Stress and Displacement Analysis of First Molar Hollow Tooth during Dental Filling Operation using Three-Dimensional Finite Element Method

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Abstract: the amount of rotten tooth that is come out of teeth is an important issue in dental filling because of its effects on strength of teeth. The main goal of this study is to determine a criterion for the amount of rotten tooth which can be brought out. To do so, first, a three-dimensional finite element model of the complex shape of Right First Molar Mandibular has been established. Then, cylindrical holes with different values of height and diameter (diameter of holes from 3 mm to 8 mm and height of 3 mm to 5.9 mm) is created on the cusp of the tooth. A uniform pressure (from 10 Pa to 10 kPa) is applied around the tooth resembling the belt which is utilized in reality. According to the obtained displacement and stress contours, the diameter of tooth hole can be increased up to 7 mm for pressures under 10 Pa while for higher pressures, the diameter of tooth hole can just be increased up to 6 mm. In addition, due to sudden increase in stress at a pressure of 10 kPa, increasing the value of pressure to higher values is not recommended.

Keywords: Dental filling, Finite element method, Stress and Displacement analysis

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1 INTRODUCTION

Permanent molar teeth are the latest posterior teeth that grow behind the primary teeth. They are also the largest and the most powerful human teeth which usually, have several roots. The role of molars is to chew of food. In addition, molars support the facial muscles and establish the vertical shape of face. According to what mentioned above, these teeth play an important role in the action of chewing and shaping the face. Because of the size of these teeth, they are prone to fracture during dental filling due to the implemented hole and applied loads. Accordingly, finding a suitable criterion for the size of the hole and the amount of applied load is of great importance. Since experimental analysis are expensive and limited, it is preferable to develop numeral models to predict such criteria [1].

Among all the available numerical approaches, finite element method (FEM) is found a great popularity due to its efficiency and ease of use. This method is widely used in the field of dentistry to assess the mechanical response of tooth and jaw. Yettram et al. [2] studied stress distributions for a normal and a restored mandibular second premolar under masticatory-type forces. Peters et al. [3] studied the distribution and magnitude of stresses of a tooth restored with a post and core. Khera et al. [4] assessed the stress distribution of maxillary tooth with or without filling using FEM.

Salis et al. [5] investigated the fracture of premolar teeth due to the impact loading. Yang et al. [6] analyzed the stress of the prosthetic tooth with tightened roots. Winkler et al. [7] compared three filling techniques in terms of the transient stresses induced at the resin composite/tooth interface during polymerization. Yaman et al. [8] used FEM to obtain stress distribution in maxillary central incisor teeth under Endodontic Treatment. Versluis et al. [9] studied the treatment and dental filling with light composite materials.

Toparli et al. [10] presents the stress analysis of the maxillary second premolar tooth under thermal loading as a result of hot/cold liquid in the mouth using 3D FEM. Joshi et al. [11] evaluated the mechanical performance of endodontically treated teeth by means of comparing the stress distribution in the teeth restored with a few variants of posts. Ausiello et al. [12] investigated the residual stress analysis on a filled human maxillary premolar through a generic class II MOD cavity using 3D FEM. Ausiello et al. [13] modeled teeth which adhesively was restored with resin-based materials. Toparli [14] utilized the FEM to predict distribution of stresses in dentin of an endodontically treated tooth, restored with cast post and cores.

De Castro Albuquerque et al. [15] evaluated the effect of different anatomic shapes and materials of posts in the stress distribution on an endodontically treated incisor. Nakamura et al. [16] evaluated stress distribution in maxillary central incisors treated endodontically and restored with a post and an all-ceramic crown. Sorrentino et al. [17] analyzed the strain and stress distributions in endodontically treated maxillary central incisors restored with different post, core and crown materials.

Yamanel et al. [18] evaluated the effects of restorative material and cavity design on stress distribution in a permanent molar tooth structure and restorative materials. Coelho et al. [19] used FEM to investigate the influence of different post systems on the stress distribution of weakened teeth under oblique-load application. Jiang et al. [20] calculated the von Mises stresses in a mandibular first molar using a 3D FE Model. Al-Omiri et al. [21] investigated stress distribution of endodontically treated teeth restored with post-retained crowns. Kumar et al. [22] evaluated the stress formed around an implant and a natural tooth under occlusal forces, on different tooth implant-supported fixed prosthesis designs in order to suggest a design, which transmits less stress to the bone.

Palka et al. [23] analyzed the stress level in hard dental tissues, restored with class I dental filling and exposed to thermal and mechanical load. Kazemi et al. [24] evaluated the effect of canal diameter on the stress distributions of post and dentin in post-core restored endodontically treated maxillary incisor under various static loads. Benazzi et al. [25] compared the patterns of stress distribution in a lower second premolar using three conventional occlusal loadings and two more realistic loading scenarios based on occlusal contact areas.

According to the literature review presented above, the effects of the applied loads and the size of the hole, which might be drilled on the tooth by the dentist in order to remove the rotten part of it, on the quality of tooth filling are not investigated. To compensate this deficiency, in this paper, a finite element model is developed in order to obtain the maximum allowable values of the first molar tooth hole diameter as well as maximum allowable applied pressure, which might be applied by the belt around the tooth, during dental filling. To do so, the geometrical model of the first molar tooth, the boundary conditions, and the applied loads are implemented though ANSYS finite element package. Then, a hole is created on the occlusal surface of the tooth and a uniform pressure is applied around its crown. The effects of the hole diameter, hole depth, and the amount of applied pressure on the maximum von-Mises stress of the tooth is then investigated.

2 MATERIALS AND METHODS

To analyze hollow molar tooth, it is necessary to create the geometrical model of the tooth in a finite element package such as ANSYS. Since the geometry of the tooth is complicated, it is not easy to construct the model in ANSYS. Accordingly, a third party CAD software might be utilized for the construction of the 3D geometric model and then this CAD model would be transferred into the FEM package.

In this paper, Autodesk Inventor V9 is chosen for modeling purposes. To simulate the tooth according to the existing two-dimensional sketches of its surfaces, two-dimensional layouts of the buccal, mesial and occlusal surfaces are prepared. This task was done by matching tooth contour through each level with a curve related to information available on the convexity and concavity of each of tooth surfaces. Then all these sketches are drawn on the faces of a cube with the same dimension of the tooth. After that, based on the drawn sketches, the cube is cut starting from its mesial surface, followed by buccal and occlusal surfaces, respectively. Error! Reference source not found. shows the final geometrical model of the first molar tooth which is constructed by the proposed method.

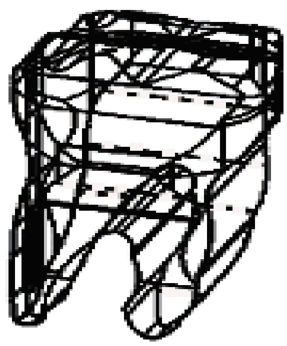

Fig. 1 Initial model of first molar tooth in ANSYS software

After preparing the geometrical model of the tooth, it should be imported into ANSYS FE package. Since a tooth is made of several different materials, i.e. Enamel, Dentin and pulp, different material properties must be defined for each of which. To do so, again, some sketches of different sides of the tooth is prepared and imported into the software. Then, the tooth model is divided into separate volumes relevant to each material of the tooth portions based on these sketches. Table 1 shows the material parameters of Enamel, Dentin and pulp used for simulations.

Table 1 Material parameters of Enamel, Dentin and pulp used for simulations [26]

Material	Yong's Modulus (MPa)	Poisson's Ratio
Enamel	$4.1*10^4$	0.30
Dentin	$1.9*10^4$	0.31
Pulp	2.07	0.45

When the full geometrical model of the tooth is constructed in the FEM software, a hole with the diameter of D, and the depth of H is created on the occlusal surface of it to resemble the hole which is drilled by a dentist to remove the rotten part of the tooth in reality. In order to evaluate the effects of hole diameter and depth, the value of these two parameters, D and H, is changed according to the data provided in Table 2. Referring to this table, to prevent the collision with tooth nerve, the maximum depth of the hole is restricted to be 5.9 mm. To model the pressure of the belt, P, which is placed around the teeth, a surface with the width of belt and in the same shape as top view of the occlusal surface of the first molar tooth was placed around the modeled tooth. Then, those areas which are in contact with this surface are found and used for partitioning the perimeter faces of the tooth. A pressure with the value of P is applied on the partitioned portions resembling the pressure produced by the belt. The value of this applied pressure is changed to assess the effects of the applied pressure by the belt. The value of this pressure is supposed to be 10, 100, 1000, 10000 Pa for each combination of the hole diameter and depth presented in Table 2.

Table 2 Tooth hole dimensions for simulation purposes

Combination No.	1	2	3	4	5	6
D (mm)	3	4	5	6	7	8
H (mm)	3	5	5.9	5.9	5.9	5.9

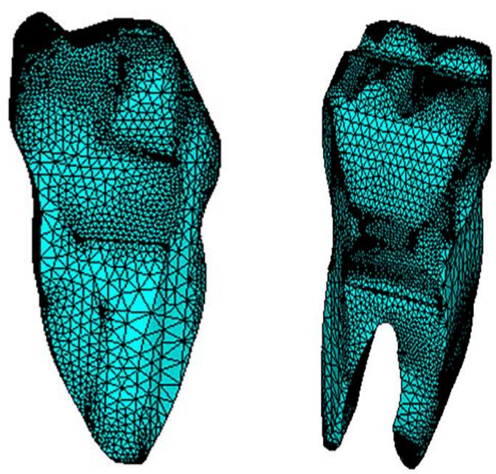

Fig. 2 Meshed model of the tooth

It is supposed that the root of the tooth is completely fixed so that all the degrees of freedom of the nodes on the surface of the root are constrained. The model is then meshed using Solid 95 elements from ANSYS library. A mesh sensitivity analysis is performed in such a way that the mesh size decreased till the change in the obtained results is negligible. Figure 2 shows the meshed model of the first molar tooth created using the above-mentioned approach.

3 DISPLACEMENT ANALYSIS

Figure 3 shows the maximum displacement of the tooth, δ_{max}, for different hole dimensions and values of applied pressure. As it is obvious, the value of maximum displacement increases by increasing the value of applied pressure and the size of the hole. The trend of the changes is almost similar for all the values of the applied pressure, but the magnitude of the maximum displacement is linearly proportional to the applied pressure. As another result, the effects of hole dimensions are more pronounced for higher values of the hole diameter. As it can be seen, although the value of the hole depth is constant for combination No. 3, 4, 5, and 6, the value of the maximum displacement increases significantly by increasing the combination No. It means that the hole diameter drastically affects the mechanical response of the tooth.

Referring to the displacement contour of the tooth, the maximum displacement is occurred on its crowns for all cases. In addition, for all applied pressures, the location of the maximum displacement varies from lingual surface for the smallest hole to mesial surface for the largest hole. Figure 4 (a) to (f) shows the displacement contour for the pressure value of P=100 Pa.

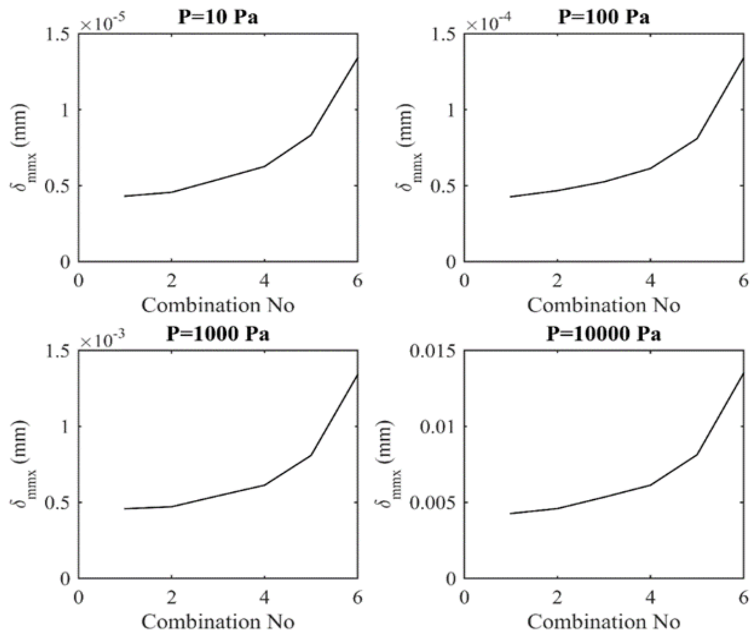

Fig. 3 The value of maximum displacement of tooth, δ_{max} for different hole dimensions and values of applied pressure

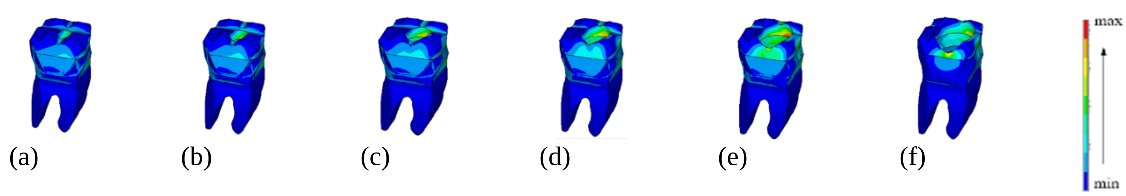

Fig. 4 First molar tooth displacement contour for P=100 Pa and combination No. (a): 1, (b): 2, (c): 3, (d): 4, (e): 5, (f): 6

It is obvious that after removing the tooth belt, a residual stress might be generated because the hole edges tend to return to their original position but they are constrained by the filling material. The maximum value of this residual stress might be produced where the maximum displacement happens. The residual stress after tooth filling can cause pain or discomfort, or even cause the separation of filling materials from the tooth edges. Accordingly, it is of great importance to be able to calculate and control the amount of the residual stresses

[12]. As a preliminary analysis, it can be seen that for the diameter of 7 mm and depth of 5.9 mm, the maximum displacement concentrated almost on the hole walls, and its value is significant. Therefore, after removing the belt, that position with maximum displacement is intended to be a place of residual stresses and cause high risks of material separation. But for the holes with lower diameters, the maximum displacement continues from the hole surface to lingual or mesial surfaces, and after the belt removal, returning rate is very low because of uniform transition of the maximum displacement. In addition, since the displacement are smaller, the value of residual stresses would be smaller for smaller values of hole diameter. The analysis of the residual stresses which might be produced after tooth filling is beyond the scope of the present study and is postponed for future works.

4 STRESS ANALYSIS

Figure 5 shows the maximum von-Mises stress of the tooth, $\delta_{\max}$, for different hole dimensions and values of applied pressure. Referring to this figure, the value of this parameter increases by increasing the value of hole dimensions and its trend is almost similar for all values of applied pressures. However, for all pressure levels, for hole diameter of 7 mm, the value of maximum von-Mises stress is significantly higher in comparison with other hole dimensions. To vindicate this observation, the von-Mises stress contours for P=100 Pa are depicted in Figure 6. Referring to this figure, for D≤6 mm, the maximum von-Mises stress occurs in the drilled hole of the tooth. However, by further increasing the hole diameter, the hole intersects the buccal surface and makes a sharp edge causing stress concentration at this region.

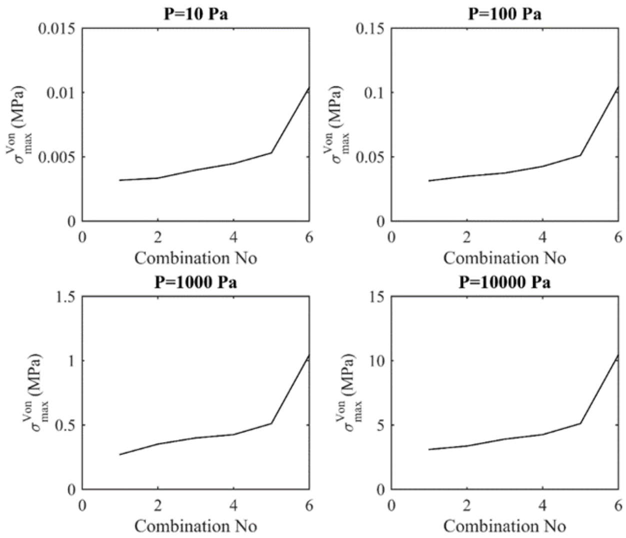

Fig. 5 The value of maximum Von-Mises Stress of tooth, $\sigma_{\max}^{Von}$, for different hole dimensions and values of applied pressure

According to what stated above, both maximum displacement and maximum von-Misses stress increase with the hole diameter. This increase is highly significant for D>6 mm due to the intersection with the buccal surface of the tooth. Due to high values of displacement and von-Misses equivalent stress, this region of intersection is intended to be cracked and causes future troubles. However, when the intersection with buccal surface is unavoidable due to the high amounts of rotten tooth material, the value of applied pressure must be kept as low as possible.

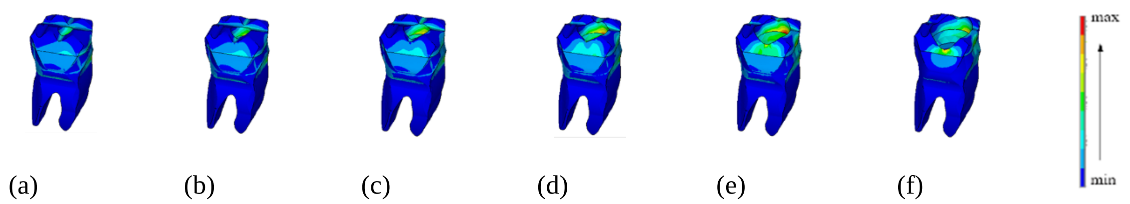

Fig. 6 First molar tooth displacement contour for P=100 Pa and combination No. (a): 1, (b): 2, (c); 3, (d): 4, (e): 5, (f): 6

5 CONCLUSION

During dental filling, the amount of rotten tooth that is come out of teeth is important because more rotten tooth brought out higher strength after filling. However, the risk of tooth fracture increases by the amount of emitted rotten tooth. The main goal of this study is to determine a criterion for the amount of rotten tooth which can be brought out. In this regard, first, a three-dimensional finite element model of the complex shape of Right First Molar Mandibular has been established. Then, cylindrical holes with different values of height and diameter (diameter of holes from 3 mm to 8 mm and height of 3 mm to 5.9 mm) are generated on the cusp of the tooth. A uniform pressure (from 10 Pa to 10 kPa) is applied around the tooth resembling the belt around actual tooth. According to the obtained displacement and stress contours, during dental filling, the diameter of the tooth hole can be increased up to 7 mm for pressures under 10 Pa, while for higher values of pressure, diameter of tooth hole can be just increased up to 6 mm. In addition, due to sudden increase in stress at a pressure of 10 kPa, higher values than 10 kPa are not recommended.

REFERENCES

[1] Wakabayashi, N., et al., "Nonlinear Finite Element Analyses: Advances and Challenges in Dental Applications", Journal of dentistry, Vol. 36, No. 7, 2008, pp. 463-471.

[2] Yettram, A., Wright, K., and Pickard, H., "Finite Element Stress Analysis of the Crowns of Normal and Restored Teeth", Journal of Dental Research, Vol. 55, No. 6, 1976, pp. 1004-1011.

[3] Peters, M., et al., "Stress Analysis of a Tooth Restored with a Post and Core", Journal of Dental Research, Vol. 62, No. 6, 1983, pp. 760-763.

[4] Khera, S., et al., "A Three-Dimensional Finite Element Model", Operative dentistry, Vol. 13, No. 3, 1987, pp. 128-137.

[5] Salis, S. G., et al., "Impact-Fracture Energy of Human Premolar Teeth", The Journal of prosthetic dentistry, Vol. 58, No. 1, 1987, pp. 43-48.

[6] Yang, H. S., Chung, H. J., and Park, Y. J., "Stress Analysis of a Cantilevered Fixed Partial Denture with Normal and Reduced Bone Support", The Journal of prosthetic dentistry, Vol. 76, No. 4, 1996, pp. 424-430.

[7] Winkler, M., Katona, T., and Paydar, N., "Finite Element Stress Analysis of Three Filling Techniques for Class V Light-Cured Composite Restorations", Journal of dental research, Vol. 75, No. 7, 1996, pp. 1477-1483.

[8] Yaman, S. D., Alaçam, T., and Yaman, Y., "Analysis of Stress Distribution in a Maxillary Central Incisor Subjected to Various Post and Core Applications", Journal of Endodontics, Vol. 24, No. 2, 1998, pp. 107-111.

[9] Versluis, A., Tantbirojn, D., and Douglas, W., "Do Dental Composites Always Shrink Toward the Light?", Journal of Dental Research, Vol. 77, No. 6, 1998, pp. 1435-1445.

[10] Toparli, M., Gökay, N., and Aksoy, T., "An Investigation of Temperature and Stress Distribution on a Restored Maxillary Second Premolar Tooth Using a Three-Dimensional Finite Element Method", Journal of oral rehabilitation, Vol. 27, No. 12, 2000, pp. 1077-1081.

[11] Joshi, S., et al., "Mechanical Performance of Endodontically Treated Teeth", Finite elements in analysis and design, Vol. 37, No. 8, 2001, pp. 587-601.

[12] Ausiello, P., et al., "3D-Finite Element Analyses of Cusp Movements in a Human Upper Premolar, Restored with Adhesive Resin-Based Composites", Journal of biomechanics, Vol. 34, No. 10, 2001, pp. 1269-1277.

[13] Ausiello, P., Apicella, A., and Davidson, C. L., "Effect of Adhesive Layer Properties on Stress Distribution in Composite Restorations a 3D Finite Element Analysis", Dental Materials, Vol. 18, No. 4, 2002, pp. 295-303.

[14] Toparli, M., "Stress Analysis in a Post-Restored Tooth Utilizing the Finite Element Method", Journal of oral rehabilitation, Vol. 30, No. 5, 2003, pp. 470-476.

[15] de Castro Albuquerque, R., et al., "Stress Analysis of an Upper Central Incisor Restored with Different Posts", Journal of Oral Rehabilitation, Vol. 30, No. 9, 2003, pp. 936-943.

[16] Nakamura, T., et al., "Stress Analysis of Endodontically Treated Anterior Teeth Restored with Different Types of Post Material", Dental materials journal, Vol. 25, No. 1, 2006, pp. 145-150.

[17] Sorrentino, R., et al., "Three-Dimensional Finite Element Analysis of Strain and Stress Distributions in Endodontically Treated Maxillary Central Incisors Restored with Different Post, Core and Crown Materials", dental materials, Vol. 23, No. 8, 2007, pp. 983-993.

[18] Yamanel, K., et al., "Effects of Different Ceramic and Composite Materials on Stress Distribution in Inlay and Onlay Cavities: 3-D Finite Element Analysis", Dental materials journal, Vol. 28, No. 6, 2009, pp. 661-670.

[19] de Miranda Coelho, C. S., et al., "Finite Element Analysis of Weakened Roots Restored with Composite Resin and Posts", Dental materials journal, Vol. 28, No. 6, 2009, pp. 671-678.

[20] Jiang, W., et al., "Stress Distribution in Molars Restored with Inlays or Onlays with or Without Endodontic Treatment: A Three-Dimensional Finite Element Analysis", The Journal of prosthetic dentistry, Vol. 103, No. 1, 2010, pp. 6-12.

[21] Al-Omiri, M. K., Rayyan, M. R., and Abu-Hammad, O., "Stress Analysis of Endodontically Treated Teeth Restored with Post-Retained Crowns: A Finite Element Analysis Study", The Journal of the American Dental Association, Vol. 142, No. 3, 2011, pp. 289-300.

[22] Kumar, G. A., Kovoor, L. C., and Oommen, V. M., "Three-Dimensional Finite Element Analysis of the Stress Distribution Around the Implant and Tooth in Tooth Implant-Supported Fixed Prosthesis Designs", Journal of Dental Implants, Vol. 1, No. 2, 2011, pp. 75.

[23] Pałka, K., et al., "Finite Element Analysis of Thermo-Mechanical Loaded Teeth. Computational Materials Science", Vol. 64, No. 2, 2012, pp. 289-294.

[24] Kazemi, A., Khamesi, V., and Hajimahamadi, S., "Finite Element Study of the Effect of Canal Diameter on the Stress Distributions in Post-Core Restored Endodontically Treated Maxillary Incisor", Applied Mechanics and Materials, Vol. 19, No. 11, 2012, pp 34-41.

[25] Benazzi, S., et al., "Comparison of Occlusal Loading Conditions in a Lower Second Premolar Using Three-Dimensional Finite Element Analysis", Clinical oral investigations, Vol. 18, No. 2, 2014, pp. 369-375.

[26] Rubin, C., et al., "Clinical Science Stress Analysis of the Human Tooth Using a Three-dimensional Finite Element Model", Journal of Dental Research, Vol. 62, No. 2, 1983, pp. 82-86.