APPLICATION OF ADVANCED PRODUCTION METROLOGY FOR QUALITY IMPROVEMENTS IN BIOMEDICAL ENGINEERING - ANALYSIS AND EVALUATION OF SURFACE STRUCTURES OF DENTAL IMPLANTS

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Abstract – Rapid development in biomedical engineering demands the application of modern computerized measurement techniques and utilization of measuring devices with new technologies. Computer aided co-ordinate measuring technique can be particularly applied to evaluate the shape of non-technical structures with high accuracy. Measurement results create the basis for the improvement and optimization of future work in biomedical techniques and related areas.

There are numerous important characteristics that describe the implant quality required for a successful implant. Besides defining the macroscopic structure like material and shape, an implant should reach defined microscopic structure such as the chemical, physical, mechanical, and topographic characteristics of the implant surface. These different characteristics describe the effect activity of the attached cells that are in close proximity to the medical implant surface.

By using initially developed advanced measurement techniques for engineering applications, the clinicians could be able to characterize biomedical surfaces to assist in their maintenance, modification, optimisation and trauma repair. With development of robust measurement tools of sophisticated production metrology and best practice protocols it will be possible to quantify the appropriate metrology so that it will be possible to improve the medical product and process quality and to provide assurance feedback to the clinicians to assure good practice, functional achievement and long service life of the restoration, implantation object.

Keywords: dental implant, co-ordinate metrology, surface measurement

1. INTRODUCTION

There exists rapid development in biomedical engineering and this demands the application of modern sophisticated measurement technique and measuring devices. Especially computer aided co-ordinate measuring technique and 3D digitizing systems can be applied to evaluate the shape of non-technical structures with high accuracy. The results of such measurements give for example the basis for the improvement and optimization of future work in biomedical engineering.

Increasing demand for quality and reliability on the one hand and competition with cost consciousness on the other hand are contradictory requirements in today's production engineering. This issue must be also considered from the point of view of international standards dealing with quality management and quality assurance [1, 2].

In this study, the advanced measurement and evaluation of non-technical structures have been described and the measurements have been compared using a contact-stylus profilometer, a digital microscope, a white light 3D scanning system and a medical CAD/CAM device. The qualitative results of the measurements were used to characterize the roughness levels of the surfaces that describe the effect activity of the medical implants.

The current study demonstrates the analysis and evaluation of dental implants to enable the quality characteristics required by the clinical experience. The cooperation research was processed based on the invention of a dental plant. According to the invention, the geometry of the dental implant was modelled by computer aided systems e.g. computer topography, laser scanning, micro observation and analysis [3].

2. ADVANCED MEASUREMENT AND EVALUATION OF NON-TECHNICAL STRUCTURES IN BIOENGINEERING

It is believed that through evaluating existing biomedical devices and prostheses it will be possible to determine how they perform in their functional environment. To achieve this, we need to develop or to adapt the measurement tools, the data acquisition methods and the digital processing of data that are associated with it that are appropriate to medical surfaces. From this combination of activities it is possible to evaluate many important components of the human body and their prosthetic replacements and then to discover areas where their functional performance deteriorates in service [4].

In the study of medical implants, not only the macroscobic structural shape and material but also the microscobic structure such as the contribution of surface roughness and precision are absolute necessary determinants for a long-term successful enhanced biocompatibility providing quality criterias. The current study demonstrates the analysis and evaluation of dental implants to enable the quality characteristics required by the clinical experience.

The dental implants are characterized for every individual tooth. The process flow of the implantation and manufacturing of the implants consist of hand made modelling. However with the aid of advanced measurement techniques, the new method was introduced for enhanced implantation processes (Fig. 1 and Fig.2).

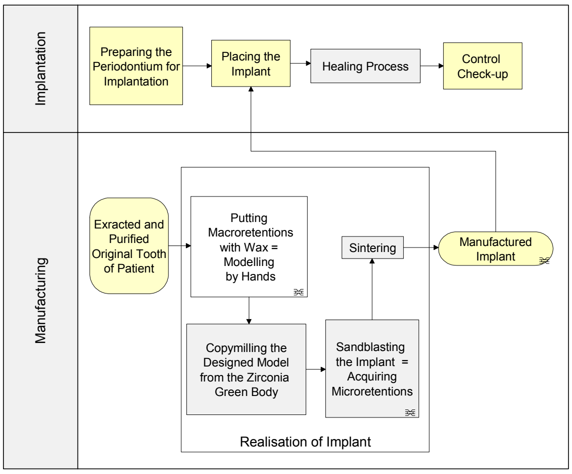


Fig. 1. Process Flow of the Implantation (Classical Method)

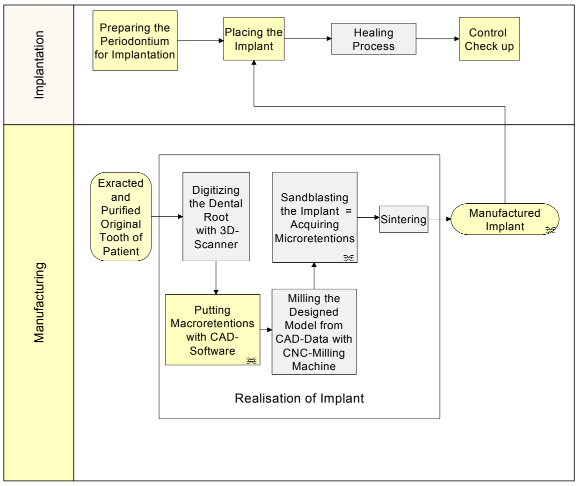


Fig. 2. Process Flow of the Implantation (Advanced Method)

3. COORDINATE METROLOGY FOR MEASUREMENT OF NON-TECHNICAL OBJECTS

Computer aided co-ordinate measuring technique can be applied to measure and evaluate with high accuracy shapes of non-technical objects as dental implants, human limbs or joints. Measurement results can create and widen the basis for the improvement and optimization of future work in the area of biomedical techniques. At the time being co-ordinate metrology is a very important tool for solving various problems in production metrology especially in the case of high flexibility and high accuracy are demanded [5].

The CAD form of an original tooth surface can be evaluated from measured data when the form measurement is carried out by using Coordinate Measuring Machines (CMMs) with both tactile and optical systems (Fig.3 and Fig.4).

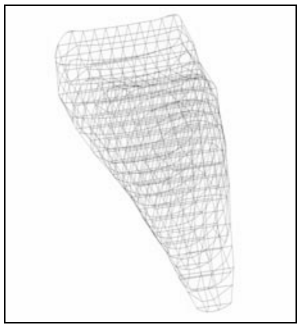


Fig. 3. CAD image of the original tooth

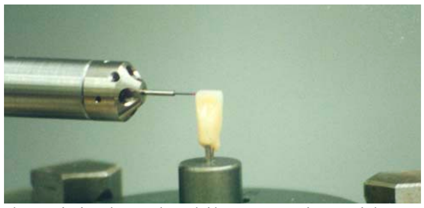


Fig. 4. The original tooth while measuring with Coordinate Measuring Machine (CMM)

The surfaces of the non-technical objects are boundaries between the working environment and the surface texture. The surface metrology is the measurement of the deviations of a workpiece from its intended shape that is from the shape specified on the technical drawing. A set of requirements regarding the geometry of a workpiece (or of an assembly of some workpieces) is known as the "Geometrical Product Specifications (GPS)" covering requirements of size and dimension, geometrical tolerance and geometrical properties of the surface (Fig. 5).

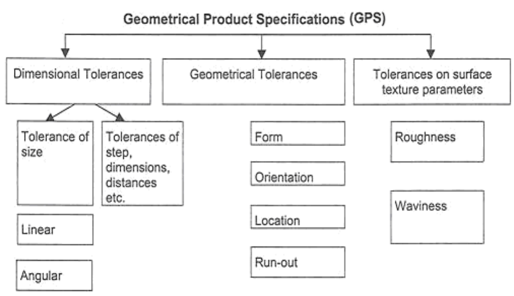


Fig. 5 General concept of "Geometrical Product Specifications" [6]

One of the most important surface properties of precision workpieces is their roughnesses. Surface roughness measurement is conventionally defined by two parameters [7]; arithmetical mean deviation of the assessed profile R_a and average maximum height of assessed profile R_z since they are one of the most common used and accepted by researchers and industry as well [8].

Stylus based measurement methods assess surface finish by means of stylus profilometer. The contact roughness measurement of the non-technical surfaces was carried out by the Form Talysurf Intra 50 profilograph with µltra software (FTS Iµ) illustrated in Fig. 4 according to the ISO 4287 [7]. The surface roughness was analysed by mapping the readings by calculating the parameters R_a and R_z from a standard spectrum of roughness.

Clinical results achieved from successful placement of dental implants have a critical determinant called osseointegration. It is maintained by esthetic and functional stability of the implantation without any complications [9]. The anatomically specific macro retentions and micro retentions of the analogue tooth is the key to the successful osseointegration that must be individually measured, analysed and evaluated due to specific anatomic properties. The reason of choosing the dental surfaces was to see the differences between the methods, which are tactile and optical. Hence the differences are significant particularly when such non-technical surfaces are being measured.

Stylus profilometer and digital microscope are commonly used instruments in the field of precision metrology.

The stylus traverses the surface peaks and valleys, and the vertical motion of the stylus is converted to an electrical signal by means of a transducer. Stylus profilometer generates quantitative profile outputs of the surface under measurement [8].

Figure 6 illustrates the contact-stylus profilometer while measuring a dental sample.

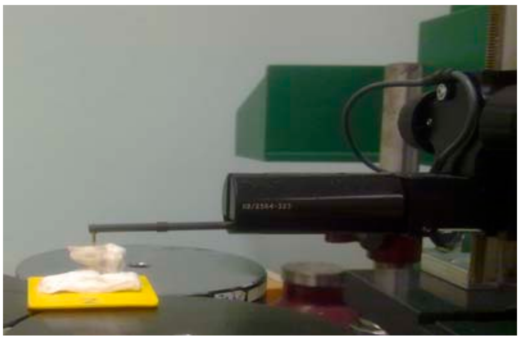


Fig. 6 The contact-stylus profilometer while measuring a dental sample

For the optical measurement, a medical CAD/CAM scanner device (Bego Speedscan) was used in order to record the topographical features of dental samples. The device consists of integrated functions with a scanning module and a computation modul with the software compatible in the device hardware. The complex dental structures are scanned, measured and calculated providing results of required models.

Figure 7 illustrates the medical CAD/CAM scanner device with a dental sample.

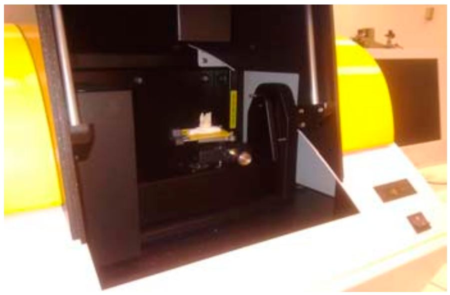


Fig. 7 The medical CAD/CAM scanner device with a dental sample

4. DATA EVALUATION AND APPLICATIONS

Three-dimensional representation of tooth surfaces can give the basis for quality assurance of tooth preparations and restorations and also the production of artificial teeth. By developing the process of objective feedback of dental restoration through metrology, it is possible to identify the areas of sites of bacterial accumulation at the rough margin [10]. To achieve the high quality of tooth preparation and improved restoration, it is necessary to have a quantitative method that supports the appropriate tolerances to express the size, shape and roughness of the tooth modification essential to achieve the desired restoration.

The digital microscope (Keyence VHX-1000) was used to observe, measure and record stabilized, fully-focused, uniformly illuminated image of dental samples. This process is a step for modelling a dental implant in order to evaluate the surface topography.

Fig. 8 and Fig. 9 represent the original and the implant tooth sample consequently.

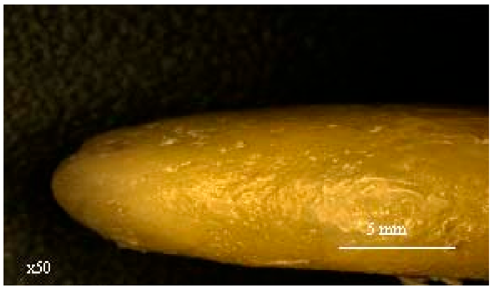


Fig. 8 The original tooth sample

Fig. 9 The implant sample

The focused 2D and 3D images of the original tooth sample are observed by means of the digital microscope. These images were both quantitatively analyzed and also were evaluated in terms of the surface roughness using the digital microscope software.

Fig. 10 and Fig. 11 represent the captured 2D image of the tooth sample and assessed 3D image of the tooth sample consequently.

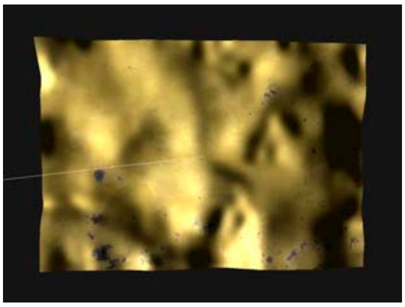


Fig. 10 The captured 2D image of the tooth sample (x2000)

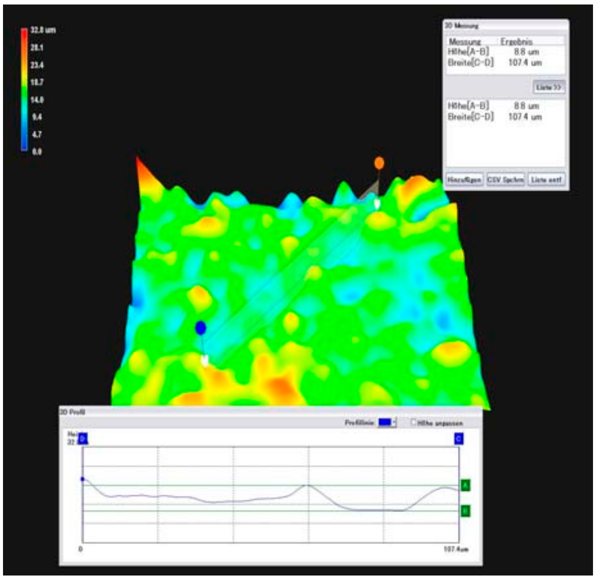
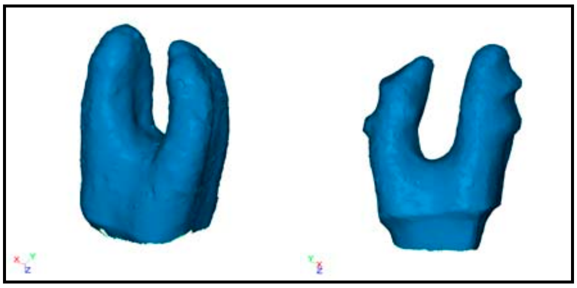


Fig. 11 The assessed 3D image of the tooth sample

As a non-contact measurement method, the white light 3D scanning system (Steinbichler COMET 5) with the advantage of measuring fragile and delicate non-technical objects was used to capture 3D models and then make an assessment by measuring the difference in three axes *X*, *Y* and *Z* (Fig. 12 and Fig.13).



(a) (b)

Fig. 12 The scanned 3D models of the original (a) and implant (b) tooth samples

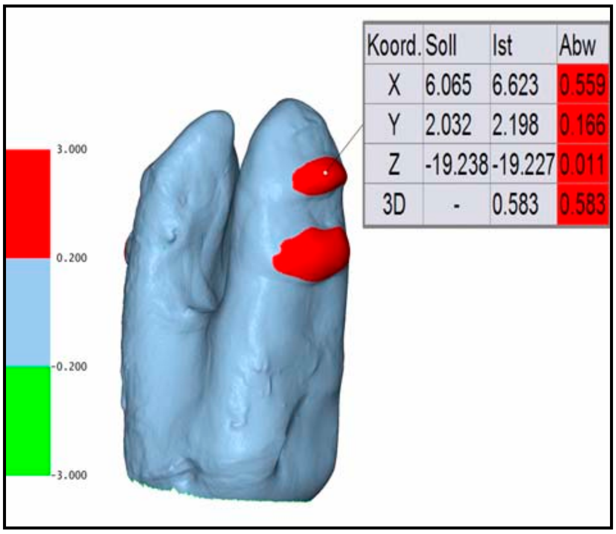


Fig. 13 The assessment of the difference in original and implant tooth sample using the scanned 3D image

In this experimental study, roughness measurements of dental applications were carried out with a stylus profilometer and a digital microscope. Measurements were repeated for five measurement points with 1mm intervals on an original tooth, its implant and other three test implant samples. Each measurement point taken from both stylus profilometer and digital microscope represent the mean values.

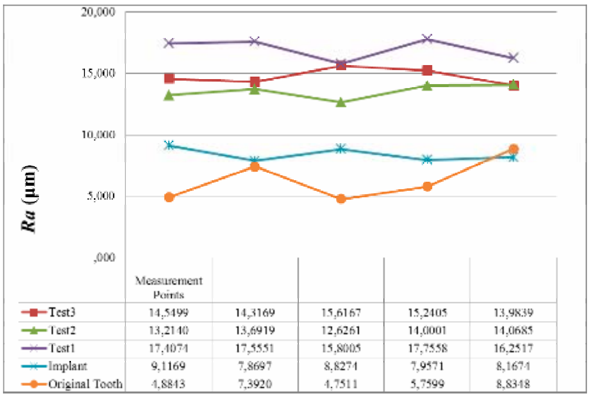


Fig. 14 The roughness measurements of the original tooth, its implant and other three test implant samples

The target is to produce the original tooth analogue with the implant in order to fulfil successful results on the patients. Therefore the roughness measurement as represented is of key importance to compare the original tooth topography with its test implants.

The test implants belonging to the original tooth were manufactured with different machining processes in this experimental study. Therefore, the surface finishes of each test implants had become different surface topography. The surface roughness values of the original tooth were in the range of 4-9µm (Fig.14). As a result of the investigations performed in this study work, the implant of the original tooth were the most suitable with the original tooth comparing with other test implants in terms of their surface finishes.

5. CONCLUSION

In the paper is described an extensive measurement of non-technical objects, here dental implants carried out using the co-ordinate metrology with tactile probing methodology and non-contact approach using laser scanner for feature measurement.

This can create the standard method for a great variety of different and especially complex tasks for workpiece measurement. Results of various measurement and measurement evaluation can help to start, develop and enhance basis for the quality improvement and optimization of biomedical techniques for the future.

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