The use of mastication simulator in *in vitro* comparative studies in dental implant prosthetics

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Abstract

In recent years, implant supported dentures have been widely used for missing teeth replacement. Such dentures are becoming increasingly popular with the patients. However, despite the fact that commonly conducted clinical and laboratory tests allow for the evaluation of wear changes in implant-crown assemblies, their results are difficult to compare. The in vitro research methods applied to date are characterised by a considerable diversity of simulation models of conditions occurring in the human oral cavity. Clearly, there exists the need to devise a test stand which would ensure the replication of research results. In order to carry out a comparative in vitro analysis of implant-abutment-crown assembly wear process, a specially designed mastication simulator was used.

Key words:

implant supported dentures, mastication simulator, fatigue tests

The device simulates long-lasting, cyclically changeable mechanical loads similar to those in the oral cavity. The aim of the project was to assess the usefulness of mastication simulator in research on implant systems. X-ray microtomography was employed to evaluate the wear of the specimens used. Research methods implemented by the authors of this paper have been shown to be effective in examining some causes of implant treatment failure

Introduction

For many decades, tooth-supported crowns and bridges were considered a golden standard in prosthodontics. Where large sections of teeth were lost, the patients were offered skeletal or acrylic partial removable dentures. Throughout this period tooth-supported prostheses underwent a lot of in vitro tests and clinical observations.

More recently, implant supported dentures have been commonly used to replace missing teeth. Thanks to endosseous implants the number of indications for removable dentures has decreased, whereas fixed dentures have become more popular. Various types of endosseous implants and connections with different prosthetic restorations may be used. Such variety poses potential problems with choosing the most appropriate treatment option for the patient.

There are very few papers offering test results pertaining to the development of changes in implant supported crown assemblies [1–13]. Such works provide detailed descriptions of the influence of mastication forces on various aspects of implant-abutment-crown-bone of the alveolar process assembly. However, the results of the published research are difficult to compare as there exist considerable differences in the adopted methodology. Consequently, it is of vital importance to devise a test stand which would accurately imitate the conditions of the oral cavity and thus ensure the reproducibility of test results [17]. A stand designed in such a way would make it possible to compare various implant systems, implant-crown assemblies as well as materials used to make dental crowns.

The paper presents the adaptation and implementation of a specially devised mastication simulator which allows for subjecting dental implants to reproducible cyclical mechanical loads in conditions similar to those naturally occurring in the oral cavity. The mastication simulator was used to carry out a comparative study on the influence of mastication forces on both the shape of the implant supported dentures and the quality of implant-abutment-crown assembly.

Aim

The paper is aimed at the assessment of the usefulness of the laboratory mastication simulator combined with X-ray microtomography for conducting tests on dental implant systems.

Material and method

The mastication forces simulation stand

The stand is composed of a device which submits dental implant specimens to cyclical mechanical loads, simulating forces of mastication. It is characterised by the following features [15,16]:

- two specimens are pressed down in vertical direction, with assigned force independent of the location,
- the lower specimen performs movements in a horizontal plane; the movements imitate those of the mandible in the oral cavity
- the specimens are elastically fixed,
- the specimens are placed in wet environment.

Mastication simulator is composed of the pneumatic mechanism which applies pressure and a two-axis plotter. Such structural solution guarantees the small inertia of mobile components as well as the complete freedom to select the force and trajectory of motion. The diagram of mastication simulator is presented in Figure 1. The work of the device is controlled by a personal computer equipped with a special steering card. The computer software allows for entering individual courses of chewing cycles. Both the speed of correlated shifts of the specimens and pressure force in vertical direction can be regulated. The trajectory of motion of the lower specimen can be randomly generated in a horizontal plane. Each simulated cycle of mastication consists of the act of dropping the upper specimen onto the lower one, pressuring it down with a fixed force, the performance of motion by the lower specimen according to the preprogrammed trajectory and lifting of the upper specimen.

The view of mastication simulator is presented in Figure 2.

The object of the test and preparation of specimens

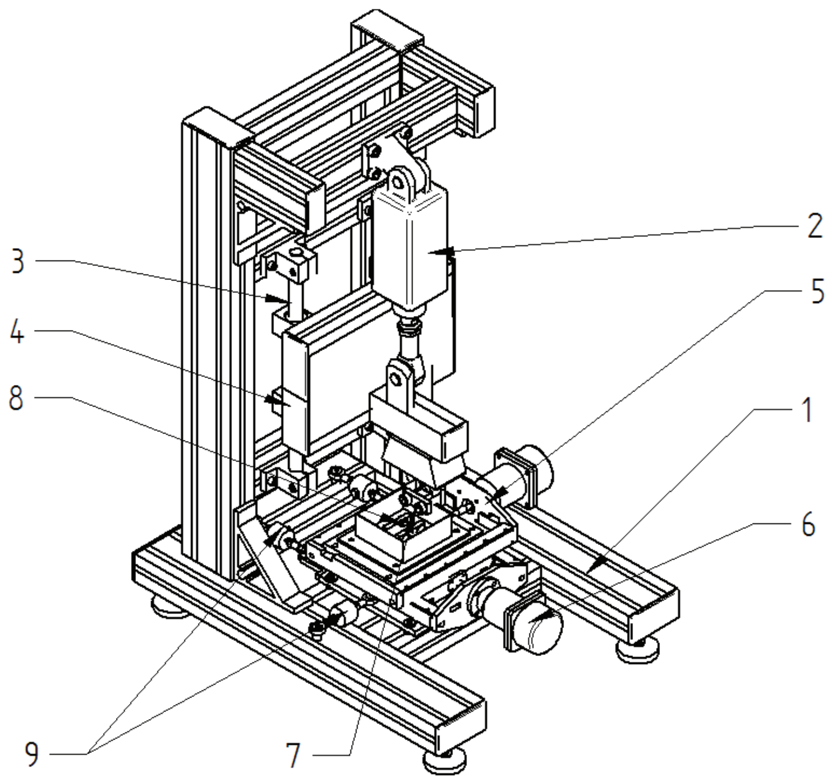
The test was conducted on a screw type dental implant comprising a fixture, an abutment and a crown (Fig. 3). A screw-like dental implant was put in epoxy resin to allow for an easy placement of an entire specimen in the simulator. An abutment was then screwed to the fixture and the crown was bonded with the abutment with cement. The crown used in the test was made of polymethyl methacrylate (PMMA).

After the specimens had been placed in the simulator, their central contact point was determined and the trajectory of motion was established with respect to this point. The trajectory was described by the coordinates of eight specific points on the plane so as to obtain a curve similar to the one in Bates cycle [14]. Then the value of force in vertical direction was set.

Fatigue test on the simulator

In the presented test cycle, the force in vertical direction was determined as equaling 400 N, whereas the range of mutual dislocations of the specimens amounted to 1.16 mm. Such a configuration of the loads of the simulator guarantees obtaining maximal resultant of shearing forces at the level of 50 N. Figure 4 presents the distribution of shearing forces during the tests in the simulator and their relation to the programmed trajectory. In spite of the fact that

Fig. 1.
The diagram of mastication simulator: 1-body, 2-pneumatic motor operator, 3-guides, 4-linear bearings, 5-plotter, 6-stepper engine, 7-upper specimen, 8-lower specimen, 9-set of measurement tensometers



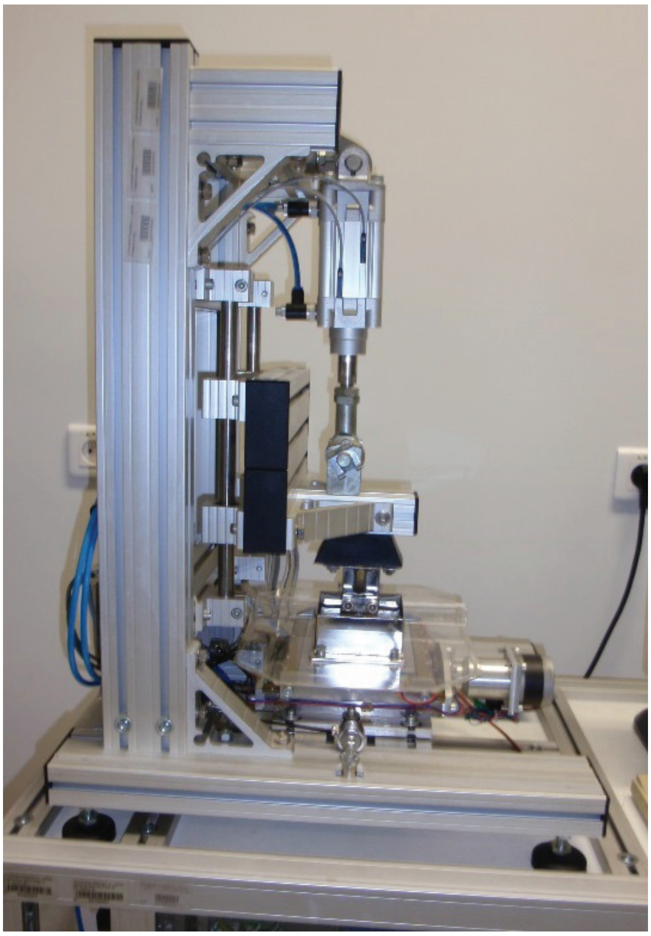


Fig. 2.
The view of mastication simulator

the trajectory of mutual dislocations of teeth is similar, there occurs a markedly different distribution of forces, and consequently, a different system of stresses in the tested specimens. The test cycle can be programmed in such a way that it consists of any number of mechanical loads cycles. The typical test cycle of one pair of specimens consists of 100 000 mechanical loads cycles, which corresponds to a five-year period of implant use [20]. After finishing the test cycle realization, the damages to the internal structure of the implant were analyzed.

Microtomographic test

On completion of the series of cyclical mechanical loads the implant specimens were analysed with the use of X-ray microtomograph General Electrics Phoenix V/Tome/xs. The machine allows for obtaining the detailed geometric structure of specimen sections (2D) and for using them as a basis for compiling a spatial image (3D). The aforementioned microtomograph can be used to analyse details measuring 260 x 420 mm in resolution equal to (voxel): 2÷4 [μm]. Measurements made in study were characterized by a resolution of 13 voxels. Tomographic imaging contains information on the location and density of absorption agents in an object. This allows for the detection of inner flaws, stratifications and inclusions and for taking measurements of the geometric elements of monitored components. Such data provide a solid basis for the assessment of the implant-abutment-crown assembly wear and fatigue changes.

Test results

Selected 2D images of the analysed specimens are presented in Figures 5a, 5b, 6a, 6b. Figures 5a and 6a show front view and right side view sections of the assembly respectively before it has undergone the fatigue test, whereas figures 5b and 6b show the same sections after the specimens have undergone 100000 load cycles in the mastication simulator. The measurements taken before and after the fatigue test are collated in Table 1.

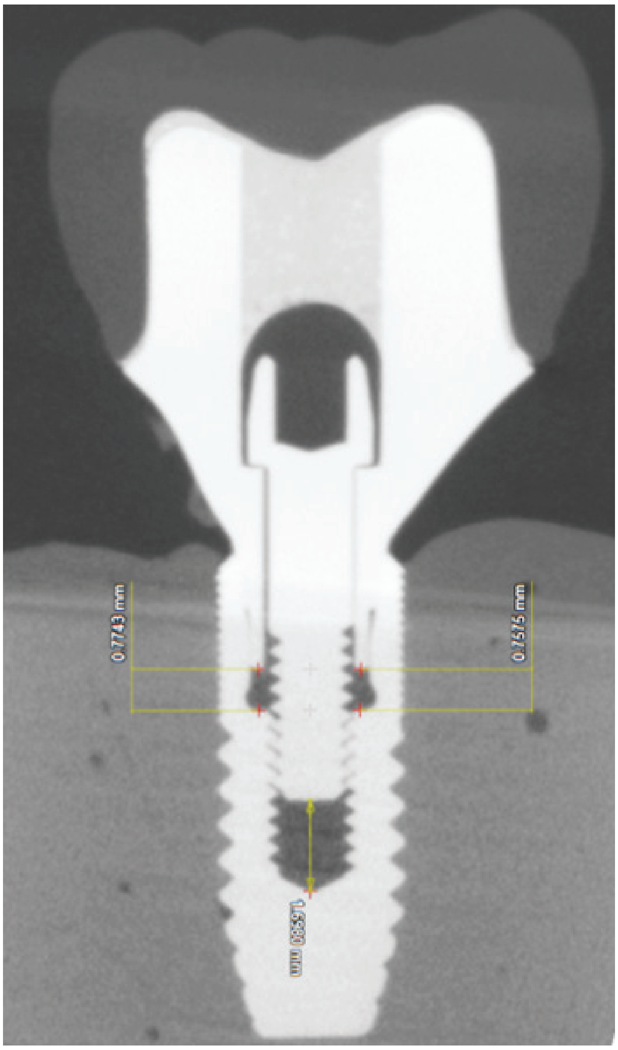


Fig. 3.
The diagram of an implant specimen fixed in the resin before its placement in the simulator, 1-screw--like fixture, 2-epoxy resin, 3-abutment, 4-abutment screw, 5-crown, 6-composite resin

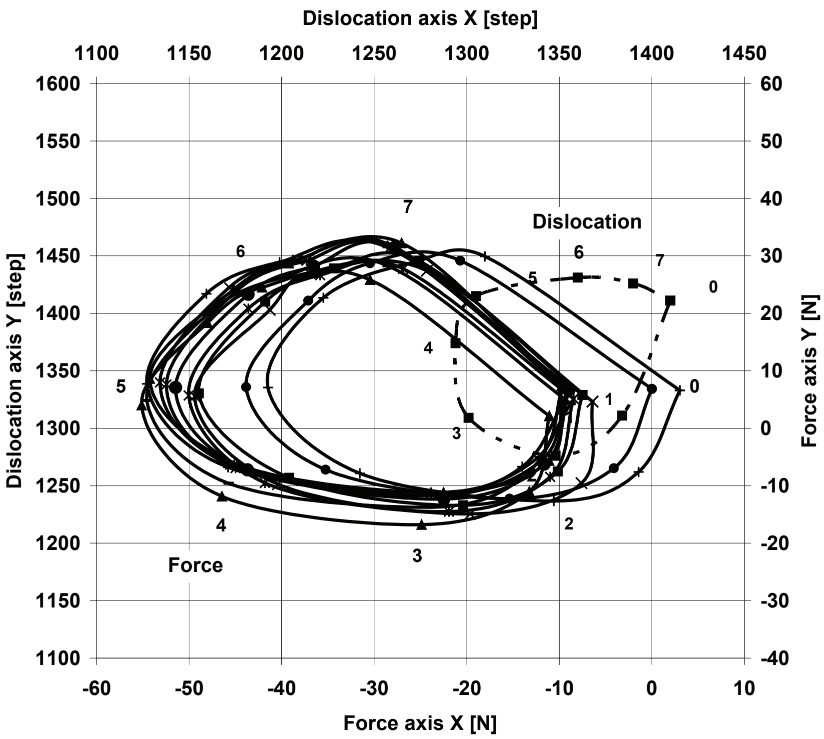


Fig. 4.
The trajectory of motion (intermittent line) and distribution of forces (solid line) for the two separate pairs of cooperating specimens. The foregoing curves represent the distributions of forces measured at different stages of advance in the cycle of fatigue tests

Fig. 5.
The results of microtomographic examination, front view: a) before the fatigue test, b) after the fatigue test; x1 and x2 - the distance between the abutment edge and the implant on both sides; x3 – the distance between the abutment screw and the implant

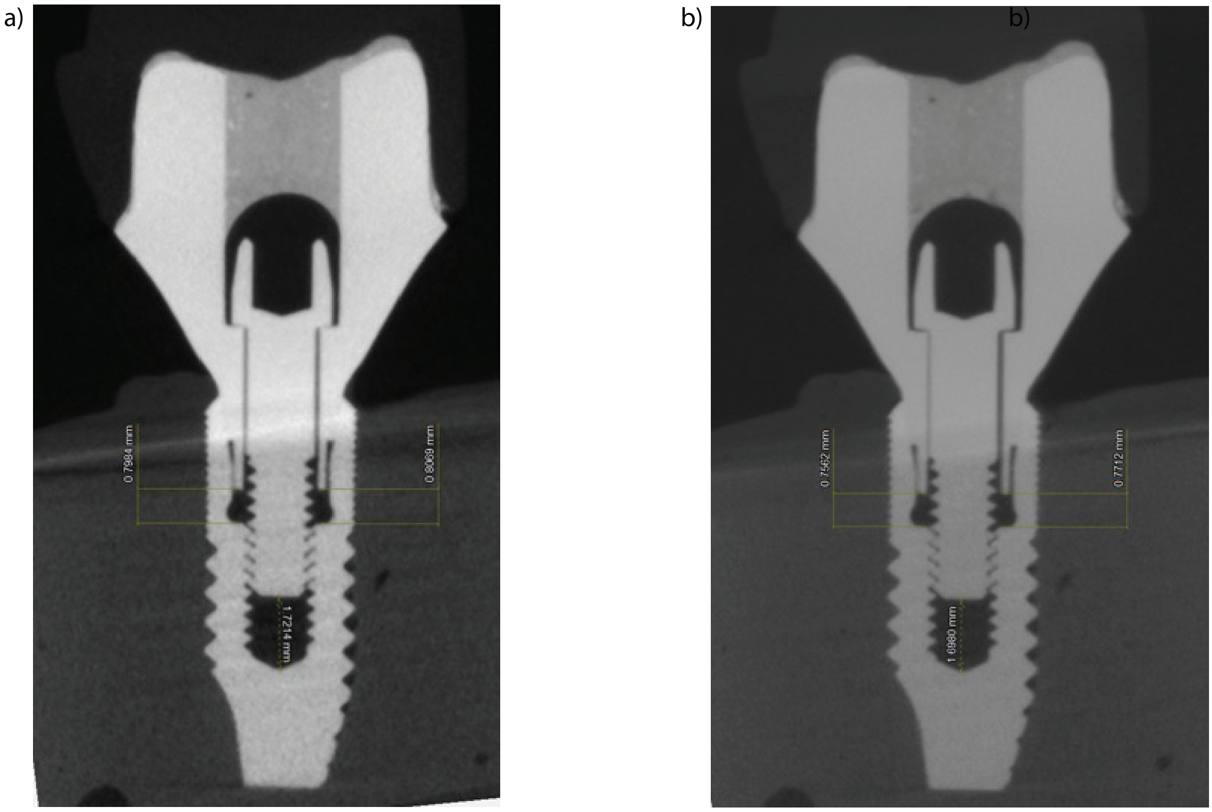


Fig. 6.
The results of microtomographic examination, right side view: a) before the fatigue test, b) after the fatigue test; x1 and x2 - the distance between the abutment edge and the implant on both sides; x3 – the distance between the abutment screw and the implant

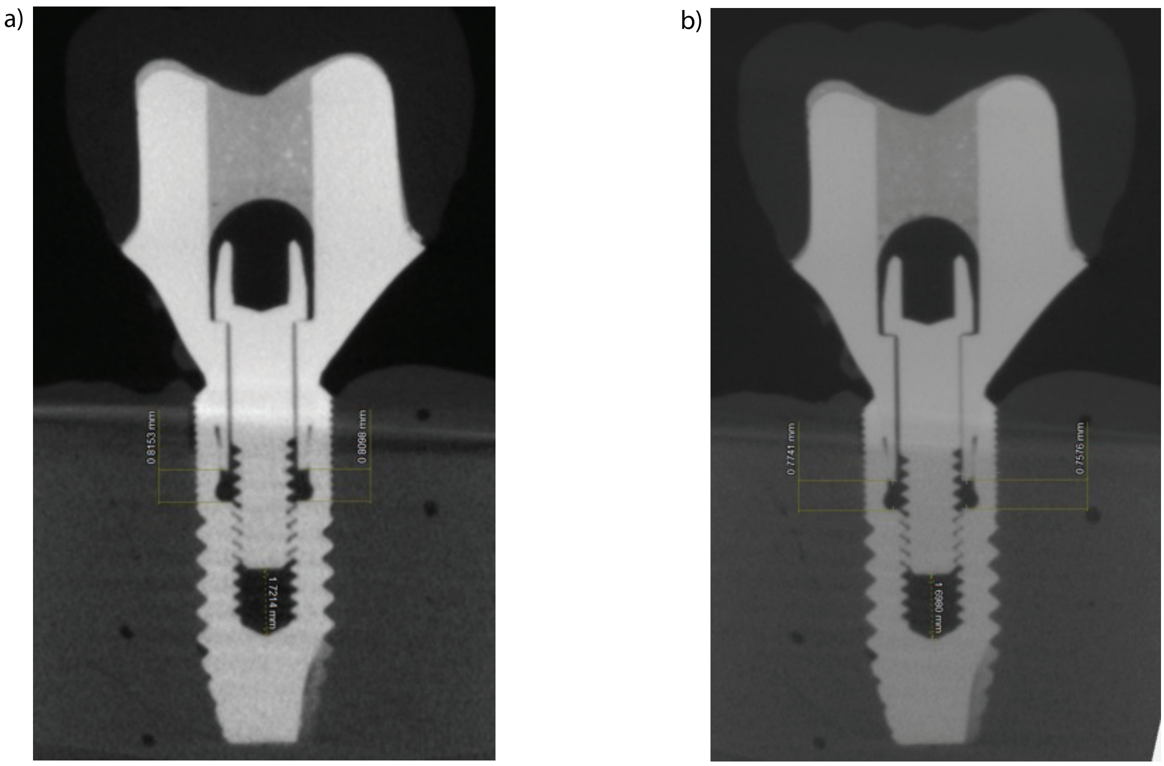


Table 1.
The measurements taken before and after the fatigue test. F – front view; R – right side view

	F			R		
	x1	x2	x3	x1	x2	x3
Before the test	0,7984 mm	0,8069 mm	1,7214 mm	0,8153 mm	0,8098 mm	1,7214 mm
After 50 000 cycles	0,7562 mm	0,7712 mm	1,698 mm	0,7741 mm	0,7576 mm	1,6980 mm
The difference	0,042 mm	0,036 mm	0,023 mm	0,041 mm	0,052 mm	0,023 mm

Discussion

It is important to note, that after the fatigue test in the simulator has been completed, the distances between the head of the abutment and the bottom of the fixture as well as the distances between the lower edge of abutment screw and the stop edge of the fixture have considerably shortened. Two probable causes of these changes are the deformation of the thread connection between the abutment and the fixture as well as the deformation of the contact point between the crown collar and the fixture. The long-lasting, cyclical, mechanical loads to which the implant was subjected in the mastication simulator also caused the deformation of the lateral fissure between the abutment screw and the walls of the mounting hole in the implant. As a result, the fissure lost its centricity. It is possible to observe these alterations in the implant specimen cross section. In figures 5a and 6a, which show the implant before it was subjected to the fatigue test, the dimensions of the lateral fissure on the right and left sides of the abutment screw are comparable with respect to width, whereas in figures 5b and 6b, which show the implant after it was subjected to the fatigue test, the width of the fissure on the right and left sides of the abutment screw is markedly different. This difference is indicative of the loss of centricity between the implant and the abutment screw.

Conclusion

The in vitro method presented in this paper employs both the mastication simulator and X-ray microtomograph. This allows for obtaining comparable test results which show damage to dental implant-abutment-dental crown assembly after it has undergone a specified number of load cycles. The same method may also prove useful in laboratory assessment of the tightness of selected prosthetic connections such as tooth-crown connection, tooth-inlay connection, and tooth-post and core connection.

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