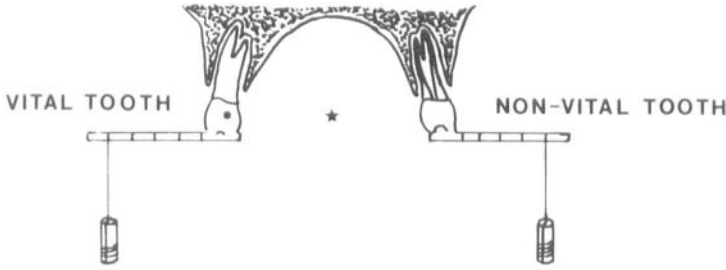


Fig. 2. Schematic experimental design of studies of in vivo cantilever loading of vital and non-vital teeth. Pain loading levels were determined by random load application at defined positions along horizontal buccal extension bars on

veneer crowns, temporarily cemented to the tested vital and non-vital teeth. The center of rotation (hypomoklion) is marked for vital tooth (●) and for non-vital tooth (★).

the material from which the veneer crowns and buccal extension bars were made suggested that, in the relationship to the test teeth being used, it was unlikely that major deformations in either component occurred under the loadings applied. To test this hypothesis, two rosette strain gauges were placed on the buccal surfaces next to the points of insertion of the bars on the crowns of one of the test subjects (no. 1). The laboratory and clinical procedures described by Glantz et al. (11, 20) were used to monitor any deformation that might have occurred.

During loading experiments in this subject no deformations were recorded by any of the gauges or gauge components, which were calibrated to a precision of 23.8, 24.1, 15.6, 15.2, 14.4, and 14.9 true $\mu\epsilon$, respectively. It was therefore concluded that, under the experimental conditions in this study, no appreciable deformation occurred either in the cemented crowns or in their extension bars.

Results

The cantilever loading pain levels for the

Table 2. Loading positions in cantilever experiments: distance (in mm) from the occlusal center of veneer crowns

Test person	Position				
	I	II	III	IV	V
1	8	14/16*	23	32	41
2 and 3	9	17	25	35	44

* 14 for the non-vital tooth; 16 for the vital tooth.

various loading positions in the initial experiment are shown in Table 3. These results clearly show marked differences between vital and non-vital teeth. Table 3 also gives the calculated direct ratios between the cantilever loading pain capacities of the non-vital and vital teeth. It shows that non-vital teeth withstood markedly higher cantilever loading levels before pain was elicited than did the contralateral or neighboring vital teeth.

Assuming mainly rotational deformation and approximately linear stress/strain relationships during the cantilever loading experiments, a constant relationship (c in Equation 1) was believed to be present between the rotational centers (hypomoklion) at the occlusal plane of the buccal extension bars (x), the distance from the occlusal center of the crown to the loading position (a), and the critical pain/discomfort-producing load (y):

$$(a + x)y = c \tag{1}$$

By the method of least square the values of x and c were determined from Equation 2 (n = number of measurements per test subject):

$$f(x, c) = \sum_{i=1}^n [(a_i + x)y_i - c]^2 \tag{2}$$

The thus calculated positions of these centers of rotation are shown in Table 4, in which a positive value denotes a position/projection that is lingual to the occlusal center of the tested tooth and a negative value denotes a lateral position/projection.

As can be seen in Table 4, calculated cen-

Table 3. Pain loading levels (N) at different points of loading (I, II, III, IV, and V) along horizontal bars soldered to the occlusal surfaces of veneer crowns on non-vital (*) and vital teeth and ratios between these levels

Loading point	Pain loading levels for test subject 1			Pain loading levels for test subject 2			Pain loading levels for test subject 3		
	Tooth 24*	Tooth 14	Ratios	Tooth 34*	Tooth 44	Ratios	Tooth 44*	Tooth 45	Ratios
I	22.6	24.5	0.92	33.4	12.8	2.61	43.2	23.5	1.84
II	20.6	19.6	1.05	22.6	8.8	2.57	21.6	10.8	2.00
III	17.7	8.8	2.01	17.7	6.7	2.64	17.7	8.8	2.01
IV	14.7	6.7	2.19	14.7	4.9	3.00	14.7	6.6	2.23
V	8.9	4.9	1.82	10.8	3.9	2.77	12.8	4.9	2.61
Total mean			1.60			2.72			2.14

ters of rotation were located in markedly more lingual directions for root-filled teeth during the experiments without anesthesia.

Test person 1 was provided with maxillary experimental appliances during cantilever loading under anesthesia. The crowns on both vital and non-vital teeth became loose under similar loads. The levels at which retention was lost were approximately 50% higher than those given in Table 3 for the non-vital tooth.

Different biomechanical situations with higher risks of tooth fracture were believed to be present in test subjects 2 and 3. Therefore, in these experiments the cantilever loadings were terminated when the original pain threshold levels for the non-vital teeth were exceeded by about 25%, even if no discomfort reaction had appeared.

Despite this precaution, an accidental coronal dentin fracture and loss of retention of the cemented post appeared at the 25-mm loading position in the experiment under local anesthesia with the non-vital tooth in test person 3. The fracture extended from

the top of the central part of the remaining coronal dentin and proceeded at an approximate angle of 30°–45° to the long axis of the tooth and ended just above the level of the buccal alveolar bone margin.

The results of the cantilever loading experiments on anesthetized teeth may be summarized as having shown that, for every loading position, the final loading level for the anesthetized teeth exceeded that of the non-anesthetized non-vital teeth by 3–10 N. Furthermore, during the experiments under local anesthesia, no differences in reaction levels were observed between vital and non-vital teeth. Consequently, under local anesthesia no differences were found between the positions of the rotational centers of the extension bars in the vital and non-vital teeth.

Discussion

For mainly psychological and social reasons

Table 4. Calculated positions (mm) of the centers of rotation (hypomoklion) of vital and non-vital (*) experimental teeth. Positive values denote a position of hypomoklion lingual to the occlusal center of the tested tooth, and negative values denote a position buccal to this point. *n* = 10

	Test person 1		Test person 2		Test person 3	
	Tooth 14	Tooth 24*	Tooth 44	Tooth 34*	Tooth 45	Tooth 44*
Hypomoklion	-2.0	13.2	6.6	9.0	0.6	4.5

many members of contemporary Western society have adopted an increasingly negative attitude to wearing removable prosthetic appliances. Consequently, restorative treatments are used frequently to save even severely damaged non-vital teeth. Such root-filled teeth are often used as critically positioned abutments for various types of fixed prosthetic appliances. During function many of these appliances are exposed to cantilever loading or to other types of non-symmetric loading (20).

As mentioned previously, when used as abutments in extensive prosthetic reconstructions, root-filled teeth show mechanical failures more frequently than do vital teeth (9). Since one possible reason for such failures can be the presence of different biomechanical reaction mechanisms or reaction patterns in vital and non-vital teeth, it was considered to be of interest to study the clinical cantilever loading of vital and non-vital teeth.

The experiments were performed with buccal extension bars on veneer crowns, and loads were applied at predetermined positions until pain or pain-like reactions were noticed by the test person. Because these mechanically simple experiments were separated by long relaxation periods, it was considered unlikely that major systematic errors due to adaptation were present. Thus, paired comparisons were made between the recordings for the individual loading levels.

When these recordings were compared, it was originally assumed that elastic deformation predominated in the teeth and their supporting structures. The occurrence of an accidental fracture in a non-vital tooth during one of the experiments under local anesthesia did show, however, that plastic deformation was also present.

Originally, it was planned to perform the experiments described on 10 pairs of vital/non-vital teeth, but because of the accidental fracture described the experiment was terminated for ethical reasons.

In spite of the limited number of teeth tested, the results given in Tables 3 and 4 clearly warrant the conclusion that on cantilever loading there is a definite difference in the biomechanical reactions between vital

and non-vital teeth, with the higher tolerated loading levels being in non-vital teeth. Even if this difference could be due partly to systematic differences between the dentinal dimensions of these teeth, the periodontal conditions and the cervical extensions of the veneer crowns were such that a true difference in biomechanical function must be present. Furthermore, since anesthetization brought vital and non-vital teeth to the same increased level of tolerated loading, the conclusions were drawn that: 1) some kind of mechanoreceptor function is probably present in vital teeth, and 2) for teeth with optimal alveolar bone support this mechanoreceptor function is efficient at lower degrees of bending than those at which the mechanoreceptors of the periodontium of non-vital teeth are brought into action.

In this context it must be noted that when the alveolar bone support is markedly reduced, high initial strain levels in the periodontal membranes can probably be reached. In such cases, periodontal mechanoreceptor function may be engaged at lower levels of cantilever loading than those engaging the mechanoreceptor function of vital tooth structures.

The exact nature of the observed mechanoreceptor function of vital teeth cannot be elucidated from the results of this study. However, it is pertinent to associate it with the known hydrodynamic functions of dentin (21). If a mechanoreceptor function is generated through the fluid phase of vital dentin, the high recorded reactions for bending of teeth can be explained as being caused by the common differences in elasticity between the solid and liquid components of the tooth. Such a mechanism would further explain why no reactions have been found in axial loadings of teeth.

The observed shifts of the rotation centers (hypomoklion) are dramatic between vital and non-vital teeth. Therefore, the possibility cannot be excluded that mechanoreceptor function in the periodontal membrane is to some extent dependent on the vitality of teeth. This possibility will be further studied in future experiments.

Since there is no reason to assume that loading of a tooth in a mesiodistal direction

is fundamentally different from that buccolingually, the observed differences have clear relevance in restorative dentistry. When the remaining distal teeth are root-filled, prosthetic appliances with inherently high tendencies to generate functional bending should be avoided. Such appliances include fixed bridges with multiple cantilever pontics (20) and perhaps also free end-saddle removable partial dentures retained through precision attachments.

The exact failure mechanisms in root-filled teeth cannot be determined from the result of this study. However, it was observed that plastic deformation can occur near the pain threshold levels of non-vital teeth under load. Moreover, a time dependence for abutment tooth fractures has been found in an epidemiological study of restorative treatments with extensive fixed appliances (9). It is, therefore, reasonable to assume that fatigue is a significant factor.

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