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Biomechanics in restorative dentistry

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Abstract

Biomechanics is a branch of bioengineering, which we define as the application of engineering principles to biological systems. Orofacial biomechanics constitutes the determination of the mechanical stresses that the orofacial complexes are subjected to under both physiologic and pathologic conditions, response of the various oral tissues and restorative materials to the mechanical stress and modification of mechanical stresses applied to the oral tissues by restorative procedure and appliance. While masticating food or restoring tooth, the tooth undergoes deformations by a biting force or a stress induced from the restorative procedure. Before designing and implementing an instrument for measurement of stress, strain, motion, and flow during restoration in dental research, we need to understand the biomechanics of dental tissues and restorative materials separately. Stresses in dental structures have been studied by such techniques as brittle coatings, strain gauges, two and three-dimensional photoelasticity, and finite element analysis. Stress analysis studies of inlays, crowns, bases supporting restorations, fixed bridges, complete dentures, partial dentures, and implants have been reported. An adequate understanding of relationship between periodontal tissues, tooth and restoration is paramount to ensure adequate form, function, aesthetics and comfort of the dentition. The clinician should have an adequate knowledge about anatomy and the functional aspects of natural dentition so as to reproduce using proper restorative material.

Keywords: Biomechanics, force, restoration, stress analysis

Introduction

Mechanics (statics and dynamics) describes the forces and motions of any system. The biological world is also a natural object for the study of mechanics. Classical mechanics is classified in to two basic approaches: continuum mechanics and statistical mechanics6.

Thermodynamics, fluid dynamics and solid mechanics play prominent roles in the study of biomechanics. By applying the laws and concepts of physics, biomechanical mechanisms and structures can be simulated and studied. Such a study helps us to understand its normal function, predict changes due to alteration, and propose methods of artificial intervention.

Biomechanics in Restorative Dentistry

Orofacial biomechanics constitutes the study of following.

1. Determination of the mechanical stresses that the orofacial complexes are subjected to under both physiologic and pathologic conditions.
2. Response of the various oral tissues and restorative materials to the mechanical stress.
3. Modification of mechanical stresses applied to the oral tissues by restorative procedure and appliance. While masticating food or restoring tooth, the tooth undergoes deformations by a biting force or a stress induced from the restorative procedure.

There are three biomechanical units:

1. Tooth structure,
2. Restorative material
3. Interface between the restoration and tooth.

Before designing and implementing an instrument for measurement of stress, strain, motion, and flow during restoration in dental research, we need to understand the biomechanics of dental tissues and restorative materials separately. In many respects the design of structures for the oral environment is among the most demanding because of the complexity of the.

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Functional and para functional loads and because of esthetic and space limitations. In spite of these special conditions however all dental tissues and structures follow the same laws of physics as any other material or structure.

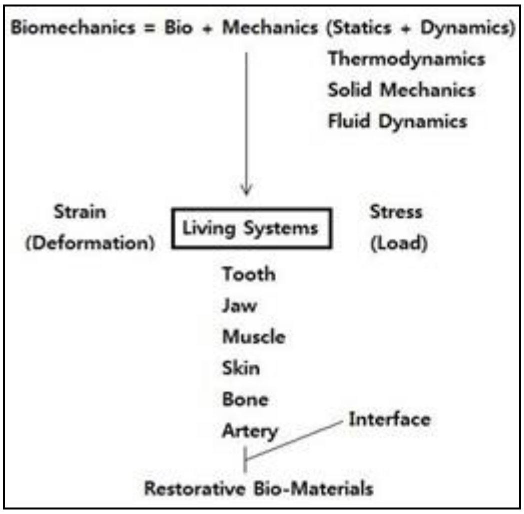

Fig 1: Biomechanics

Forces on dental structures

The maximum forces reported have ranged from 200 to 2440 N in natural dentition (45 to 550 lb).

Normal biting forces

Experiments conducted on adults have shown that the biting force decreases from the molar region to the incisors. The average biting forces in persons with normal and modified occlusion were measured. Data indicate that when the bite was raised 0.5 mm, the measured forces were generally higher, approaching twice the values obtained with normal occlusion.

This observation may be explained by the fact that the force on teeth are determined by muscular effort, and this effort is controlled by the nervous system. Thus it was concluded that some force – regulating mechanism was operating and it probably influences in case of malocclusion.

First and second molars - 390 to 800 N (88 to 198 lb), with the average being 565 N (127 lb).

Bicuspids- 288N (65 lb) Cuspids- 208N (47 lb) Incisors- 155N (35 lb). In children, increase in force from 235 to 494 N (53 to 111 lb) as age increased, with the average yearly increase of 22.2 N (5 lb).

Stress

When a force acts on a body, tending to produce deformation, a resistance is developed to this external force application. Stress is the internal reaction to the external force. Stress = force / Area. Area over which the force acts is an important factor of consideration especially in dental restorations in which areas over which the force applied often are extremely small. Since stress at a constant force is inversely proportional to the area, the smaller the area, the larger the stress and vice versa.

Types of stresses

Depending upon the nature of the force, all stresses can be divided into 3 basic types which are recognized as

1. Tension

Results in a body when it is subjected to 2 sets of forces that are directed away from each other in the same straight line. It is caused by a load that tends to stretch or elongate a body.

2. Compression

Results when the body is subjected to 2 sets of forces in the same straight line and directed to each other. It is produced by a load that tends to compress the body.

3. Shear

A stress that tends to cause a twisting motion, or a sliding of one portion of a body over another.

Complex Stresses

Whenever force is applied over a body, complex or multiple stresses are produced. There may be a combination of tensile, shear or compressive stress.

Stress transfer

Normal tooth structure transfers external biting loads through enamel into dentin as compression. The concentrated external loads are distributed over a large internal volume of tooth structure and the localstresses are lower. During this process a small amount of dentin deformation may occur which results in tooth flexure. A restored tooth tends to transfer stress differently than an intact tooth.

Any force on the restoration produces compression, tension, or shear along the tooth restoration interface. Once enamel is no longer continuous, its resistance is much lower. Therefore, most restorations are designed to distribute stresses onto sound dentin, rather than to enamel. The process of stress transfer to dentin becomes more complicated when the amount of remaining dentin is thin and the restoration must bridge a significant distance to seat onto thicker dentin (Liners or bases).

Stress transfer and the resulting deformations of structures are principally governed by:

1. The elastic limit of the materials
2. The ratio of the elastic moduli
3. Thickness of the structures Materials with a high elastic modulus transfer stresses without much strain.

Lower modulus materials undergo dangerous strains where stresses are concentrated, unless there is adequate thickness.

Stress patterns of teeth

Every tooth has its own stress pattern, and every location on a tooth has special stress patterns. Recognizing them is vital prior to designing a restoration without potential failure.

Stress bearing and Stress concentration areas of anterior teeth

The junction between the clinical crown and clinical root bears shear stress, tension on the loading side and compression on the non-loading side, during excursive mandibular movements.

The incisal angles bears tensile and shear stress in normal occlusion. Massive compressive stresses will be present in edge-to-edge occlusion.

The lingual concavity in upper anterior teeth bears compressive stresses during centric occlusion, tensile and shear stresses during protrusive mandibular movements.

The axial angles and lingual marginal ridges bear shear stresses. On the loading side, tensile stresses and on the nonloading side, compressive stresses.

The slopes of the cuspid bear concentrated stresses (3 types), especially if the cuspid is a protector for the occlusion or part of a group function during mandibular excursions.

The distal surface of a cuspid exhibits a unique stress pattern as a result of the anterior component of force concentrating compressive loading at the junction of the anterior and posterior segments of the dental arch and microlateral displacement of the cuspid during excursive movements.

The incisal edges of lower anterior teeth are subjected to compressive stresses. Tensile and shear stresses are present during protrusive mandibular movement.

The incisal ridges of upper anterior teeth will have these same stresses during the mid-protrusive movement of mandible.

Stress bearing and Stress concentration areas of Posterior teeth

Cusp tips on the functional side, bear compressive stresses. Facial or lingual concavity will exhibit compressive stress concentration, especially if it has an opposing cuspal element in static or functional occlusal contact with it.

Marginal and crossing ridges bear tensile and compressive stresses. Axial angles bear tensile and shear stresses on the non- functional side, and compressive and shear stresses on the functional side.

Weak areas of tooth

Weak areas in the tooth should be identified and recognized before any restorative attempt, in order to avoid destructive loading.

I. Bifurcation and trifurcation area.
II. Cementum should be eliminated as a component of a cavity wall. The junction between the cementum of the dentin is always irregular, so the dentin surface should be smoothed flat after cementum removal.
III. Thin dentin bridges in deep cavity preparations.
IV. Cracks or crazing in enamel and/or dentin. Both should be treated passively in any restorative design. They may act as shear lines leading to further spread.

Occlusal considerations in Restoring teeth posterior restorations

Prior to cavity preparation, its opposing occlusal surface should be examined. Malposed opposing supporting cusps and ridges should be recontoured in order to achieve optimal occlusal contacts in the restored tooth.

Use articulating paper to register the centric holding spots and excursive contacts so that these marked areas can either be excluded from the outline form or properly restored. Plunger cusps and over erupted teeth should be reduced, removing all the cuspal interferences so as to improve the plane of occlusion and decrease the chances of fracture of new restoration.

When carving for occlusion, attempt to establish stable centric contacts of cusps with opposing surfaces that are perpendicular to occlusal forces should be made. Occlusal contacts located on a cuspal incline or ridge slope are undesirable because these create a deflective force on the tooth and hence should be adjusted until the resulting contact is stable.

Amalgam Restorations

Prepare floors or planes perpendicular to the direction of Occlusal loading. Inverted truncated cone shaped cavity. Designing the outline form with minimal exposure of the restoration surface to occlusal loading.

Rounded line and point angles are essential to prevent micro movements of restorations, with shear stresses on remaining tooth structures. Sufficient bulk of amalgam is mandatory when restoring a cavity with amalgam so as to withstand the load of occlusion.

Adequate thickness of amalgam should be provided at the marginal ridges in order to support the opposing supporting cusps. Amalgam restorations are carved following the cuspal inclines. In case of large restorations, where there are no cuspal planes to guide carving, the operator should follow a cautious approach:

- Buccal and lingual cusp tips should be placed in lines joining those of adjacent teeth.
- The level of central fossa and the marginal ridge should be carved similar to that of adjacent teeth.
- The bucco-lingual width of the occlusal surface is kept narrower than the original buccolingual width of the tooth.

Cast metal Restorations

Before preparation of any tooth, evaluate the occlusal contacts of the teeth in centric occlusion and in excursive movements. After evaluation, decision can be made if the existing occlusal relationships can be improved with the cast metal restorations. The cuspal interferences are depicted in mandibular working movements, non working movements and protrusive movements.

The opposing occlusal surfaces should be examined and the malpositioned cusps, plunger cusps and over erupted teeth should be recontoured. Premature contacts or cuspal interferences from the teeth opposing the required restoration should be removed.

Composite restoration

For composite restoration, the biomechanical factors include the material properties of composite prior to setting, change in physical properties of thematerials during curing, interaction between the tooth and composite at bonding interface, and the fluid flow through dentinal tubules.

After placement of the composite on the tooth cavity, the composite curing by chemical or photo activation is essentially accompanied with the polymerization shrinkage and increase in viscoelastic modulus. The interactions at the tooth- composite interface shows de-bonding, tooth crack, and cusp deflection caused by the polymerization contraction.

Anterior restorations

The resin composites and the glass ionomer cements are mainly used in anterior restorations. Though these teeth do not come under direct occlusion, they do take part in various movements of the mandible. The restoration should be carved and finished, maintaining the contacts and the cervical curvature of these restorations.

The lingual area is carved to maintain the anatomy of cingulum and the lingual marginal ridges. Patient is asked to protrude and the interferences are checked and removed. Over-contouring, if any, is removed and the gingival extension of the material is taken care of to maintain the periodontal health.

Stress analysis and Design of Dental structures

The mechanical properties of a material used in a dental restoration must be able to withstand the stresses and strains caused by the repetitive forces of mastication. It is necessary to use designs that do not result in stresses or strains that exceed the strength properties of a material under clinical conditions.

A common quantity used to evaluate masticatory function is the maximum voluntary bite force (MVBF) [12]. In most cases, the MVBF corresponds only to the vertical component of the overall bite force. However, the complex kinematic nature of mandibular movement, bite forces occur not only in the vertical direction but also in the transverse directions, particularly in chewing or bruxism.

Therefore, when considering the total force exerted by the mandible, three- dimensional force measurements may ultimately enrich the diagnoses of masticatory pathologies.

Methods to determine bite force12

Experimental methods to measure bite force

- Brittle coatings
- Gnathodynamometers and other mechanical methods
- Strain-gauges and induction
- methods
- Optical techniques
- Piezoelectric sensors

Virtual methods to predict bite force

- Holography
- Photoelasticity
- Finite element analysis
- Digital moire interferometry

Brittle coating analysis (Fig 2)

Brittle stress analysis makes use of a brittle coating also known as brittle lacquer. The brittle coating will fracture in response to the surface strain beneath it. The coating indicates the direction and magnitude of stress within the elastic limit of the base material. Stress coatings provide a graphic picture of the distribution, direction, location, sequence and magnitude of tensile strains.

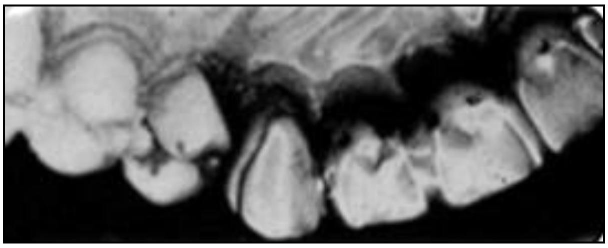

Fig 2: Brittle Coating

Gnathodynamometers

In 1893, Black proposed an approach to measure the bite force using a spring-based device called a gnathodynamometer. This device measured bite force by relating the deformation of a spring with a known stiffness. Alternatively, mechanical techniques such as manometers were also employed, which measure force by fluid displacement.

Strain-gauges (Fig 3)

One of the early electronic devices to measure bite force was reported by Howell and Manly, an instrument that operates on the principle of inductance of a silver foil, under the action of biting, move towards an inductance coil. The use of electronic devices has allowed the reduction in size of force measuring devices.

This has enabled the use of strain gauges implanted in complete dentures or previously restored teeth. The smaller size of the measurement devices has also allowed simultaneous measurement of per tooth force and global biting force through the use of multiple strain gauges attached to a dental bridge.

Fig 3: Strain Gauge

Optical technique- Pressure- sensitive film

Another popular method to measure occlusal contact area and pressure is by means of pressure-sensitive film. These load sensitive membranes are of a sandwiched arrangement, where coloured microcapsules rupture at certain pressure levels and stain an opposing colour developing sheet.

Since the microcapsules are rated to rupture at varying pressure loads (above 30 kg/cm2), the resulting colour map gives an indication of the pressure applied at the film surface.

Recently, Umesh *et al.* [18]. (2016) developed a novel sensor based on a fibre Bragg grated optical fibre. The sensor operates on the principle that an external strain applied to the fibre alters the refraction and reflection of light passing through it (Frensel reflection).

The refraction and reflection can be quantified and related to the strain. The fibre (3mm gauge length) itself is embedded onto a base-plate with a biting pad.

Piezoelectric sensor

Piezoelectric transducers are small in size, and have been used to measure forces in three-dimensions by directly placing the sensor in previously restored teeth. Piezoelectric materials also allow for relatively thin sensors to be developed (≈7.5mm). They can also be fabricated to be flexible and deformable.

Holography (Fig 4)

Holography is a method for recording three-dimensional information on a two-dimensional recording medium (photographic emulsion, thermoplastics, etc)

Unlike a photograph, the hologram contains all the information about the surface of the object. Holography follows a different principle from conventional photography. A laser is needed to produce a coherent, monochromatic light beam.

The difference in phase between a reference ray and the object ray (to be analyzed) produces an interference pattern that is recorded on a high- resolution photographic plate (hologram). When developed and suitably exposed to laser light, this hologram reconstructs a three- dimensional image of the object. Resolution is that of the order of the laser wavelength or that of a photographic film. Basic principles of holography - as tension moves perpendicularly to the fringes, it is possible to evaluate tension distribution within the body of the mandible quantitatively. The higher the number of fringes, the greater the tension transmitted. Qualitative evaluation is achieved by observing the aspect and direction of the fringes.

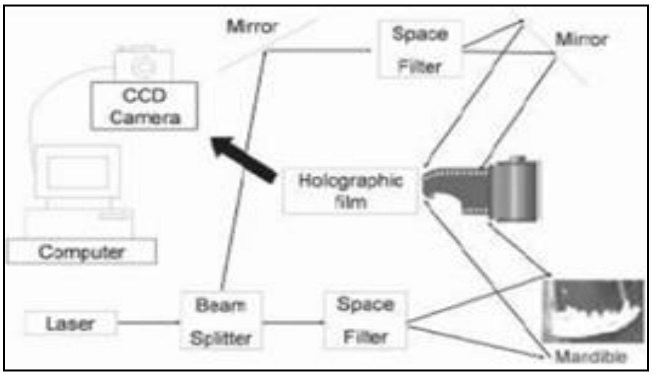

Fig 4: holography

Photo elasticity (Fig 5)

The procedure is to prepare a transparent plastic or other isotropic model of the restoration. This model is usually larger than the actual size. The material becomes axis atropic when stressed, and so the behaviour of light is affected by the direction it takes. As a result of the applied stress, the plastic model exhibits double refraction because of its anisotropic structure.

The light from the source passes through a polarizer, which transmits light waves parallel to the polarizing axis, or plane polarized light. The plane polarized light is converted to circularly polarized light by a first quarter wave plate, and this polarized beam is split into two components travelling along the direction of principal stress in the model. Depending on the state of stress in the model, the two beams travel at different rates. After the light emerges from the model, it passes through a second quarter – wave plate, which is crossed with respect to the first, and an analyzer that is most frequently perpendicular to the polarizer.

The interference pattern may be recorded photographically, which is the isochromatic fringe pattern. These isochromatic fringes, or dark lines, represent locations where the difference in the principal stresses is a constant. Areas in the model where the fringes are close together are under higher stress gradients than areas where there are fewer fringes, and areas containing fringes of higher order are under higher stress than those having fringes of lower order.

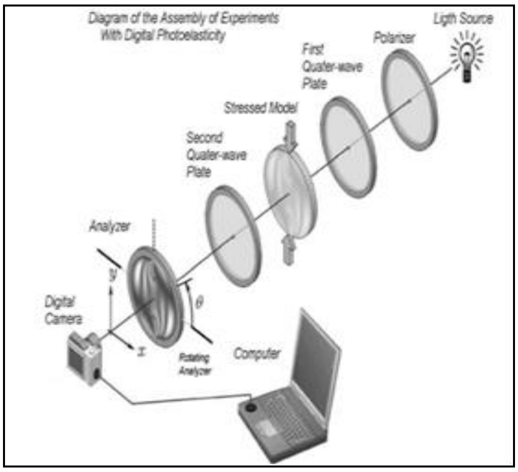

Fig 5: Photo elasticity

Finite element analysis (Fig 6)

The finite element is a newer method than photoelasticity and offers considerable advantages. In this method a finite number of discrete structural elements are interconnected at a finite number of points or nodal points.

These finite elements are formed when the original structure is divided into a number of appropriately shaped sections, with the sections retaining the actual properties of the real materials.

The information needed to calculate the stresses and displacement in the model is

1. The total number of nodal points and elements.
2. A numbering system for identifying each nodal point and element.
3. The elastic modulus and Poisson's ratio for the materials associated with each element.
4. The coordinates of each nodal point
5. The type of boundary constraints
6. The evaluation of the forces applied to the external nodes.

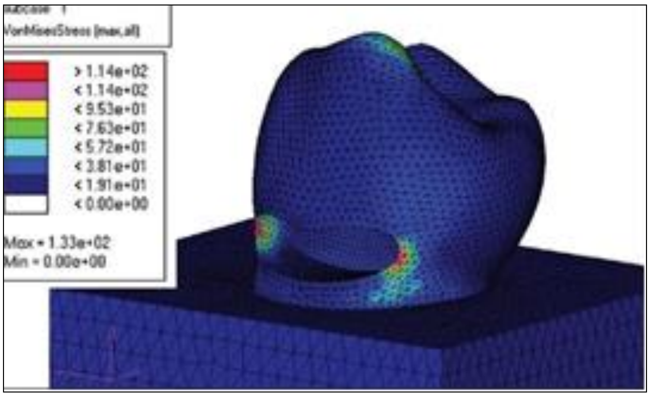

Fig 6: Finite Element Analysis

Digital moire interferometry [5] (Fig 7)

A virtual reference grating was formed by the interference of 2 mutually coherent beams from a diode laser that were incident on the specimen plane at a fixed angle.

Patterns of moire fringes (resulting from interference between the deformed specimen grating and the virtual reference grating), representing residual microstrain distribution, were acquired using a high-resolution charge-coupled camera.

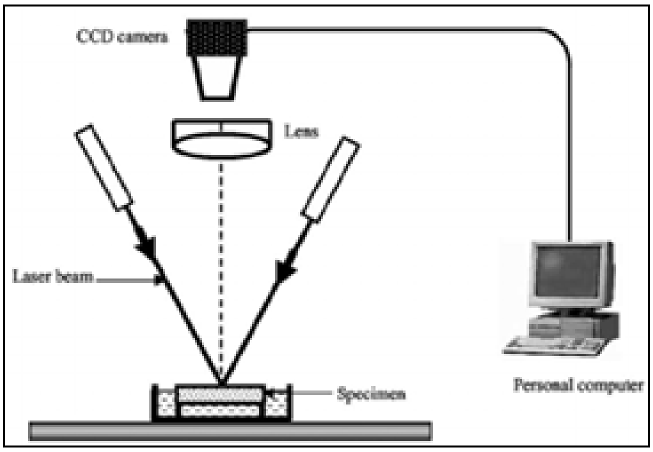

Fig 7: Digital Moiré Interferometry

Conclusion

The relationship between restoration and periodontal health of the teeth is intimate and inseparable and their maintenance constitutes one of the keys for tooth and dental restoration

longevity. An adequate understanding of relationship between periodontal tissues, tooth and restoration is paramount to ensure adequate form, function, aesthetics and comfort of the dentition.
The clinician should have an adequate knowledge about anatomy and the functional aspects of natural dentition so as to reproduce using proper restorative material.

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