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In Vitro Simulation of Axial Cyclic Chewing Loads

Döngüsel Dikey Çiğneme Yüklerinin İn Vitro Simülasyonu

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Abstract

Objective: This study was conducted to characterize time/strain relation in a chewing cycle and use the graphical array of this dynamic data as a reference to design a functional load simulator.

Methods: An experimental implant suprastructure was designed as a transducer. *In vivo* functional strains were recorded on the suprastructure during gum chewing and simulating chewing when no food occluded. A loading device was designed and produced to simulate the time related behaviors of chewing loads. The same experimental suprastructure was then mounted on the implant analogue in the plaster cast and the model was loaded *in vitro* by the loading device. *In vivo* and *in vitro* plots were compared for the simulation criteria.

Results: Time/strain plot obtained from the patient who has implant supported crown described both an impact and a stationary effect when no food was chewed. There was no sign of impaction during gum chewing.

Conclusion: The time/strain relation plots acquired from the patient and the experimental model were analog.

Keywords: Dental implants, biomechanics, strain gauge, functional loading, chewing pattern

Özet

Amaç: *Bu çalışma ağız içerisinde bir çiğneme siklusundaki zaman/gerilme ilişkisinin karakterize edilmesi ve buradan elde edilen verilerin fonksiyonel bir yük simülatörünün yapılması için referans olarak kullanılmasını hedeflemektedir.*

Yöntem: *Deneysel olarak hasta ağzında kullanılacak implant üst yapısının bir dönüştürücü olarak görev yapması sağlanmış ve çiğneme sırasında yapıda oluşan gerilimler in vivo olarak kaydedildi. Elde edilen veriler bir veri toplama modülü sayesinde işlenerek edildi ve grafik haline getirildi. Yükleme ünitesi çiğneme yükünün zamana bağlı ilişkisini yansıtacak şekilde yapıldı. Aynı implant üst yapısı alçı modeldeki implant analoğu üzerine yerleştirilerek in vitro olarak yüklendi. İn vivo ve İn vitro grafik verileri daha sonra simülasyonun kontrolü için karşılaştırıldı.*

Bulgular: *Ağız içerisinde gıda olmadığında elde edilen verilerde ilk çarpma (impact) anı ve ardından statik bir alan izlendi. Sakız çiğneme sırasında çarpma (impaction) şeklinde bir veri elde edilmedi.*

Sonuç: *Sonuç olarak hastadan alınan in vivo veriler ve aynı örnek üzerinden alınan in vitro veriler karşılaştırıldığında fonksiyonel yük simülatörünün yaptığı simülasyonun karşılaştırılabilir olduğu görüldü.*

Anahtar sözcükler: *Dental implantlar, biyomekanik, gerilme ölçer, fonksiyonel yükleme, çiğneme modeli*

Introduction

The biomechanics of implant-bone interface and bone around dental implants has been the major concern on the survival of implants. It has been stated that *in vivo* studies[1-3] designed to understand the biomechanical behavior of the implant-bone interface and bone around implants do not prove, but support the etiology of overload failure.[4] Although basic researches on loading of implants through experimental, analytic or computer-based studies have been implemented, it has been claimed that none of the biomechanical models had been validated in view of *in vivo* data.[4]

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In addition, nominal strain in bones as a result of static loading calculated using existing models in the literature might severely underestimate actual strains occurring at micro structural level.[5] Such a discrepancy at micro structural level is so far unpredictable either under functional loads due to their undefined energy absorption rate within duration of milliseconds. Load functions are dynamic and applied through duration of contact. The mechanical behavior of hard tissues and implant-bone interface vary by cyclic loading. Thus, the components of biomechanical system may perform a time dependent stress distribution and the materials would behave differently due to the altering rate of energy transferred.

Up to date, various masticatory simulators have been developed to imitate *in vivo* conditions.[6-9] Although, most of them are effective in simulating clinical conditions, their major disadvantage is that they can only imitate different magnitude and cycle conditions in order to evaluate the fatigue characteristics of dental materials[10,11] and implant components[12,13] without time-dependent factors.

In order to define the effects of dynamic characteristics of functional loading on a model or specimen, the applied loads should simulate not only the magnitude but the duration of contact within a cycle period also. Experimental stress analysis for time-dependent parameters, however, is a challenge of carrying *in vivo* loading conditions into laboratory and recording altering stresses in real time. While the recording media can be provided in systems for engineering applications, the simulation of functional loads both in magnitude and its time-dependent behavior has not been introduced.

This study was conducted to design and develop a functional loading device that simulates axial cyclic chewing loads with their time dependent characteristics including duration of contact and whole cycle duration.

Materials and Methods

A cyclic loading pattern was obtained from a patient to be used as a reference in designing the loading device. The duration of contact and the cycle duration were accepted as time related properties for a functional load and were determined *in vivo* by means of strain on an experimental implant suprastructure using the following method. The loading device was designed to imitate the time-strain relation.

The stress-time characterization during functional loading

To characterize the load time relation during a chewing cycle, stresses on an experimental implant suprastructure were analyzed *in vivo*. A 28-year old male patient in good general health and who needed a single implant supported fixed partial denture was analyzed in the study. The patient had full dentition except for maxillary left first premolar and third molars. He had no history of orthodontic therapy, any restorations, good periodontal health, stabilized canine guidance occlusion and he was free of premature contacts. The *in vivo* experimental procedure was approved by the ethical board of Faculty of Dentistry, Çukurova University, Adana, Turkey and an informed consent had been obtained from the patient before an implant (D3.8 mm / L13 mm) (Frialit II, Friadent GmbH, Germany) was placed at site of missing 24.

An experimental implant suprastructure that was produced from implant abutment (Frialit-2 MH6 Abutment, Friadent Gmbh, Germany) was designed as a transducer. A strain gauge, (EA-06-031F-120 Measurements Group Inc. Raleigh, NC, USA) capable of dynamic measurements, was bonded at the prepared facial surface of the abutment with self-cured adhesive (M-Bond Adhesive, M-Line Accessories, Measurements Group, Inc., Raleigh, NC, USA) and isolated with polyurethane coating (M-Coat-A Air Drying Polyurethane Coating, M-Line Accessories, Measurements Group, Inc., Raleigh, NC, USA). A partial crown was built to provide simultaneous occlusal contacts (Figure 1a). Below the cervical finish line of partial crown a slot was prepared at lingual surface of the suprastructure to amplify the deformation at the strain gauge surface (Figure 1b).

A data acquisition module (ESAM II, Vishay Intruments, Raleigh, NC, USA) was used to measure and record the dynamic changes in strain data. The recorded data was processed and prepared for graphical analysis by the software of the module.

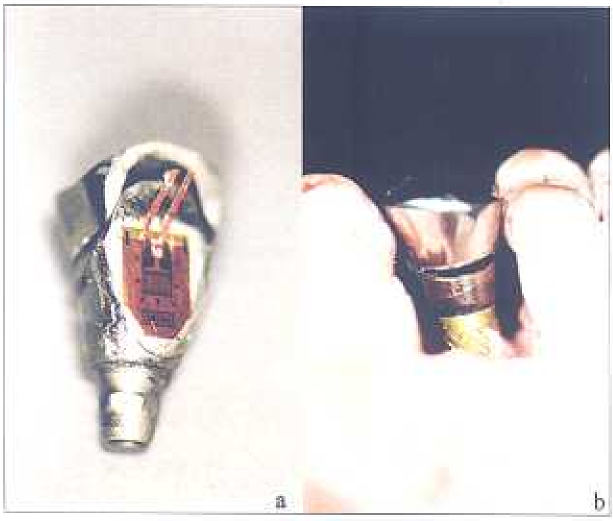
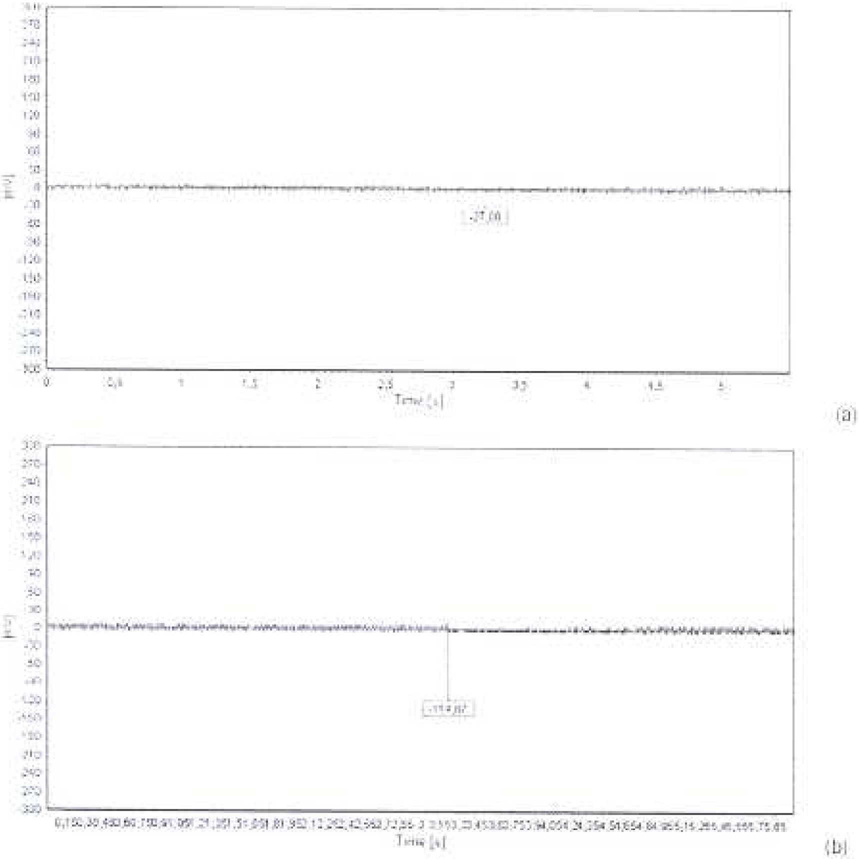


Figure 1. Experimental suprastructure; buccal (a) and lingual (b) aspects.

Impact experiment

Before *in vivo* recordings an impact experiment was performed to define the pertinent rate of data that could perceive strains as an impact effect at the initiation of tooth contact. The experimental suprastructure was screwed onto the implant analogue in the plaster model and the model was mounted on the impact loader. A stainless steel sphere rolled on an inclined plane onto the model and loaded the lingual cusp of the suprastructure. The strain measurements were performed during the impact loading. A higher rate of data was used in acquisition at each consequent impaction trial. The impact effect was evident at 500 data/sec and the magnitude of strain value increased at higher rates. The magnitude of strain values remained unchanged at the rate of 2000 data/sec and higher. Thus, 2000 data/sec was accepted as the data threshold per second to capture the impact effect for the acquisition system (Graphic 1).

After the impact experiment, the suprastructure was placed on the implant and a single contact was provided at lingual cusp tip (Figure 2). Polyurethane



Graphic 1. Impact experiment results. (a) 800 data/sec, (b) 2000 data/sec

liner was used to isolate the gauge and the wire in oral environment. The patient was then requested to try his axial chewing pattern; first without and then with a chewing gum (Figure 2). The cyclic alteration in strain data at the surface of the abutment was recorded. The time between initiation of contact and first peak, the duration of contact, the cycle duration and the strain time relation during the whole cycle were determined by the digitized active cursors on the plot and served as simulation criteria.

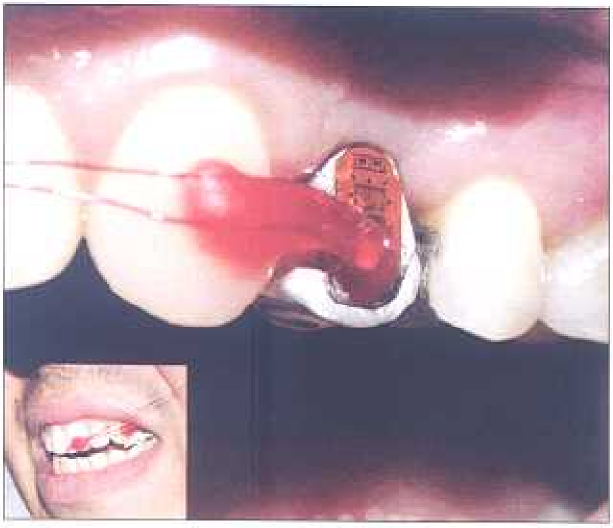


Figure 2. The solo contact at palatal cusp of partial crown provided the bending of strain gauge surface on the suprastructure. Intraoral position of experimental suprastructure during gum chewing.

Functional load simulator

A loading device was designed to simulate axial functional loads with their time-related characteristics as defined *in vivo*. The simulator was capable of applying axial forces up to 500N and contact durations of 0-250 msec in any predetermined chewing cycle period at a number of cycles up to 10^6.

The device had a mechanical part and a programmable control unit (PLC) (PWI Esit Elektronik, Istanbul) (Figure 3). The control unit had the function of setting force, duration of contact and release, chewing cycle period and number of cycles.

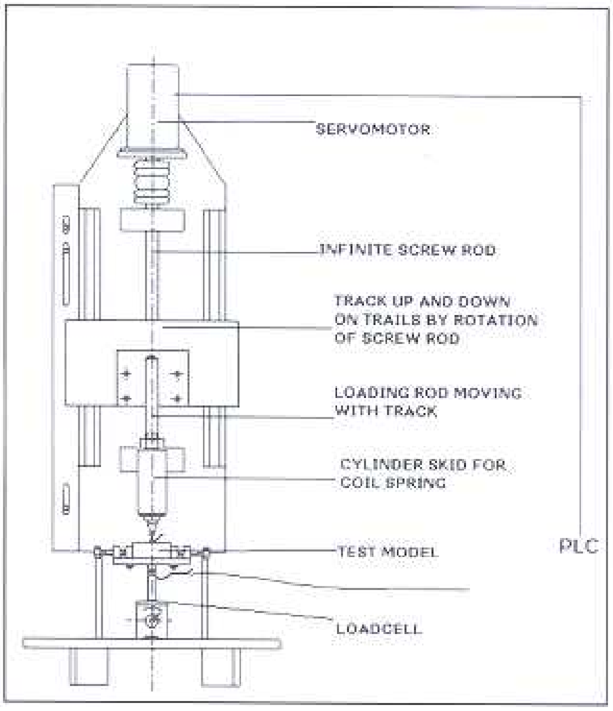


Figure 3. Schematic representation of Functional Load Simulator.

The PLC controlled a servomotor (Indramat Mini Drive; Mannesmann Rexroth, Stuttgart, Germany). The rotation of the axially-oriented infinite rod screw by servomotor has provided the movement of a track, which slid over a stainless steel pair of rails (Mannesmann Rexroth, Stuttgart Germany). Track was carrying an axially oriented load transmission rod with a cylinder attached to its end. The cylinder hosted a coil spring (DIN 17221 C, Rigidity factor; 23.684) with a loader tip screwed at its terminal. It also provided an axial guide for spring-loader-tip unit.

A mangle, which was supported by a magnet base, was designed to mount the models or specimens to be tested. The test model was positioned and stabilized under the loading stylus by this support. Between the mangle and the magnet base a load cell (9363 Universal Load Cell, Revere Transducers Inc; California, USA) was used to access the feedback data to control the unit and perform the loading conditions.

The experimental suprastructure was then placed onto the implant analogue in the plaster model again and the model was mounted on the stabilizer unit of the functional load simulator (Figure 4). The loading device was set to simulate the characteristics of the cyclic loads determined in the patient in cycle duration and duration of contact. The same data acquisition system and rate of data was used both in *in vivo* and *in vitro* recordings.

Figure 4. Functional load simulator and test model support with a load cell to gain feedback data to PLC.

Results

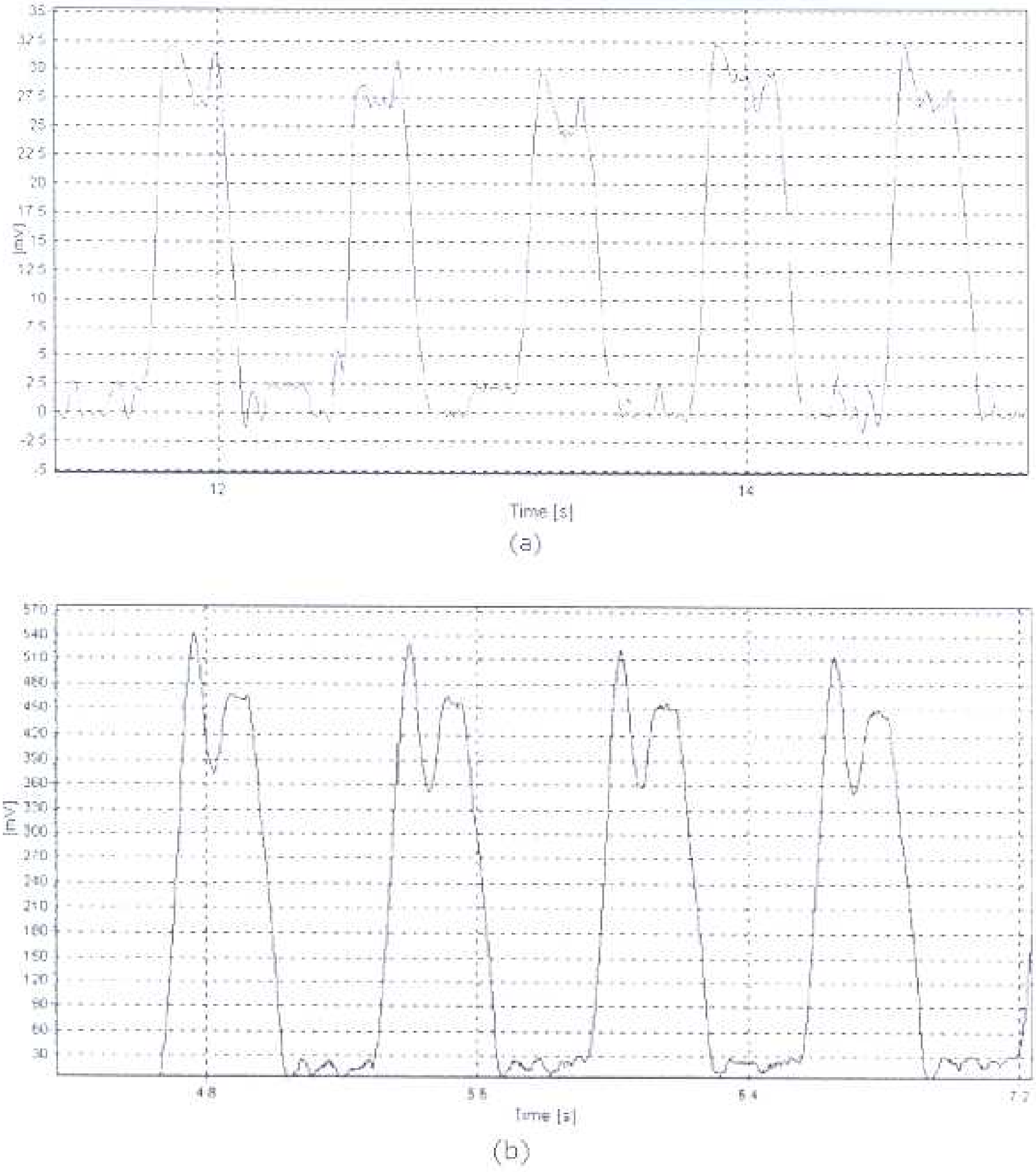
The time/strain relation obtained from the patient when no food occluded was compared to the plot acquired from the *in vitro* recording (Graphic 2). The movement characteristic was found as typically cyclic. Through *in vivo* plot for 10 cycles, the ranges were found was 650-750 msec for cycle duration; 240-310 msec for duration of contact and 100-110 msec for the time between the initiation of contact and the first peak. The loading conditions at the loading device were set to range values of 650 msec for cycle duration, 250 msec for duration of contact and 100 msec for time between the initiation of contact and the first peak. All of the time-related conditions described to the device were absolutely obtained through the *in vitro* strain time plots. The strain/time relation acquired from the patient and the experimental model was analogous.

Analysis of time-dependent strain values from intraoral recordings revealed an impact effect at the initial moment of contact and a stationary effect when the impact effect was over in case of no food is occluded (Graphic 2). The impact phase duration in the impact experiment was momentary (t<1 msec) (Graphic 3). When the experimental suprastructure was loaded *in vivo*, it was approximately 60 msec. The impact effect was not observed when a chewing gum was chewed and peak stresses were reached gradually (Graphic 4).

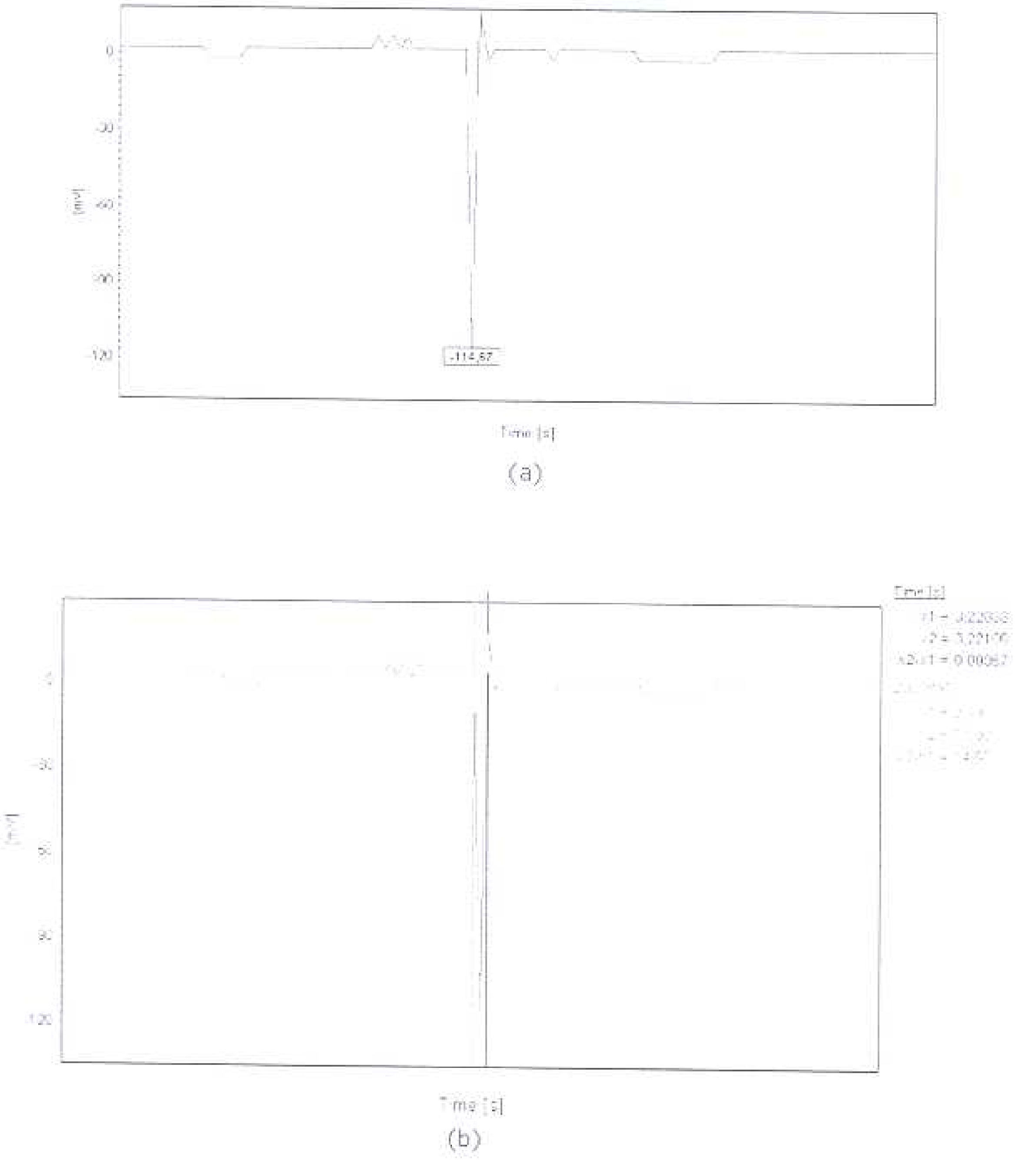
Discussion

The aim of this study was to develop a loading device which imitates the cyclic time/load pattern of axial functional loads. A method has been described in order to determine the real force-time relation functionally. The changes in strains during loading were directly recorded with a high rate of data acquisition through a test suprastructure on a single implant that was modified to a transducer. A real time-strain relation was captured as the suprastructure had simultaneous and homogenous contact at intercuspal position and physiologic muscle length.

Time-strain relation was determined first during gum chewing and than during chewing simulation without food. It certainly should be accepted that chewing pattern for food chewing would differ from either of the above cases. As a requirement of an agreement on the existence of impact forces at least after a hard food is broken,[5] this study aimed to reveal and simulate any type of force that can occur during occlusion. Thus, the dynamic strain measurements were performed both during gum chewing and during simulation of chewing which were consequently presumed to be the least and the highest possibility of impaction.



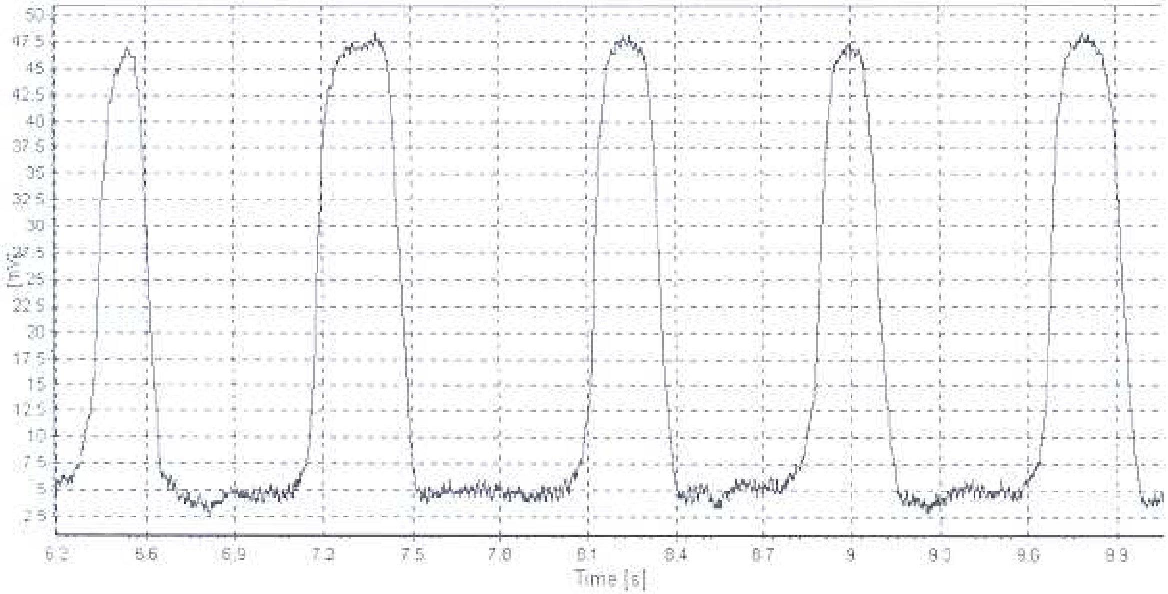
Graphic 2. (a) -Time-strain relation recorded *in vivo* - when patient simulating chewing; no food occluded. (b) Strain-time relation recorded *in vitro* - when the superstructure was loaded by functional loading device.



(a)

(b)

Graphic 3. The magnitude (a) and duration of impaction (t<1msec) (b) during impact experiment.



Graphic 4. Time-strain relation recorded *in vivo*- during gum chewing; no impact forces occurred.

The impact effect perceived on the same suprastructure at impact experiment was different from the effect at the initial suprastructure-tooth contact. When the experimental suprastructure was on the plaster model as a solid support, a momentary increase in strain was observed at the impact experiment. However, when the same suprastructure was loaded *in vivo* during the chewing simulation, initial implant-tooth contact provided an increase in strains within a period. The duration of this impaction phase was about 60 msec. This difference can be attributed to the stress absorbent behavior of either the bone around dental implants or the periodontal tissue of opponent natural tooth. The impact phase at the strain-time plot during *in vivo* loading when no food was occluded may be accepted as impaction absorbed to an extent. On the other hand, there was no evidence of impaction during gum chewing in our study.

When *in vivo* and *in vitro* (Graphic 2) experimental strain-time relation is compared, they can be considered analogous. As a result, it should be accepted that the experimental apparatus has successfully simulated the dynamic behavior of the force pattern and can be used for functional stress analysis. The rate of increase in strains starting at the initiation of contact, chewing cycle period and duration of contact has been successfully duplicated. The strains were not converted into force magnitudes, as it was not the scope of the present study. However, the device was designed to apply any magnitude of force in any predetermined cycle characteristics.

Any examined system might have different reactions to loads in different characters in terms of stress distribution. Since simulated models may not be sufficient to observe the realistic behavior of materials at static loads,[14] they neither might be sufficient to observe at functional loads. The difference in mechanical behavior of bone around dental implants due to either static or functional loads has not been defined in evidence.

Further research should be advanced to understand the time-dependent mechanical behavior of hard tissues and its effects on stress distribution under cyclic loads. By means of applying functional loads onto biomechanical models or specimens that host an osseointegrated dental implant, the stress absorption capabilities of tissues and materials can be studied. That study plan inevitably would require a device that simulates functional loading including the time-dependent parameters. Although these time-dependent factors could be imitated in our study model, further research is needed to improve such a simulator which will be developed with the data from a larger study population.

Conclusions

The aim of this study was to develop a functional load simulator which could be used to evaluate the behaviour of materials and bone under time- and force-dependent factors. Although the data from only one patient who chewed only one kind of food was evaluated in this study, this simulator was able to imitate functional loading with their time-dependent characteristics during chewing. The results of the study showed that the time-strain relation plots acquired from the patient and the experimental model was analogous. Therefore, this functional load simulator can be used in larger study populations to simulate different load-time relationships.

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Kaynaklar

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