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Literature Review Article

Photoelasticity in Dentistry: a literature review

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Abstract

Introduction and Objective: Photoelasticity consists of an experimental technique of stress analysis. This technique is very used in most different areas including Dentistry. This literature review presents the several applications of photoelastic technique in Dentistry as well as its advantages and disadvantages. **Literature review:** Based on this method of analysis, it is possible the verification of the stress distribution and deformation in structures with complex geometry as maxilla and mandible. It can be used to evaluate the distribution of stress on several types of prosthesis as removable partial denture systems with different retention systems, conventional implant prosthesis, overdentures and Brånemark protocols. Moreover, photoelasticity can be used to assess the stress generated by various orthodontic movements, different orthodontic systems and different materials (orthodontic wires). In addition, it is used to analyze different defects of maxillectomy, splint types on traumatized tooth and post-core restoration methods. This technique can also be used to assess dental instruments such as evaluation of different designs of periodontal probe. **Conclusion:** The photoelastic analysis has been a technique of great importance in health area studies, more specifically in Dentistry. Based on this method of analysis, it is possible to measure the stress distribution and deformation in structures with complex geometry as maxilla and mandible.

Introduction

Photoelasticity consists of an experimental technique of stress analysis. It is based on the property that certain transparent materials have that is to exhibit fringes (optic parameters), when observed through polarized light. This effect is the result of the alteration (refraction) of the polarized light by internal deformations resulted of the stress condition present in the model. The interpretation of these fringes shows all stress distribution and allows the measurement of their direction and magnitude in any model points. In materials with photoelastic properties, the changes in the refraction index happen according to the stress application [6].

In the photoelastic method, a model similar to the studied structure is made in transparent material that has photoelastic properties. This model is submitted to a representative loading of the work conditions, which take to a deformation [13].

An appliance denominated polariscope is used for this method, which allows the establishment of the light propagation plan and, therefore, the main stress directions, as well as the difference between the two components of main stress. This appliance is composed by an association of filters disposed among the observer, the luminous source and the model. The polarized light crosses the filters and the model arrives at the observer as an image of the optic parameters [5].

When the white light is used, the optic effects come out as colored fringes, which have an order number, depending on the load intensity. The fringe order in a determinate point is related with the state of stresses in the model. The fringes exhibited in the photoelastic model appear as successive and continuous series of different colored bands. The whole fringes are located between the red and blue fringes and, the second and consecutives whole fringes are located between the red and green fringes [5].

According to this concept, the aim of this study was to report the different applications of photoelasticity in Dentistry.

Literature review

The photoelastic technique has been very used in the Dentistry. Some of its several applications will be described in each specific Dentistry area.

Implantology

The study of photoelasticity in the specific area of Implantology is of great interest since it can be useful to assess the distribution of stress in both abutments (different designs and types) and implants screws (different types and angulations).

Cehreli *et al.* [6] analyzed the force distribution and magnitude around implants with different designs and abutments types. The authors tested conical and cylindrical Branemark® and Astra Tech® implants and ITI® solid screw implant. The abutments were submitted to vertical and 20° oblique forces of 100 N and 150 N, and then they were analyzed through the photoelastic and strain-gauged techniques. The obtained results showed that the forces distribution was similar in both loading conditions. The strains around the Branemark® implants were smaller than around the other implants, particularly under vertical loads. The study conclusion is that the different types of implant/abutment set used have similar distribution of forces and the implant-abutment mating design is not a decisive factor in the distribution and magnitude of the forces in a simulated bone.

Akça *et al.* [1] investigated by photoelastic analysis the difference in load distribution of dental implants with different implant neck designs. For this, the models were tested in situations of intact and compromised cortical bone. The Astra Tech®, 3i® and Straumann® abutments were submitted to vertical and 20° oblique loads of 10, 20 and 30 lb and analyzed in a polariscope. The authors observed that the highest stress values, in the condition of intact bone, were localized around the crest and apical region. For the compromised cortical bone group, regarding all designs and load directions, it was observed that the higher stresses occurred in the supporting structures. The study conclusion was that the condition of the cortical bone considerably influenced on stress distribution. Thus, a compromised condition of the cortical bone caused higher stress levels for all implants tested.

Markarian *et al.* [21] evaluated the stress distribution in 30° angled and parallel implants with and without gap among the implant/abutment junction. Four different models were created to simulate the studied conditions. The models were loaded with 100 N and analyzed by photoelastic analysis. The results showed that for the parallel implants the stress distribution followed the implant axis and, in the model with angled implant, the stress magnitude was higher and non-homogeneous around the apical region of the lateral implants. It was concluded that the stress is generated after screws tightening of the abutments and it is increased after mechanical loading. Gaps among implant/abutment junction can generate increase in the stress distribution on parallel implant. The angled implants resulted in patterns of oblique and non-homogeneous stress.

Ochiai *et al.* [24] studied implant-tooth connected prosthesis with segmented (conical abutment attached to implant by abutment screw) and non-segmented abutments (restoration fabricated directly to machined abutment). In this study, a photoelastic model of a posterior region of a mandible was used with one or two implants. The implants were placed at the first and second molar positions. The restorative technique included the implants and the anterior adjacent tooth. The model was analyzed after the load application in 5 different points on the restoration occlusal surface. The results showed that the stress distribution on the model with two posterior implants was similar compared to the segmented and non-segmented abutments. The stress magnitude observed for both abutments types was also similar on the model with single posterior implant. Vertical loading produced more non-axial stress in the condition of one implant with nonsegmented abutment.

Prosthodontics

In Prosthodontics, the photoelastic technique can be utilized to compare different systems of overdenture retention and to verify the biomechanical behavior of implant-tooth-supported fixed prosthesis as well as removable prosthesis.

Fanuscu and Caputo [14] compared the characteristic of stress distribution of two systems of overdenture retention supported by 4 implants, after protrusive and laterotrusive movements. The first system consisted of splinted-bar ERA (harder bar splinting 4 implants and anterior clip with 2 distal resilient cap attachment) and the other system was composed of four O-ring isolated (4 individual ball/O-ring attachment). The four implants were inserted in a maxillary photoelastic model. Prosthesis in acrylic resin was made for both systems. Protrusive and laterotrusive loads from 1.4 to 14.4 kg were applied. Instability in the overdenture happened in both retention systems when protrusive and laterotrusive loads lower than 4.6 kg were applied. The protrusive loads were better distributed than the laterotrusive loads in both retention mechanisms. The O-ring system transferred bending load to implants in the laterotrusive loading, mainly for posterior implants. The splinted-bar ERA system transferred higher intensity of stresses to posterior implants during the laterotrusive loads. Higher stresses were observed in the O-ring system in the laterotrusive loads in the distal side. It was concluded that both retention systems demanded an occlusion balanced for the overdenture stability under the application loads that varied from 1.4 to 14 kg. The protrusive and laterotrusive loads were not distributed equally in both mechanisms, and the highest stress happened in the posterior implants.

Another study that used implant-tooth-supported fixed prosthesis was accomplished by Srinivasan and Padmanabhan [28]. In that study one implant and a tooth served as support for a fixed prosthesis of 3 elements. The prosthesis was loaded on 3 different points not simultaneously. The periodontal ligament was simulated in the photoelastic model to evaluate the intrusion of the tooth and the implant that supported the prosthesis. The results indicated that the force cannot be light and continuous and it may not cause dental intrusion. However, intrusion of natural tooth may be not just related to excessive forces as shown in this study and it needs more investigation.

Ochiai *et al.* [23] used the photoelastic technique to evaluate the effect of palatal support on three different designs of maxillary implant-supported overdentures. The fitting systems tested were: a splinted Harder bar incorporating 2 distal ERA with anterior clips, non-splinted Zaag 4 mm direct abutments and attachments, and non-splinted Locator 2 mm direct abutments and attachments. The three prosthesis types were installed with complete palatal coverage in the maxilla model, made by photoelastic material, containing the 4 implants. The overdentures received 111 N of loading in the first right and left molars and in the incisive papilla area for the stress distribution verification. The same procedure was accomplished in the overdentures after removal of the palatal coverage. The authors concluded that the palatal coverage removal from the maxillary overdentures produced a greater effect of the loading transfer and more difference on the concentrated stress around the implants than the attachment designs used.

Celik and Uludag [7] assessed the stress distribution in different retention mechanisms (ball attachment, direct abutments with attachments, bar framework, bar with distally placed ball attachments) for mandibular overdenture retained by 3 implants with parallel or inclined positions, by photoelastic technique. A force of 135 N was applied unilaterally in the right first molar. The study showed that the lowest stress values were observed in the bar-ball attachment system for both parallel and inclined implants.

Jiao *et al.* [16] accomplished studies using the photoelastic method to analyze the stress distribution in different designs of removable partial denture (RPD). Lyons *et al.* [20] used the same method to analyze the stress distribution of different sized surgical resection with RPD designed to restore this maxillectomy defects. Jiao *et al.* [16] compared the stress distribution of three different RPD designs (RPD made by polyacetal, traditional metal framework and hybrid) and concluded that the structure that had the best stress distribution is the traditional metal framework I-bar RPD, which has the most equitable stress distribution. The hybrid structure has an intermediate behavior. Despite these observations, the hybrid structure can be considered a viable alternative when the primary concern is the esthetic.

Lyons *et al.* [20] compared the photoelastic maxillas models with different sizes of defects (partial maxillectomy, total maxillectomy, and total maxillectomy involving the contralateral premaxilla), rehabilitated with RPD using splinted and non-splinted teeth as abutments. The study results suggest that the splinting of the 2 teeth adjacent to the resection defect can reduce the tension in the teeth pillars and improves stress distribution around the roots during loading.

Costa *et al.* [12] analyzed by photoelastic technique the stress distribution in the distal-extension of the RPD in three different retainers: T bar, rest proximal plate I bar (RPI), and circumferential with mesialized rest. The photoelastic models represent a Kennedy Class II inferior arch. A force of 20 N was applied in all models with the frameworks with the different retainers. The stress distribution was observed in 8 different points. The best results of stress distribution between teeth and residual ridge were the RPI retainer, following by T bar.

Furthermore, the photoelastic analysis can be used to verify the applicability of a theoretical method as studied by Kim *et al.* [18]. In their photoelastic experiment, the O-ring specimen was made of epoxy resin, the applied fractional compression was 20% and the lateral pressure was varied as 1.96, 2.94 and 3.92 MPa. The authors obtained similar results in the verification of the pattern and values of the stress in the photoelastic technique and theoretical method. It was concluded that the theoretical method is valid for the stress analysis and can predict a failure of an O-ring attachment.

Orthodontics

Another area of the dentistry in that which photoelastic technique has been very used is orthodontics. In that area the photoelastic analysis is used to examine the stress produced during the several orthodontics movements as the canine retraction [3], incisor retraction [9], in masse distalization of mandibular premolar and molar [30], increasing the reverse curves of Spee in the rectangular stainless steel archwire when reducing an increased overbite [11]. Nakamura *et al.* [22] accomplished a study that simulated distal movement of mandibular molars with skeletal Anchorage system, in which almost 3-dimensional technique was used.

Cengiz *et al.* [8] evaluated the behavior of different splint types on traumatized tooth using the photoelastic analysis. A model with natural teeth positioned equidistantly received three different splint types (the wire-composite splint, fiberglass splint and titanium trauma splint). That model received a static axial and 20° oblique force of 100 N in a circular polariscope. The generated images were registered in a photographic camera and transferred to a computer for quantification of the fringes. The study concluded that the use of the orthodontic wire resulted in lowest fringe orders around of the traumatized tooth and titanium trauma splint did not have any effect on reduction of stresses.

Yamamoto *et al.* [31] in a study of stress analysis of different post and core restoration methods (composite resin post and core, composite resin with glass fiber post, and cast metal post and core) also used the photoelastic method and suggested that abutment made by composite resin core in combination with fiber post model produced the lowest stress concentration in endodontically treated teeth.

Surgery

In the specific area of maxillofacial surgery, Sato *et al.* [26] used the photoelastic method to evaluate different techniques of sagittal split ramus osteotomy in mandibular advancement. The positions of tested splint were: linear arrangement at 60°, linear arrangement at 90°, reverse L arrangement and miniplates and screws. The hemi-mandibles models made by photoelastic resin were fixed in agreement with different positions. Under analysis in the polariscope, a photographic was taken after 3.0 mm of displacement was reached. The results show that the linear 90° and reversed L arrangements provided the most favorable behavior.

Sato *et al.* [27] published a comparative study of hybrid technique for fixation of the sagittal split ramus osteotomy in mandibular advancement using a finite element analysis to validate the photoelastic models. The positions of the tested splint were: fixation using a hybrid technique fixation using bicortical screws and fixation using a 4-hole miniplate with monocortical screws. The results suggested that the hybrid technique is most favorable because it increased the resistance and improved the stress distribution.

Lima *et al.* [19] used photoelasticity to analyze the mechanical behavior of bone and teeth of rapid maxillary expansion with or without separation of pterigomaxillary suture. In this study, a model of maxilla was done in material with photoelastic properties, the orthodontic appliances were installed and then the expansion was carried out with and without osteotomy of suture. The results showed that the model with osteotomy has less stress in molar area, maxillary tuberosity and pterygoid plates.

Moreover, Christopoulos *et al.* [10] verified the stress in mandible with condylar fracture by means of photoelasticity through three fixation systems. The first system used a miniplate at the posterior border under load, the second system used a miniplate parallel to the sigmoid notch under load and the third system used two miniplates at the position of the first and second system. It was concluded that the use of two miniplates offers better stabilization in all loading conditions studied.

Dental instruments

The photoelastic analysis can also be utilized for investigation of the applicability of new dental instruments. For instance, Vartoukian *et al.* [29] investigated the physical-mechanical behavior of a new periodontal probe tip design. The control and test probe were embedded axially up to the 5.0 mm mark in photoelastic resin. The blocks were analyzed under white light in a transmission polariscope under loading of 3.15 or 5.0 N. The images were photographed and analyzed. The results of this study showed that the test probe obtained lower stresses and less local stress concentration than the control (conventional probe).

Discussion

Nowadays, there is a tendency towards replacing experimental analyses by computer-aided techniques (numerical methods). Notwithstanding, with the increasing of the complexity of the structures studied and the development of new advanced materials, the use of experimental techniques still exists and, frequently, it is the only one that can provide reliable results. The techniques of stress analysis most used currently are: strain-gauged (extensometry), finite elements method, photoelasticity and speckle interferometry (ESPI). These technique associations have been very used for numerical methods validation.

The photoelastic method is an experimental technique of stress/deformation analysis that is used to solve complex engineering problems, when the numerical solution is of difficult application. Moreover, the photoelastic method is used in the validation and experimental verification of numerical solutions, in the study of the stress distribution in geometry problems and complex loadings, as well as in the shape optimization. This methodology allows fast qualitative analyses of the stress state through the observation of the optical effects and models. In addition, the association between the photoelastic method and computer software allows a quantitative analysis of the stress in the models.

Despite the information described above, the photoelastic technique presents some limitations when stress quantification is requested. Among them is the requirement of models with faithful reproduction to the original especially. Another important factor that must be observed is that the applied force should not cross the limit of the material resistance. When the value of the applied force reaches the resistance limit of the materials, the results can be modified. Moreover, the material can fail when the applied force exceeds its maximum resistance limit. For the accurate results interpretation, when observed by polariscope, the model should not present tensions prior to the force application [4].

The great advantage of photoelasticity is that it is an experimental method that allows the visualization of the set of internal stresses in the models [4, 15]. The method such as strain gauge just can measure the surface stresses in the model. And the finite element method is a computational method highly manipulable.

As limitations of the technique, it is its difficult in faithful reproduction of the original model and that these should be free of stresses before the analysis [4] and, according to Sadowsky and Caputo [25], it is impossible to differentiate cortical and medullar bones.

As the photoelastic technique, the others methods of stress analysis have advantages and disadvantages in its application. The strain gauge is a device used to measure the deformation of an object under load [2]. A great advantage of this method is the possibility to use in studies in vivo, but has disadvantages such as the superficial measuring and the active area of the strain gauge being about 2 to 10 mm.

The finite elements method is a numerical analysis of stress that divides a known geometric problem into much smaller domains with simplified geometry, in which the variables can be interpolated to obtain the solution of the problem. The main advantage of this method is its versatility since every shape or structure can be analyzed and the load applied can have any intensity and direction. However, in some studies the properties of the models do not accurately represent the actual in vivo model conditions and the results can not be extrapolated to the real situation [2].

The ESPI is a technique that uses laser radiation and a video recorder of interferometric patterns for high resolution in the assessment of the displacements on the surface of objects. The fringe patterns obtained with this non-contact technique show equal displacement regions in the direction of the sensitivity vector [17]. The advantages of ESPI are: non invasive technique and detection of stress values higher than 100 nm. Some disadvantages are: complex procedure and not applicable in models in vivo.

Conclusion

The photoelastic analysis has been a technique of great importance in health area studies, more specifically in Dentistry. Based on this method of analysis, it is possible to measure the stress distribution and deformation in structures with complex geometry as maxilla and mandible. Furthermore, the photoelastic analysis can improve the resolution of problems and can be helpful to answer questions not solved by conventional methods of analyses used in Dentistry studies.

References

1. Akça K, Fanuscu MI, Caputo AA. Effect of compromised cortical bone on implant load distribution. J Prosthodont. 2008 Dec;17(8):616-20.

2. Assunção WG, Barão VAR, Tabata LF, Gomes EA, Delben JA, Santos PH. Biomechanics studies in dentistry: bioengeneering applied in oral implantology. J Craniofac Surg. 2009 Jul;20(4):1173-7.

3. Baeten LR. Canine retraction: a photoelastic study. Am J Orthod. 1975 Jan;67(1):11-23.

4. Campos Jr A, Passanezi E, Nahás D, Janson WA. A fotoelasticidade na pesquisa odontológica, parte I: campo de aplicação. Rev Odontol Univ São Paulo. 1986;16(1):20-5.

5. Campos Jr A, Passanezi E, Nahás D, Janson WA. Bases teóricas fundamentais para a utilização da fotoelasticidade como método de estudo de distribuição de força. Estomat Cult. 1985;15(1):20-4.

6. Cehreli M, Duyck J, De Cooman M, Puers R, Naert I. Implant design and interface force transfer. A photoelastic and strain-gauges analysis. Clin Oral Implants Res. 2004 Apr;15(2):249-57.

7. Celik G, Uludag B. Photoelastic stress analysis of various retention mechanisms on 3-implant-retained mandibular overdentures. J Prosthet Dent. 2007 Apr;97(4):229-35.

8. Cengiz SB, Atac AS, Cehreli ZC. Biomechanical effects of splint types on traumatized tooth: a photoelastic stress analysis. Dent Traumatol. 2006 Jun;22(3):133-8.

9. Chaconas SJ, Caputo AA, Miyashita K. Force distribution comparisons of various retraction archwires. Angle Orthod. 1989 Spring;59(1):25-30.

10. Christopoulos P, Stathopoulos P, Alexandrisdis C, Shetty V, Caputo A. Comparative biomechanical evaluation of mono-cortical osteosynthesis systems for condylar fractures using photoelastic stress analysis. Br J Oral Maxillofac Surg. 2012 Oct;50(7):636-41.

11. Clifford PM, Orr JF, Burden DJ. The effects of increasing the reverse curve of Spee in a lower archwire examined using a dynamic photo-elastic gelatin model. Eur J Orthod. 1999 Jun;21(3): 213-22.

12. Costa MM, da Silva MAMR, Oliveira SAG, Carvalho PM, Lucas BL. Photoelastic study of the support structures of distal-extension removable partial dentures. J Prosthodont. 2009 Oct;18(7):589-95.

13. Durelli AJ, Riley WF. Introduction to photomechanics. Englewood Cliffs, New Jersey: Prentice-Hall; 1965.

14. Fanuscu MI, Caputo AA. Influence of attachment systems on load transfer of an implant-assisted maxillary overdenture. J Prosthodont. 2004 Dec;13(4):214-20.

15. Goiato MC, Tonella BP, Ribeiro PP, Ferraço R, Pellizer EP. Methods used for assessing stresses in buccomaxillary prostheses: photoelasticity, finite element technique, and extensometry. J Craniofac Surg. 2009 Mar;20(2):561-4.

16. Jiao T, Chang T, Caputo AA. Load transfer characteristics of unilateral distal extension removable partial dentures with polyacetal resin supporting components. Aust Dent J. 2009 Mar;54(1):31-7.

17. Jones R, Wykes C. Holographic and speckle interferometry. Cambridge: Cambridge University Press; 1989.

18. Kim HK, Nam JH, Hawong JS, Lee YH. Evaluation of O-ring stresses subjected to vertical and one side lateral pressure by theoretical approximation comparing with photoelastic experimental results. Eng Fail Anal. 2009 Sep;16(6):1876-82.

19. Lima Jr SM, de Moraes M, Asprino L. Photoelastic analysis of stress distribution of surgically assisted rapid maxillary expansion with and without separation of the pterygomaxillary suture. J Oral Maxillofac Surg. 2011 Jun;69(6):1771-5.

20. Lyons KM, Beumer J, Caputo AA. Abutment load transfer by removable partial denture obturator frameworks in different acquired maxillary defects. J Prosthet Dent. 2005 Sep;94(3):281-8.

21. Markarian RA, Ueda C, Sendyk CL, Laganá DC, Souza RM. Stress distribution after installation of fixed frameworks with marginal gaps over angled and parallel implants: a photoelastic analysis. J Prosthodont. 2007 Mar-Apr;16(2):117-22.

22. Nakamura A, Taratani T, Itoh H, Sugawara J, Ishikawa H. Photoelastic stress analysis of mandibular molars moved distally with skeletal Anchorage system. Am J Orthod Dentofacial Orthop. 2007 Nov;132(5):624-9.

23. Ochiai KT, Ozawa S, Caputo AA, Nishimura RD. Photoelastic stress analysis of implant-tooth connected prostheses with segmented and nonsegmented abutment. J Prosthet Dent. 2003 May;89(5):495-502.

24. Ochiai KT, Williams BH, Hojo S, Nishimura R, Caputo AA. Photoelastic analysis of the effect of palatal support on various implant-supported overdenture designs. J Prosthet Dent. 2004 May;91(5):421-7.

25. Sadowsky SJ, Caputo AA. Effect of anchorage systems and extension base contact on load transfer with mandibular implant-retained overdentures. J Prosthet Dent. 2000 Sep;84(3):327-34.

26. Sato FRL, Asprino L, Consani S, de Moraes M. Comparative biomechanical and photoelastic evaluation of different fixation techniques of sagittal split ramus osteotomy in mandibular advancement. J Oral Maxillofac Surg. 2010 Jan;68(1):160-6.

27. Sato FR, Asprino L, Consani S, Noritomi PY, de Moraes M. A comparative evaluation of the hybrid technique for fixation of the sagittal split ramus osteotomy in mandibular advancement by mechanical, photoelastic, and finite element analysis. Oral Surg Oral Med Oral Pathol Oral Radiol. 2012 Nov;114(5 Suppl):S60-8.

28. Srinivasan M, Padmanabhan TV. Intrusion in implant-tooth-supported fixed prosthesis: an in vitro photoelastic stress analysis. Indian J Dent Res. 2008 Jan-Mar;19(1):6-11.

29. Vartoukian SR, Palmer RM, Wilson RF. Evaluation of a new periodontal probe tip design. A clinical and in vitro study. J Clin Periodontol. 2004 Oct;31(10):918-25.

30. Yamada T, Sugawara J, Itoh H, Sasaki T, Sasaki K, Umezaki E. Photoelastic stress analysis of en masse distalization of mandibular premolar and molar with Skeletal Anchorage System – using isochromatic fringes and isoclinic fringes. Intern Congress Series. 2005 Sep;1284:77-8.

31. Yamamoto M, Miura H, Okada D, Komada W, Masuoka D. Photoelastic stress analysis of different post and core restoration methods. Dent Mater J. 2009 Mar;28(2):204-11.