Effects of bonded composites *vs.* amalgam on resistance to cuspal deflection for endodontically-treated premolar teeth

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ABSTRACT: ***Purpose:*** To determine, by means of a non-destructive experimental procedure, the extent to which tooth cusps are weakened by endodontic procedures and the effectiveness of adhesive bonding restoration in reducing cuspal deflection as a function of different restorative procedures. ***Methods:*** A mechanically controlled loading device induced cuspal deflection by axial force (range 98-294 N) on an occlusal surface while LTS laser twin sensors registered the amount of deflection. Cusp deflection values, in microns, were recorded for each tooth. Thirty sound maxillary premolars teeth were sequentially evaluated in the following conditions: A) intact tooth; B) completion of endodontic and restorative procedures. Teeth were randomly divided into five groups and restored respectively with: A) amalgam (Dispersalloy); B) Spectrum TPH; C) Surefil; D) Esthet-X; E) Esthet-X + Dyract Flow. ***Results:*** The average loading force needed to induce 1 µm cusp deflection was evaluated, for all groups, in intact teeth (range 49.52-58.76 N/µm) and in restored teeth (range 8.56 – 47.05 N/µm). Statistical analysis (ANOVA for repeated measures) has been performed. Mean structural recovery values after restorative treatment were 17% with amalgam, 60% with Spectrum TPH, 59% with SureFil, 54% with Esthet-X, and 99% with Esthet-X/Dyract. (*Am J Dent* 2004;17;295-300).

CLINICAL SIGNIFICANCE: Bonded composite restorations are effective in reducing cuspal deflection after treatment and in recovering tooth stiffness in endodontically treated premolars.

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Introduction

Posterior teeth tend to deflect cusps under occlusal load due to their structural design. Marginal ridges and occlusal enamel stabilize lingual and buccal cusps. Architectural anatomy, chemical and mechanical properties of these dental elements undergo irreversible changes after endodontic treatment,[1,2] determining a reduction in the enamel and dentin breaking strength.[3,4] *In vivo*[5,6] and *in vitro*[7,8] studies have proven how endodontic treatment and dentin dehydration made teeth more brittle,[9] increased cuspal height, thinned cavity walls, allowed loss of connecting structures between cusps due to carious pathoses (pulp chamber roof and marginal ridges) and increased the tendency of fractures.[10]

The most frequently employed method to evaluate tooth resistance, which is weakened by cavity preparation or restoration, is to apply static load until tooth breakdown.[11,12] The results of this type of experiment are influenced by the size and morphology of tested teeth, which can vary greatly. Furthermore, it is very unlikely that limit values of load breakage due to compression can be reached within the oral cavity; forces during chewing have been reported between 13 and 18 N[13] up to a maximum of 147-261 N.[14,15] The fracture mechanism of a tooth seems mostly due to a fatigue phenomenon.

On the contrary, the original non-destructive method employed in this study adopts a load range that is similar or just higher than the physiological one for the type of tooth examined. The load values we have used during this trial reach 294 N, slightly beyond the above mentioned physiological load range within the oral cavity. Furthermore, the variability from tooth to tooth is eliminated, cuspal deflection being tested in condition of integrity and following endodontic treatment/ coronal restoration in the same tooth sample.[16,20]

This study evaluated tooth cuspal deflection[16,17] to determine to the extent tooth cusps are weakened by endodontic and restorative procedures and the effectiveness of adhesive bonding agents and materials in reducing cuspal deflection and in recovering tooth stiffness for each type of restorative procedure.[21,22]

Materials and Methods

Twenty-five non-carious human maxillary premolars were selected. All of the teeth came from patients ranging from 15 to 29 years old and had been freshly extracted for orthodontic reasons. Each tooth was carefully examined visually, radiographically and by means of transillumination, in order to discard the ones with structural defects (cracks on the enamel surface).

Teeth were stored in standard (0.9% NaCl) physiological solution at 20°C during trials. During preparation and testing procedures, care was taken to prevent dehydration.

Each tooth was included in cylindric autopolymerizing polymethyl methacrylate (PMM) resin blocks (18 mm in diameter), maintaining the direction of the main vertical axis. Root surfaces were exposed for 2 mm below the cemento-enamel junction, so as to simulate the alveolar bone support in healthy teeth. In order to avoid the sinking of the tooth into the resin surface once the load was applied, the lower surface of the resin covering was scraped off by means of a Strüers machine (LS2-Remet[a]) up to the apex of the tooth (generating samples with different heights) permitting the direct contact of the root with the plane of the loading device.

A small even vertical surface (about 1 mm in diameter) was also created on the buccal and palatal side of teeth by means of abrasive disks (Sof-lex[b]) for two reasons. First of all this created a landmark that helped position the device to test each sample at the same height throughout the whole trial.

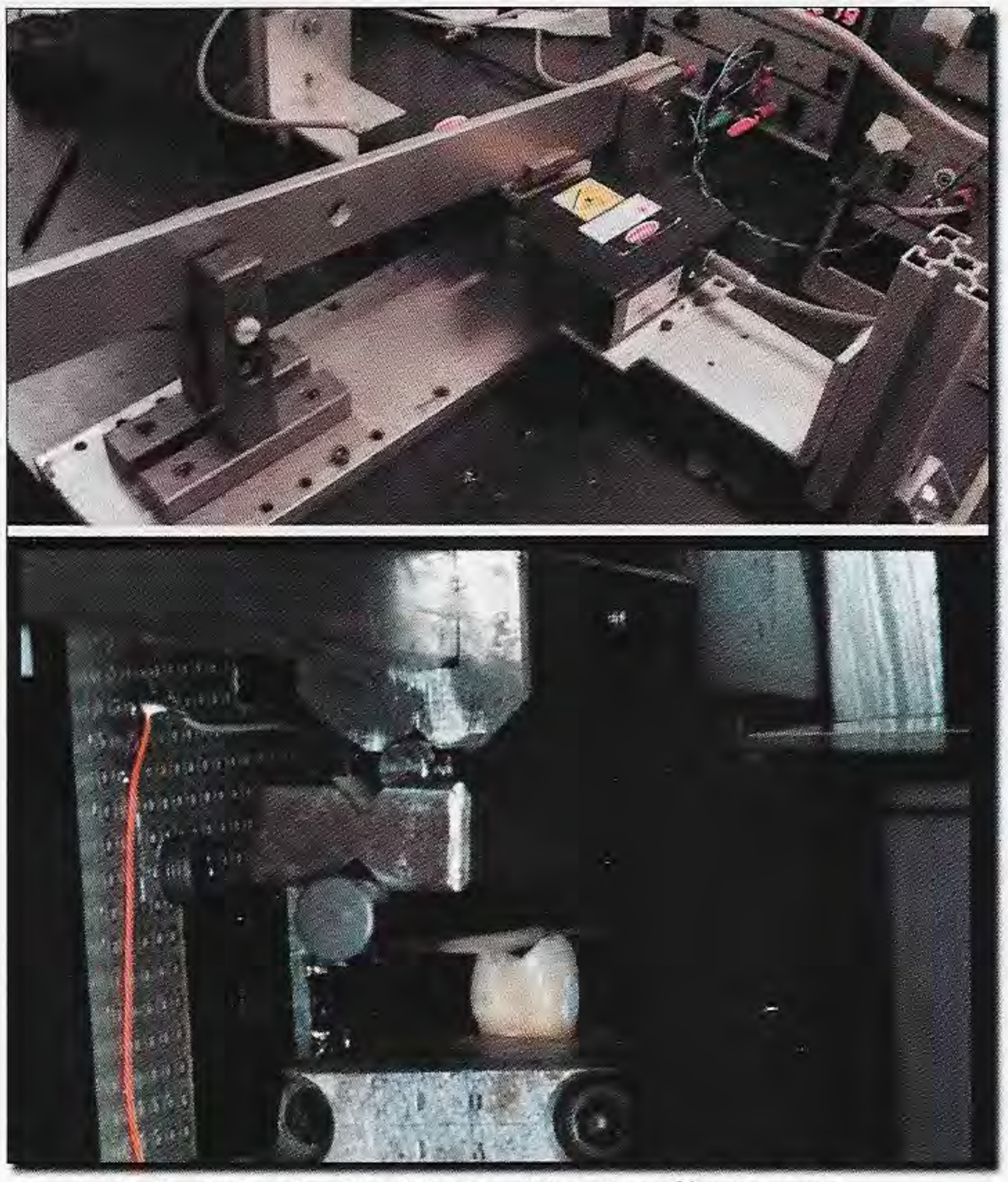


Fig. 1. Mechanical occlusal load device with system of laser sensors.

Furthermore, a possible vertical micro-movement of the tooth due to axial load could have produced unreliable data because of the convex shape of tooth surfaces (*i.e.,* teeth show a progressive and continuous change in the horizontal diameter, from the cemento-enamel junction to cusp tips); on the contrary, these small flattened surfaces allowed the laser beam to detect more accurately the cuspal displacement, without being misled by the tooth anatomy.

After centering the samples in the desired position, they were placed in a special device to immobilize them. This custom-made device is tightened by means of two external screws. The different height of the samples (due to the different root length) was compensated by means of metal cylindrical spacers (thickness = 1 mm) placed underneath, to raise them to the appropriate level.

The loading device is essentially made up of a lever arm with the fulcrum at one end, the sample placed at 10 cm from the fulcrum, and at the other end (50 cm from the fulcrum) a part specially prepared to hold the load. Load was applied by adding several 1 kg metal discs at the end of the lever arm; thus the actual force on the sample (that could be reproduced throughout the trial) was 0-98-147-196-245-294 N. Between the lever arm and the sample, a 6.3 mm in diameter steel cylinder was used; a tailor-made joint connected it to the loading device and positioned in a natural way in relation to the occlusal plane, in order to provide the tooth with a direct load, balanced between the cusps and along its major axis only. Thus a small contact area between the cuspal side and the load cylinder was created, comparable to a point that, being in the higher halves of internal cuspal sides, did not interfere with endodontic cavities and restorative procedures.

Cusp movement, induced by the force generated by the

Fig. 2 **A.** Standard size mesio-occlusal-distal (MOD) cavity. **B.** Samples after endodontic and different restorative procedures.

Table 1. Material and adhesive systems employed in coronal restoration.

	Restorative materials	*Adhesive system*
Group A	Dispersalloy	None
Group B	Spectrum TPH	Prime & Bond NT + H_3PO_4 36%
Group C	SureFil	Prime & Bond NT + H_3PO_4 36%
Group D	Esthet-X	Prime & Bond NT + H_3PO_4 36%
Group E	Esthet-X + Dyract Flow	Prime & Bond NT + H_3PO_4 36%

above mentioned equipment, was measured by means of a sophisticated laser sensor system: Laser Twin Sensor (LMI-Sensor-95©). Two separate measuring stations, made up of laser sensors recording cuspal movements of the tooth and of a micrometric slide used to take the sensors to a distance of 15 mm (ideal reading distance) from the dental surface, were employed (Fig. 1a,b). The light source of the measuring system was directed onto the vertical area of the tooth surface, treated beforehand with a thin coat of opaque varnish. This coating was meant to avoid an instrument reading error, due to the fact that laser beams can penetrate the opalescent enamel.

The measurement detected by the device at zero load, with no load on the tooth (*i.e.* with the lever arm raised) was chosen as starting measure with a value of cuspal displacement equal to zero. Then axial forces (98-147-196-245-294 Newtons) were applied onto the occlusal surface of each tooth and the cuspal deflection value was measured (tolerance ± 1 µm) for each load increase. Since load was applied on both cusps simultaneously, the results were calculated by the sum of the deflection of each cusp, ignoring the concept of "cuspal independence" reported by Sakaguchi *et al.*[23] Deflection values were taken after about

Table 2. Cuspal deflection (μm; mean ± s.d.) in all groups related to the loading force (N).

	Mean cuspal deflection (μm)									
	Group A		Group B		Group C		Group D		Group E	
Load (N)	Intact mean ± s.d.	Restored mean ± s.d.	Intact mean ± s.d.	Restored mean ± s.d.	Intact mean ± s.d.	Restored mean ± s.d.	Intact mean ± s.d.	Restored mean ± s.d.	Intact mean ± s.d.	Restored mean ± s.d.
	0	0	0	0	0	0	0	0	0	0
98	1.72 ± 1.5	11.32 ± 1.4	2.96 ± 1.8	3.56 ± 1.6	2.1 ± 2.5	3.4 ± 1.9	3.18 ± 2.2	4.42 ± 1.4	3.6 ± 1.8	4.2 ± 3.5
147	2.76 ± 2.3	16.12 ± 2.1	3.84 ± 2.1	5.08 ± 1.9	3.6 ± 2.6	5.4 ± 1.8	3.88 ± 2.6	6.24 ± 2.1	5.32 ± 3.2	6.34 ± 3.5
196	3.8 ± 2.7	21.04 ± 3.1	5.08 ± 2.7	6.88 ± 2.8	4.12 ± 2.8	6.04 ± 2.1	5.10 ± 2.8	8.74 ± 3.1	7.44 ± 4.5	8.54 ± 2.7
245	4.76 ± 3.1	27.56 ± 3.5	5.8 ± 3.4	8.2 ± 3.7	4.8 ± 3.8	6.51 ± 2.5	6.20 ± 2.7	11.00 ± 3.5	9.18 ± 4.3	10.64 ± 3.1
294	5.84 ± 3.8	35.12 ± 3.9	6.92 ± 4.1	10.76 ± 4.4	5.6 ± 3.8	8.23 ± 2.6	8.02 ± 3.1	13.04 ± 3.9	11.26 ± 4.6	11.88 ± 2.6

10 seconds after load was applied, to allow deformation to settle. Cuspal deflection going back to zero load values at the end of each load cycle was checked, which was necessary to avoid permanent deformity of dental structure.

Samples were first evaluated in conditions of integrity and then after endodontic and restorative therapy. Endodontic access cavities were performed with standard contour shapes (*i.e.* oval for upper premolars). The endodontic cavity does not extend beyond the two landmarks that had been stated (*i.e.* the contact spots with the load cylinder) and at the same time it was made large enough to guarantee the preparation of root canals without any coronal interference. Since the radicular apex had been removed during sample preparation, it was impossible to treat the apical third of the root canals properly. Thus shaping of the apical third was ended up with a file that was just larger than the first one used in the canal. The shaping of the middle and coronal third was finished off with NiTi endodontic instruments 25/.04 (Profile[d]). The root canal system was then filled with laterally condensed cold gutta-percha technique and Pulp Canal Sealer.[e]

After endodontic procedures, standard-sized mesio-occlusal-distal (MOD) cavities were prepared on each tooth. The width of the isthmus of the occlusal preparation was equal to one third of the intercuspidal distance; the bucco-lingual width of each proximal box equal to one third of the tooth width. The height of the box was made so that the cervical edge of the preparation was 1 mm above the amelo-cement junction. The internal edges of the box were then rounded and no sort of bevel was made on the outer edges of the preparation (Fig. 2 a,b).

The 25 available premolars were randomly split into five experimental groups of five teeth each. Each group had a different material and adhesive system in coronal restorations (Table 1), placed in the MOD cavity. All of the restorations were performed not interfering with the contact points with the loading device that had been marked, which, as mentioned above, lay on the upper halves of the internal cusp surfaces.

A custom matrix band was placed in Group A teeth, and amalgam was condensed, carved, and polished after 18 hours. In Groups B (Spectrum TPH[f]), C (SureFil[f]), D (Esthet-X[f]) and E (Esthet-X + Dyract Flow[f]) H_3PO_4 36% was used as enamel-dentin etchant (total etch technique). Orthophosphoric acid was applied on cavity margins and then on dentin surfaces for a total time of 40 seconds. Then one-bottle Prime&Bond NT[f] adhesive was applied, following the manufacturer instructions: (1) a large amount of P&B NT must be applied by means of an applicator brush onto cavity surfaces, wetting them accurately; adhesive must be left on cavity surfaces for 20 seconds; (2) the excess of solvent must be removed with a light air whiff for no more than 5 seconds; surfaces must have a uniform shiny aspect; (3) adhesive must be light-cured 20 seconds. Teeth were then restored with micro-incremental oblique layers of material. Each layer of material, not thicker than 2 mm, was light-cured for 40 seconds with a Visilux[b] curing lamp with a steady energy output of about 500 mW/cm^2. Restorations were then finished with Sof-lex abrasive disks.

The coronal restoration in Group E, prepared with the same micro-incremental technique, includes a layer of about 1 mm of Dyract flow within the pulp chamber, preventing this material (which contains a lower filler fraction) from reaching the cervical edges of the preparation.

Samples were then tested again after 24-hour storage in physiological solution, so as to let the restorations complete their polymerization reactions and settle the stresses of the composite contraction.

Each of these teeth underwent the same cuspal deflection trial after the restoration under the same experimental conditions, thanks to this original procedure which avoids tooth damage or destruction; to eliminate the individual variations (size, intrinsic structure, morphology), that could not be controlled and that would have compromised the sensitivity of the experiment, each tooth was tested before and after its restoration, then compared to itself. The laser sensors detecting system allowed us to set a new starting point for our deflection measures; in this way we were able to ignore an eventual change of the bucco-lingual diameter of the tooth caused by material shrinkage.

Results for all experimental groups (intact, restored) were evaluated with ANOVA test for repeated measures. Differences at 5% level ($P < 0.05$) were considered statistically significant.

To analyze the effect of the combination of load and restorative procedures on cuspal deflection, deformation values were expressed as relative deformation (RD) and relative stiffness (RS), as published by Morin *et al*:[21]

$$RS = \frac{\text{(Maximum stress of the restored tooth/Maximum strain)}}{\text{(Maximum stress of the intact tooth/Maximum strain).}}$$

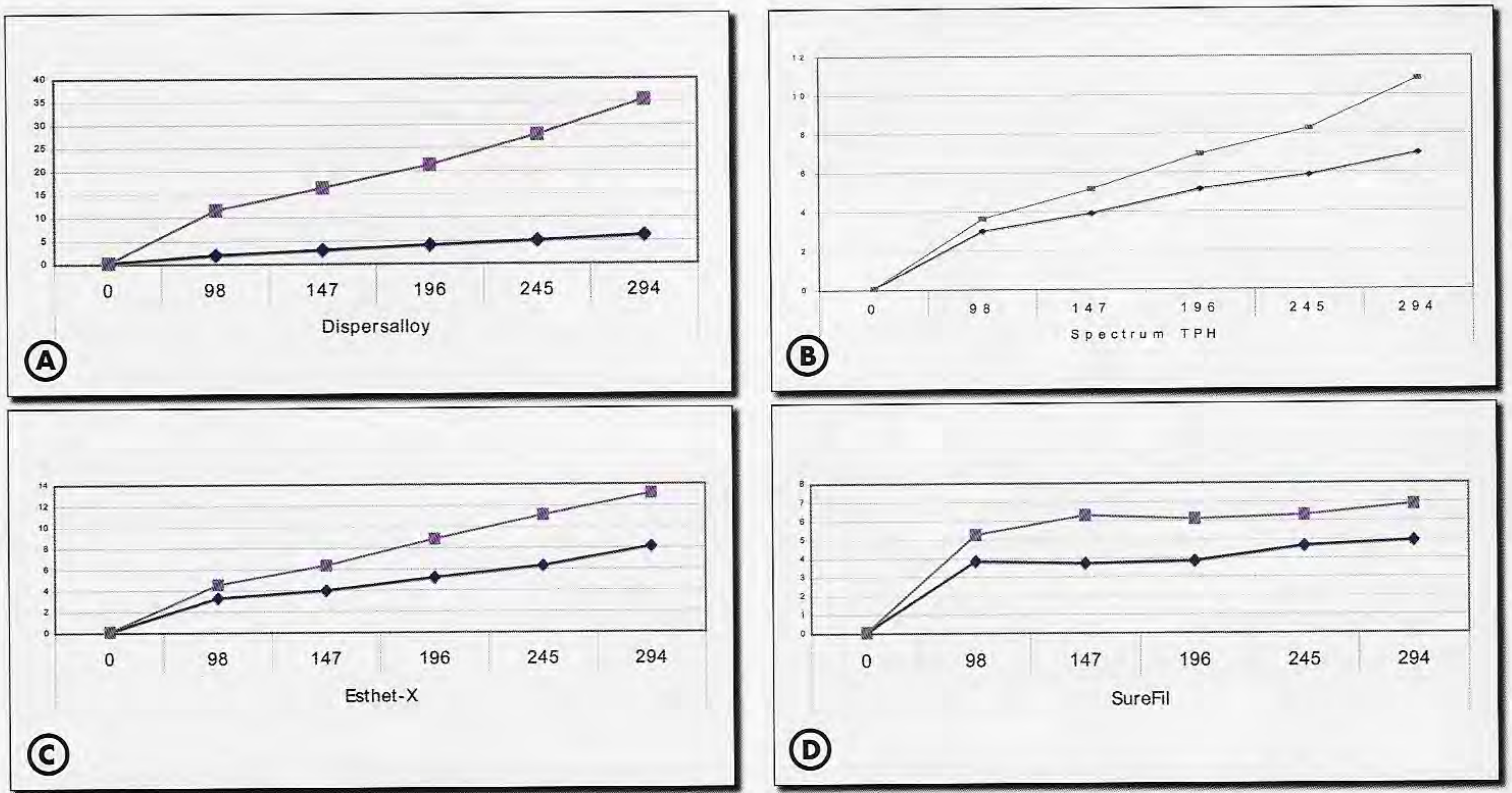
Since the maximum stress was equal to 294 N in both the tests on intact and restored teeth, RS can be calculated as:

$$RS = \frac{\text{(Maximum strain in the sound tooth)}}{\text{(Maximum strain in the restored tooth)}}$$

$$RD = 1/RS$$

However, the results we have obtained show a non-linear load-deflection curve. Therefore, instead of calculating the RS parameter only on the maximum value of the deflection, we found it more appropriate to extrapolate the average stiffness, meaning the average amount of occlusal load (N/μm) required to induce a 1 μm cuspal displacement. This parameter was calculated dividing each load increase by the increase in cuspal de-

American Journal of Dentistry, Vol. 17, No. 4, August, 2004



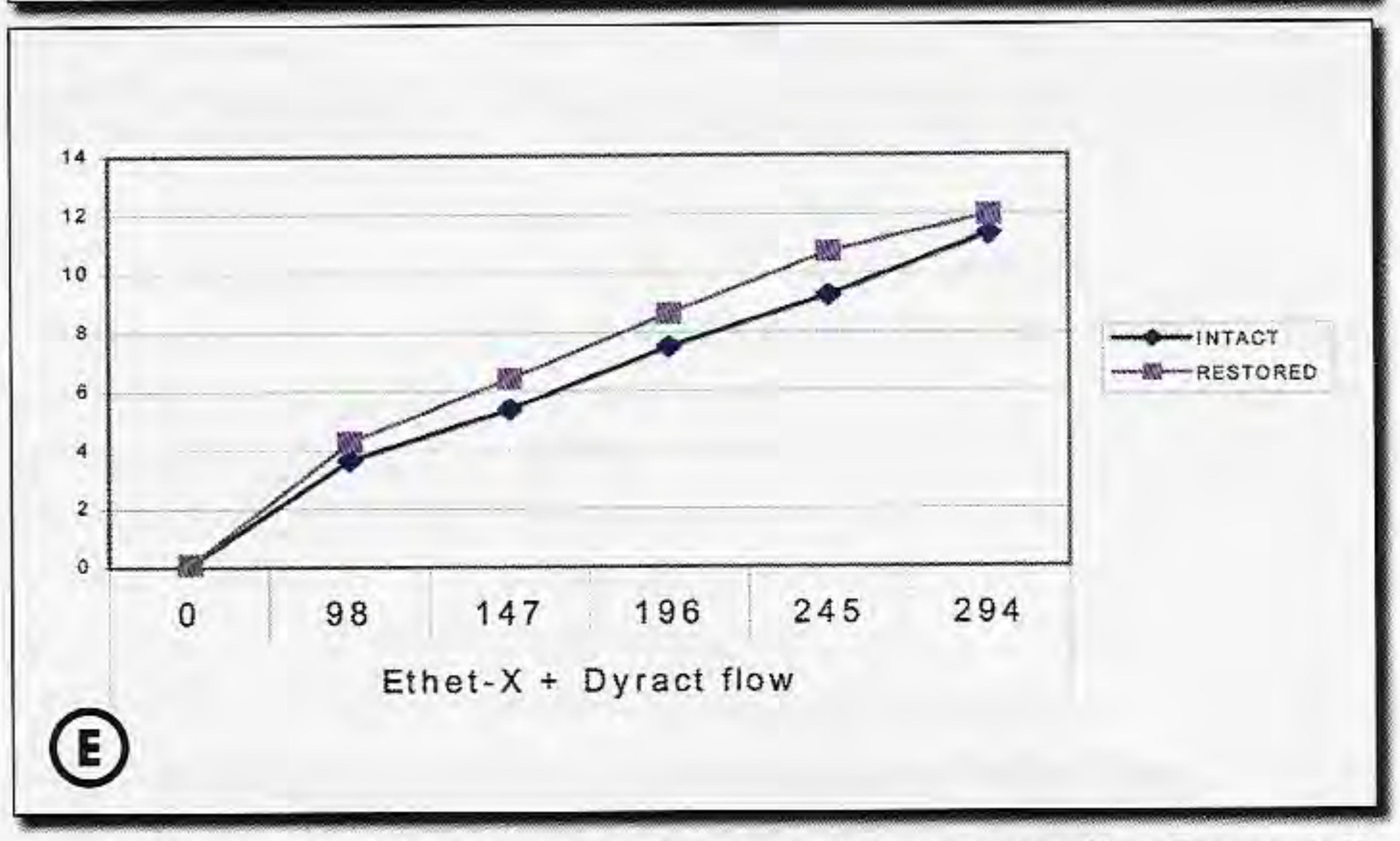


Fig. 3 **A-E.** Cuspal deflection (µm) of each tooth in corresponding Groups A-E related to the loading force (N).

flection recorded (using mean cuspal deflection values for each experimental group), then averaging the five values for each group obtained.

Structural recovery was calculated for each group, providing information about the behavior of the tested materials. The average stiffness of intact teeth was taken at baseline (stiffness of intact tooth = 100%) and then the average structural recovery was calculated, in percentage, as the resistance to deformation of restored teeth compared to analogous intact ones.

Results

The results were examined in terms of cuspal deflection, relative stiffness, average stiffness, and structural recovery.

Cuspal deflection - The mean cuspal deflection values for each group are reported in Table 2 and in Fig. 3a-e. Statistical analysis of the mean cuspal deflections obtained, by means of ANOVA test, showed how the groups of intact teeth should be considered as homogeneous: no significant differences showed up among these samples ($P > 0.15$). Conversely, there is a highly significant difference ($P < 0.0001$) in the cuspal deflection between intact and restored teeth in all experimental groups (Fig. 4).

Standard deviation values were quite high compared to the mean deflection values in relation to the individual and unique characteristics of each tooth sample. Each tooth actually reacted in a different manner to load, depending on its size, morphology and age, thus affecting its response to mechanical stress.

Relative stiffness and average stiffness - Values are shown in Fig. 5 and Table 3.

Structural recovery - The following Structural Recovery values were obtained:

Amalgam	17%
Spectrum TPH	60%
SureFil	59%
Esthet-X	54%
Esthet-X + Dyract flow	99%

Discussion

As mentioned in the Introduction, posterior teeth deflect under load as function of their structural design. Endodontic access cavities, and to a greater extent a MOD cavity, can increase this tendency to deflection under mechanical forces. Over time, repeated stresses can greatly reduce the resistance to fracture, causing the tooth to break even if the force was far below the loading force needed to break a healthy tooth. It is then imperative that the coronal restoration be able to restore to a certain level the original stiffness of the tooth, so as to decrease the mechanical fatigue of the residual cusps.

The results obtained showed, as expected, that endodontic treatment and MOD preparation weaken a tooth, lessening its resistance to cuspal deformation under load; coronal restorations contribute, in different ways depending on the material employed, to partially limit this. Both the stiffness calculation methods,[21] relative stiffness and the author's structural recovery (Table 3), show mostly similar values.

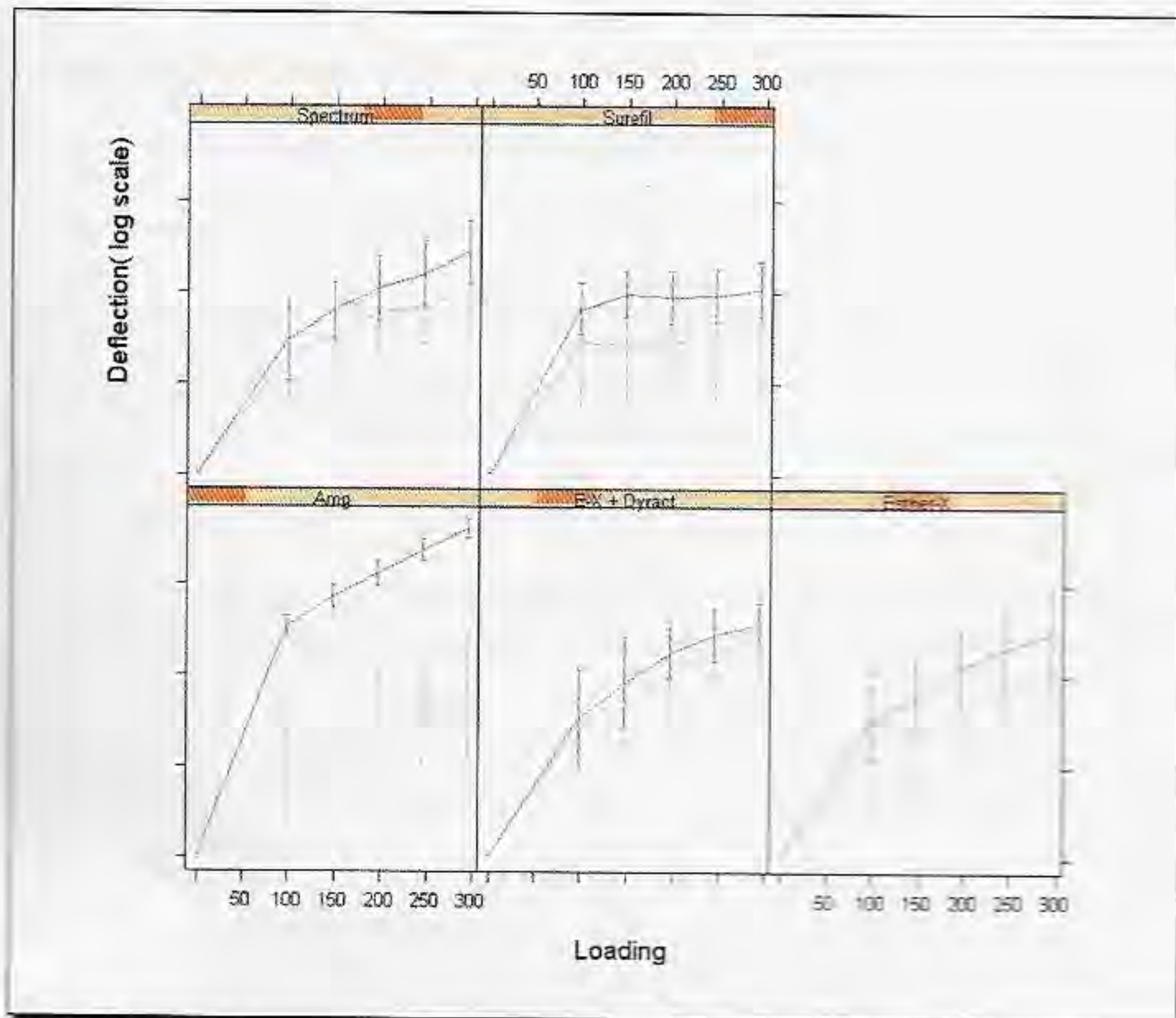


Fig. 4. ANOVA test for repeated measures.

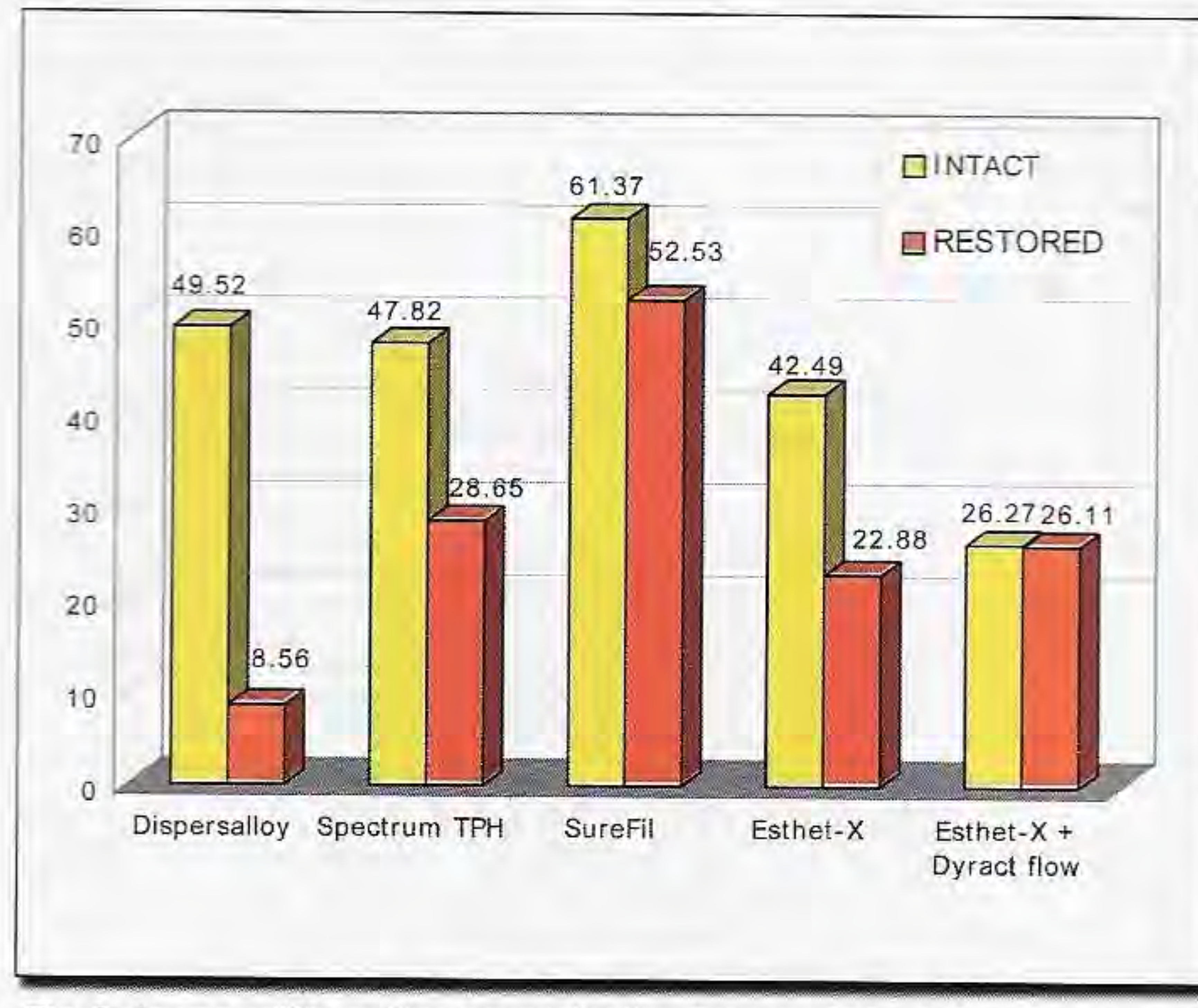


Fig. 5. Average stiffness (the average loading force needed to induce 1 µm cuspal deflection, expressed in N/µm.

The amalgam group showed a high increase in cuspal deflection values (more than 30 µm at 294 N of load) and consequently a substantial decrease in restored tooth stiffness compared to unaltered teeth.

In Groups B (Spectrum TPH), C (SureFil), D (Esthet-X), and E (Esthet-X/Dyract flow), restored teeth showed better structural recovery compared to intact ones. The adhesive bonding proved to be effective in restoring tooth biomechanical properties, by means of a partial stiffness recovery to axial loads.

The results obtained were slightly different from those found in similar studies.[6,16,20,22] This difference can be due to a number of factors, such as different types of deflection sensors (strain gauges or differential transformers *vs.* laser sensors), load range, load application mode, shape of MOD preparation and restorative material. Morin's C parameter (stiffness ratio) was not calculated, as the samples with open MOD cavities were not tested in this study. Since the weakening of cusps was reported in the literature,[6,8,11,12,16,20,22] we actually found that testing open MOD cavities could have led to a great loss of samples without being really significant.

Tests elicited substantial differences in structural recovery ($P < 0.0001$) between adhesive techniques/materials (Spectrum TPH, SureFil, Esthet-X, Esthet-X + Dyract flow) and amalgam. This fact is highlighted by the different cuspal deflection and structural recovery between teeth with amalgam restorations and other groups. No significant difference was elicited ($P > 0.35$) between Groups B, C, D, and E, restored with adhesive techniques and materials (Spectrum TPH, SureFil, Esthet-X, Dyract flow). Since the conditioning and adhesive agents were the same in all these groups, the different results can be related to the materials different E-moduli.

It is interesting that Group E elicited a higher structural recovery than the other groups. It is possible that a restoration made out of composite material and of a layer of flowable compomer grants a better adaptation and adhesion and therefore a higher strength and a smaller deformation within the physiological load range. The modulus of elasticity of the flowable compomer and of the dentin are actually similar (about 18.5 GPa); this could improve the capability of the tooth-restoration complex of absorbing occlusal stresses.

Table 3. Relative stiffness and structural recovery values.

	Relative stiffness	Average stiffness intact	(N/µm) ± s.d. restored	Structural recovery
Group A	0.17	49.52 ± 4.66	8.56 ± 1.59	17%
Group B	0.64	48.02 ± 13.9	28.65 ± 6.68	60%
Group C	0.72	61.37 ± 10.23	36.21 ± 8.58	59%
Group D	0.62	42.49 ± 16.92	22.88 ± 2.75	54%
Group E	0.95	26.27 ± 6.63	26.11 ± 2.30	99%

Future research should evaluate the deflection in teeth restored with carbon fiber or resin posts and composites, as well as in teeth restored with composite MOD inlays. Both of these procedures (the former giving more stiffness in the space previously filled by the pulp tissue, the latter being "preshrunk" and thus inducing minimal polymerization stress) may actually give the tooth even better mechanical features than the already well-performing direct composite restorations.

The limits of this study are inevitably connected to the way it has been carried out. Being an *in vitro* trial, it does not consider factors such as the changes in temperature, pH, and chemical-physical conditions which take place within the oral cavity; furthermore, the forces in the mouth follow vectors that change rapidly in direction and intensity. All of our tests were actually carried out in a laboratory at constant room temperature, applying vertical loads only. We actually analyzed an "ideal" situation, which does not consider the "patient factor" (occlusal relations, chewing cycles, muscular strength, bad habits) nor the "clinician factor" (*i.e.* the different skills of dentists). For these reasons our results must be considered with caution, not as absolute values, but as a therapeutic orientation in the choice of the materials and of the type of restoration.

Adhesive restoration of endodontically treated teeth is an appropriate way to provide good resistance to occlusal loads. Cuspal deflection values obtained in restored teeth let us suppose that the actual great development in adhesive systems and composite materials can be a valid alternative, although temporary, to delay prosthetic solutions. The results of the present *in vitro* research should be confirmed clinically by monitoring the behavior of the tested materials, since both restorative material and tooth-restoration interface undergo phenomena of fatigue and chemical-physical degeneration that can determine an unexpected failure and a possible tooth fracture even under mild loads.

a. Strüers, Remet, Casalecchio di Reno (BO), Italy.
b. 3M ESPE, St. Paul, MN, USA.
c. LMI Technologies Int., Heerlen, The Netherlands.
d. Maillefer-Dentsply, Ballaigues, Switzerland.
e. Kerr, Orange, CA, USA.
f. Dentsply, Konstanz, Germany.

Acknowledgements: To Professor Reinhard Hickel for his skillfull review, Dr. Pier Antonio Acquaviva for the assistance during the operative phases and Dr. Giovanni Parrinello for the statistical analysis. This study was supported by National Project PRIN 2002 of M.U.R.S.T. (Italian Ministry of University and Scientific Research).

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