

**SHORT THESIS FOR THE DEGREE OF DOCTOR OF  
PHILOSOPHY (PhD)**

**Investigation of silver nanoparticles created  
by ion implantation technology on titanium  
surface**

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## 2. Abbreviations

ADA: American Dental Association

CFU: Colony forming units

DPSC: Dental Pulp Stem Cells

EDS: Energy Dispersive X-ray Spectrometry

PVD: Physical Vapor Deposition

SEM: Scanning Electron Microscope

Ti: titanium

### 3. Introduction

#### 3.1. History of prosthodontics and dental implantology

The need to replace lost teeth is as old as human civilization, but these primitive replacements did not actually replace the teeth, the remaining dentition and edentulous jawbone were used to hold the replacement teeth, and these oral formulas took over the role. A significant proportion of the dentures used in today's practice still follow this principle. The possibility of true tooth replacement is the creation of a replacement tooth placed in the bone tissue in place of the lost teeth and directly transferring the load to the bone, which is what today's modern dental implants correspond to.

The beginning of modern implantology can be linked to the discovery of the phenomenon of osseointegration, which is a direct structural and functional connection between living bone and the surface of a load-bearing implant (Tamal, 2015).

#### 3.2. Osseointegration

Branemark accidentally observed during his experiments the strong bonding of titanium microcirculation chambers to the bone surface. Based on this observation, he summarized his experiments in 1969 and described this bonding as a direct implant-bone connection at the light microscopic level and called it osseointegration.

### 3.3. Osseointegration and implant surface

Osseointegration occurs only in the case of some bioinert or bioactive materials. Titanium is considered an ideal biocompatible material due to the stable oxide layer that spontaneously and very quickly forms on its surface. This oxide layer covering the surface prevents any reaction with its environment and corrosion processes (Vishnu, et al., 2019).

Altankov and colleagues have shown that there is a correlation between the degree of surface hydrophilicity and surface cell proliferation (Altankov, Grinnel, & Groth, 1996).

As the number of dental implants placed has increased rapidly since the 1990s, it has become increasingly apparent that a number of complications threaten the long-term survival of the implants. Dental implants are placed transgingivally, providing a potential gateway for bacterial invasion (Derks & Tomasi, 2015). According to a survey conducted by Lindhe and Meyle in 2008, the incidence of mucositis was more than 50%, while in the case of peri-implantitis this value varied between 28% and 56%. (Lindhe, Meyle, & working group D of the EWOP (2008), 2008).

Peri-implantitis is an inflammatory immune reaction triggered by a biofilm containing mostly anaerobic bacteria (Charalampakis, Leonhardt, Rabe, & Dahlen, 2012). Preventing bacterial infections can significantly reduce the development of inflammation around implants. Creating an implant surface that has antibacterial properties itself can play an important role in this.

### 3.4. Antibacterial effect of silver

The antibacterial effect of silver has been known for over a thousand years. Due to its properties, it is increasingly used in public health and in individual antibacterial treatments. Although the exact mechanism

of silver's antibacterial effect is not yet known, researchers agree that it has multiple points of attack (cell wall and membrane, DNA, enzymes, transport processes, gene expression, energetic processes, etc.).

In nanoparticle form, silver has a significantly larger surface area, which contributes to a much more effective antibacterial effect. Silver is toxic to both bacteria and human cells due to similar mechanisms and points of attack, however, in the case of eukaryotic cells, a higher dose is required to achieve the same toxic effect. This provides a therapeutic window to exploit the antibacterial effect of silver in human tissues (Alt, et al., 2004). By changing the diameter of the nanoparticles on the surface, the total silver surface area, and thus the amount of silver ions released from the surface, can be controlled.

## 4. Aim of study

The aim of our work is to investigate the physical and biological properties of a titanium surface coated with silver nanoparticles produced by a new method, ion implantation technique:

1. does the surface have an antibacterial effect due to the silver nanoparticles
2. how the size of the nanoparticles affects the physical properties of the surface
3. does the surface have a negative effect on the viability of human pulpal stem cells

The null hypothesis of our work is that a titanium surface coated with silver nanoparticles can be produced that has an antibacterial effect, but at the same time has no negative effect on the viability of pulpal stem cells.

We examined the shrinkage rate of polyvinylsiloxane and polyether impression materials, which are most commonly used due to their low shrinkage value in the manufacture of implant-based dental restorations, and the possible influence of the mixing technique on the degree of dimensional change.

## 5. Materials and methods

Our work was carried out on a titanium surface coated with silver nanoparticles produced using a new, previously unexplored technology. The ion implantation technology allows the geometric parameters of the particles to be controlled as a function of various parameters.

### 5.1. Sample preparation

For the preparation of samples, 10x10 mm Grade 2 titanium wafers (99.6 at%, Grade 2, Spemet Co., Taipei, Taiwan) were used. The samples were mechanically polished to a fineness of #2000 using a Struers LaboPol-35 polishing machine, Struers LaboForce-Mi tool (Struers Denmark), and then with a 3  $\mu\text{m}$  grain size polisher to create a mirror-like surface. The samples were cleaned with acetone for 3x10 minutes at room temperature in an ultrasonic bath, each cleaning was followed by a rinse with distilled water. The samples were air-dried. In the first series of experiments, the titanium sheets prepared in this way were used, and silver nanoparticles were formed on the surface of some of them.

Production of titanium surfaces covered with silver nanoparticles

The surface to be examined is produced using a four-step technological process:

1. First heat treatment
2. Silver ion implantation using an electron cyclotron resonance ion source
3. Application of a silver sputtered layer
4. Second heat treatment

### First heat treatment

In order to increase the thickness of the natural titanium surface oxide layer, the titanium surface was first heat treated for five minutes using 550 C° in a normal atmospheric environment.

### Silver Ion Implantation

A 14.3 GHz Electron Cyclotron Resonance Ion Source (ECRIS) was optimized for the generation of silver ions. Silver was evaporated in a conventional filament furnace (Pantrechnik, France). The heat source was placed 4 cm from the injection surface and filled with 170 mg of pure silver. The optimal operating temperature was between 850 and 950 Co, with oxygen as the shielding gas. The ion beam was extracted from the plasma by applying 2 kV. The ion beam shape was circular with a diameter of 50 mm. The titanium surfaces were implanted with a silver dose of  $1.5 \times 10^{16}$  ions/cm<sup>2</sup>.

### Silver sputtered layer application (Physical Vapour Deposition, PVD)

After silver implantation, a 7-8nm thick silver layer was sputtered onto the sample surface using a Bio-Rad E5000C (QuorumTech, Austin, Texas, USA) using the magnetron sputtering technique. The shielding gas was Ar, the sputtering lasted for 12 seconds using a 6mA current, so the deposition rate was 0.6 nm/s at room temperature.

### Second heat treatment

The samples were heat treated at 550 C° for 15 minutes in an Ar/H environment to create silver nanoparticles.

The first series of measurements was performed on the titanium surfaces containing the silver nanoparticles prepared in this way. We

measured the physical properties of the surface, examined the antibacterial effect of the surface and its effect on cell viability.

The effectiveness of the antibacterial effect is determined by the available silver surface. Measurements on the treated titanium surface also allowed the creation of a geometric model, according to which the effective antibacterial silver surface depends on the thickness of the sputtered layer, the size of the sputtered surface and the radius of the formed particle. The size of the formed particle depends on the technological conditions, such as the thickness of the sputtered layer, the heat treatment temperature, the applied time, and the thickness of the sputtered silver layer using the same temperature and time. In order to analyse the biological effect of the surface covered with particles of different sizes, measurements were performed on surfaces covered with particles of different sizes in order to achieve the biologically optimal configuration.

Creation of titanium surfaces coated with silver nanoparticles of different sizes

For comparative studies, 15 mm diameter titanium sheets (grade 2, 99.6at%) were used, which were polished to a #1200 grit level using a Struers LaboPol 35 polisher, Struers LaboForce –Mi tool (Struers, Copenhagen, Denmark), and then chemical polishing was applied to obtain a mirror-like surface. The samples were cleaned in an ultrasonic bath for 10 minutes twice, then rinsed with distilled water and dried at room temperature. The nanoparticles were created using the technology described earlier.

During silver sputtering, silver layers of different thicknesses were formed on the surface of the sample, the layers were 3nm, 5nm, 8nm and 15nm thick. The sputtering was performed using a Bio-Rad E5000C (QuorumTech, Austin, Texas, USA) sputtering device using pure silver and Ar shielding gas. The sputtering was performed at a speed of 0.8 nm/s, at a current of 6mA, and the layer thickness could be increased by increasing the applied time.

During the second heat treatment, when 600 C° was applied, separate nanoparticles were formed on the surface of each thickness after the one-minute heat treatment, the samples heat-treated in this way (600C°, 1 minute) were used for comparative studies. The surface morphology, the change in the surface contact angle and the viability of the cells on the surfaces were investigated.

## 5.2. Scanning Electron Microscope, (SEM)

A Hitachi S4300-CFE (Japan) scanning electron microscope was used to confirm the formation of nanoparticles and to examine the surface structure, as well as to confirm the presence of dental pulp stem cells (DPSC) attached to the surface. The surface of the samples that had been ultrasonically treated during the microbiological examination was also examined in this way, looking for any changes in the nanoparticle structure. The surface nanostructure was evaluated using the Vision Assistant 2011 (National Instruments) computer program. To examine the cells, the sample was fixed in 2% glutaraldehyde solution for 2 hours, then in 1% OsO<sub>4</sub> solution for 1 hour, then in ethanol series (10%, 30%, 50%, 70%, 80%, 90% and 100%, each for 15 minutes), and then critical point dried in CO<sub>2</sub>. The surface of the samples was coated with a gold layer. The accelerating voltage was 10 kV. For the morphological comparison of the surfaces containing silver nanoparticles of different sizes and for the comparative examination of the dental stem cells adhered to them, a JSM-IT500HR (JEOL, Tokyo, Japan) scanning electron microscope equipped with an energy dispersive X-ray spectrometer (EDS) was used. The samples containing cellular elements were prepared as detailed above.

## 5.3. Evaluating antimicrobial effect

The antibacterial efficacy of the samples containing 60 nm silver nanoparticles was compared with the antibacterial effect of the native titanium surface and glass surface without nanoparticles. The antibacterial activity was tested for all samples according to Wang (Wang, et al., 2017) using a Gram-positive strain of *Staphylococcus aureus* (ATCC 29213). The bacterial solution was prepared by culturing on Columbia blood agar twice overnight at 37°C. A bacterial solution with a density of 0.5 McFarland was prepared in BHI medium (Brain heart infusion broth), then a solution with a bacterial concentration of  $1 \times 10^6$  CFU (Colony forming units)/mL was prepared. The tests were performed taking into account the ISO22196:2007(E) protocol (ISO22196:2007(E)). The  $1\text{cm}^2$  samples were placed on a microscope slide in a Petri dish, 50  $\mu\text{L}$  (0.05 mL/cm<sup>2</sup>) of bacterial suspension was pipetted onto them, and then covered with a sterile borosilicate glass coverslip, taking care not to let the suspension drip from the edges. The Petri dishes were incubated in the dark at 37°C. After 8 hours of incubation, the samples containing the coverslip were placed in 1 mL of BHI medium and the bacteria were detached from the surface of the samples by vigorous vortexing for 5 minutes and then sonication for 3 minutes. The resulting bacterial suspension was further diluted in BHI medium for colony forming unit (CFU) counting as described by Herigstad. (Herigstad, Hamilton, & Heersink, 2001). 50  $\mu\text{L}$  of each suspension was inoculated into 5 evenly distributed 10  $\mu\text{L}$  drops on Mueller-Hinton agar. The Petri dishes were inverted after the drops dried and incubated overnight at 37°C. The number of colony-forming units on the plates was recorded. The incubation was performed in complete darkness to prevent the development of a photocatalytic effect on the titanium surface. The efficiency of bacterial separation was compared to control samples from which the bacteria were removed immediately after being placed on the sample, without incubation (zero time control). All tests were performed in duplicate, repeated three times. The antibacterial effect was calculated using the following formula:

antibacterial efficacy =  $(1 - (\text{CFU}[\text{experimental sample}] / \text{CFU}[\text{control sample}])) \times 100$  (Wang, et al., 2017)

The devices used for testing antibacterial efficacy were applied after standard autoclave sterilization. The antibacterial efficacy of titanium and silver nanoparticle-coated titanium surfaces was analysed with a one-sample Student t-test for the control glass surface, while the comparative efficacy of the two surfaces was analysed with an independent t-test. The error limits for the means were also determined. In the case of the applied method (as is usually the case with biological samples where a small number of samples can be produced) we must assume a normal distribution of the antibacterial efficacy data (this would only be proven with a large number of samples).

## 5.4. Evaluating cell viability

Cell viability on the surface of the samples was assessed using pulpal stem cells (DPSC) using the Alamar Blue assay (Thermo Scientific Waltham, MA, USA). Cells seeded on the surface of the samples were cultured for 14 days in DMEM F12 (Gibco, Waltham, MA, USA) supplemented with 10% foetal bovine serum (Gibco), 1% Glutamax (Gibco), and 1% Antibiotic-Antimycotic (Gibco). The medium was refreshed three times a week. The Alamar Blue assay was performed according to the manufacturer's instructions: the culture medium of each sample was replaced with 10% Alamar Blue solution, and after two hours of incubation in a humidified 5% CO<sub>2</sub> medium at 37°C, the fluorescence of the samples (100uL) was measured using a Hidex Sense (Turku, Finland) instrument with 544nm excitation and 595nm emission.

## 5.5. Investigating shrinkage rate of impression materials

In the studies, polyether “Permadyne Garant 2:1 type 3” (ESPE; USA) and polyvinylsiloxane impression materials “Provil Novo medium type 2” (Hareus-Kulzer; Germany) and “President low viscosity type 3” (Coltene; Switzerland) were mixed by gun and conventional hand mixing technique. Measurements were performed in accordance with ADA specification 19 using Abbe comparator.

## 5.6. Evaluating surface hydrophilicity

The wettability of surfaces coated with silver nanoparticles of different sizes was measured by contact angle measurement using the sitting drop technique using a DSA 30 Drop Shape Analyser (Krüss GmbH, Hamburg, Germany) at room temperature. 2 $\mu$ L water drops were placed on the surfaces using an automated system (0.5mm needle diameter). The contact angle was automatically calculated by comparing the drop shape with the angle calculated using the Young-Laplace formula. The average contact angle was calculated based on the results of 10 measurements. Student's t-test was used for statistical analysis ( $p < 0.05$ ).

## 6. Results

### 6.1. Surface configuration

Hitachi S4300 CFE (Tokyo, Japan) scanning electron microscope images clearly demonstrate that nanoparticles were formed on the surface after surface treatment. As a result, the surface morphology changed significantly.

As a result of the treatment, the surface roughness of the samples increased from an initial average value of 8 nm to 62 nm. The EDS surface analytical examination built into the scanning electron microscope showed that the structures formed on the surface were silver nanoparticles.

Further analysis of the SEM images, using the “Vision Assistance” (National Instruments) program package, showed that the particles covered 25% of the surface. The diameter of the particles showed a Gaussian distribution, with a median of 58 nm and a deviation of 25 nm.

The stability of the silver nanoparticles on the Ti surface was investigated using the samples that were used to measure the antibacterial effect. These samples were subjected to vigorous vortexing and then to a 3-minute ultrasonic treatment during the study. After the antibacterial measurements, the samples were examined by SEM and the images were compared with samples where ion implantation was not used during the formation of the silver nanoparticles. On the surface where ion implantation did not occur, the treatments detached the nanoparticles from the surface. Further SEM studies showed that the detachment of the silver nanoparticles was due to the peeling of the surface oxide layer. The ultrasonic treatment could be used to confirm the high physical stability of the

silver nanoparticles on the Ti surface as a result of the ion implantation treatment.

## 6.2. Antibacterial effect

The Ti sample showed practically no difference in effectiveness compared to the control glass surface. The surface containing silver nanoparticles clearly has a greater antibacterial effect. According to our measurements, the antibacterial effect is reproducible and significantly different from the effectiveness of the control glass and the ineffective Ti surface. The antibacterial effectiveness of the samples containing silver nanoparticles was 64.6%, with a margin of error of 19.6% (confidence level 90%), the standard error was 6.7%. The effectiveness was statistically significantly different from the values of both the control glass surface ( $p=0.010$ ) and the untreated titanium surface ( $p=0.005$ ).

## 6.3. Surface hydrophilicity

The contact angle values measured with water were  $63.675^{\circ} \pm 0.608^{\circ}$ ,  $66.275^{\circ} \pm 0.826^{\circ}$ ,  $70.010^{\circ} \pm 0.667^{\circ}$  and  $105.263^{\circ} \pm 0.823^{\circ}$  on the surfaces covered with 60nm, 96nm, 149nm and 368nm particles, respectively.

The contact angle values measured for 60nm, 96nm and 149nm particles are below  $90^{\circ}$ , which shows that water behaves as a wetting liquid on the tested surface and thus contributes to the hydrophilic property of the Ti surface modified with silver nanoparticles. The average contact angle on the surface covered with 368 nm particles exceeded the limit value, in this case water has reduced wetting properties on the surface covered with larger silver particles. Statistical analysis showed that the average values were significantly different ( $p<0.01$ ) for increasing particle size.

## 6.4. Cell viability

After 14 days of culture, the cells on the surfaces coated with particles with an average size of 60 nm and 96 nm showed similar viability values to the control sample. However, in the case of surfaces coated with particles with an average size of 149 nm and 368 nm, a reduction in fluorescence values was observed compared to the surface coated with 60 nm particles, and a decrease in viability was also observed when the values were compared to the value of the 96 nm surface.

## 6.5. Investigating shrinkage rate of impression materials

In case of the tested impression materials, we demonstrated a continuous shrinkage tendency during the test period, and in the case of the polyether type impression material, we were also able to demonstrate differences between the mixing methods.

## 7. Discussion

The use of osseointegrated dental implants has become a routine procedure in modern dental prosthetics. As the number of implants placed has increased dramatically in recent years, several possible complications have been reported in the literature, which may even lead to the loss of the inserted implant. Based on data presented by the Lindhe and Meyle working group in 2008, an inflammatory process can be detected around the implants of many patients with dental implants (Lindhe, Meyle, & working group D of the EWOP (2008), 2008).

Treatment is multifactorial and should be aimed at restoring a healthy state, which is often not possible. After treatment, the implant is often fixed by reduced bone mass. This also supports the importance of prevention, one of the supporting factors of which could be an implant surface with antibacterial properties.

Although the antibacterial properties of silver, which help prevent and cure infections, have been known for thousands of years, the exact and detailed background of the effect requires further research.

The effective antibacterial effect of silver nanoparticles is due to the significantly increased active surface area. The human immune system is unable to eliminate nanoparticles, and numerous publications report the development of pathological processes in several organs and tissues when they enter the circulation (Shi, et al., 2014), (Inkielewicz-Stepniak, Santos-Martinez, Medina, & Radomski, 2014), (Kang, Jung, & Lym, 2012). There is also a publication stating that silver nanoparticles cause apoptosis through

the formation of reactive oxygen radicals (Foldbjerg, Dand, & Autrup, 2011).

In our work, we have shown that the titanium surface containing silver nanoparticles prepared using the new method described has a strong antibacterial effect, consistent with the literature data. The nanoparticles are safely fixed on the surface and cannot enter the circulation.

In the initial stage of osseointegration, the adhesion of a water-based layer containing organic and inorganic components to the implant surface is essential (Ma, Ge, Zhang, & Lin, 2016). Water-based solutions spread easily on hydrophilic surfaces. Several studies have demonstrated more effective osseointegration when the implant surface has hydrophilic properties, even in the case of natural bone. (Chambrone, Shibli, Mercurio, Cardoso, & Preshaw, 2015), (Hinkle, Rimmer, Morgan, & Zeman, 2014), (Lang, et al., 2011), or placing implant in augmented area (Pinotti, deOliveira, Aroni, Marcantonio, & Marcantonio, 2018).

Based on our measurements, the increase in silver nanoparticle size on the surfaces we created resulted in a decrease in surface aqueous wettability.

The examination of surfaces containing silver nanoparticles of different sizes showed that significantly higher numbers of living cells were found on surfaces covered with particles with a diameter of 60 nm and 96 nm. The higher contact angle value on surfaces containing larger particles meant a decrease in wettability, which could significantly affect cell adhesion (Gittens, et al., 2014), (Milleret, et al., 2019). We hypothesize that the decrease in cell number measured on the surface containing particles with diameters of 149 nm and 368 nm can be attributed to this phenomenon. Our results show that the size of silver nanoparticles has a significant effect on cell adhesion, which is crucial for successful dental implantation.

Based on the results of our impression material shrinkage measurements, the shrinkage values of polyether and polyvinylsiloxane impression materials, - that are considered the best for the production of implant-supported dental restorations - , showed values between 0.15 percent and 0.6 percent, depending on the type and manufacture of the material, as well as the time elapsed since mixing. Even in the case of the smallest value, the dimensional change can have consequences such that the stress in the bone when the prepared metal-based restoration is inserted reaches the value of the moderately overloaded category.

## 8. Conclusions, new findings

In our work, we showed that the titanium surface formed by the method has an antibacterial effect, the particles are stably fixed on the surface. We were able to control the size of the particles with the applied method. We also showed that the wettability of the surface increased by reducing the particle size. This can be related to the fact that reducing the particle size improved the surface viability of the cells.

Our findings:

- The titanium surface containing the formed 60nm silver nanoparticles has an antibacterial effect.
- On the formed 60nm silver nanoparticle surface, the nanoparticles are stable, so they do not enter the interstitial fluid and the circulation.
- The formed 60nm silver nanoparticle surface is hydrophilic, which is an advantage for application in biological systems.

- The surface containing the formed 60 nm silver nanoparticles does not significantly affect the viability of the cells.
- The least amount of silver should be used to form the surface containing the formed 60 nm silver nanoparticles

The impression materials used to make restorations show continuous shrinkage depending on the time, type and make.

The surface containing the formed 60 nm silver nanoparticles may be a suitable factor in the prevention of peri-implant inflammation. When making restorations, it is important to use the appropriate impression material and impression technique to minimize the tension in the bone after the restoration is placed.

## 9. Summary

Use of dental implants has become everyday practice to restore lost dentition. As time has passed and the number of placed implants significantly increased it has become evident, that in significant number of cases periimplant inflammatory pathology developed. Predisposing factor is the transgingival position of the implant creating a preformed pathway for pathologic agents to pass to the underlying tissues. Treatment of such pathology is difficult, the result cannot be predicted. Prevention comes to first site, antibacterial implant surface at the cervical region may be a part of such preventive measures.

The presented experiments measured features of grade II titanium surface samples covered by silver nanoparticles. Antibacterial effect of such surfaces was presented. Hydrophilicity of the surface and effect on cell viability were also examined on titanium surfaces covered by nanoparticles of different size. Increased nanoparticle size significantly correlated with increased water contact angles, when biggest particle size was applied the surface has become even hydrophobic. Alamar Blue test proved decreased cell viability as particle size increased, but this may be the result of decreased cell adhesion to the surface due to decreased hydrophilicity: SEM figures proved attachment of the cultured dental pulpal stem cells on all surfaces with different particle size. The experiments also showed that the silver nanoparticles are secured on the titanium surface which prevents them getting into the circulation and causing pathology.

The experiments carried out showed that the application of smaller sized (around 60 nm in diameter) silver nanoparticles on the surface of titanium dental implants may contribute to the prevention of bacteria based periimplant inflammatory processes and may have clinical relevance

When making restorations, it is important to use the appropriate impression material and impression-taking technique to minimize the stress on the bone after the restoration is placed.

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## 10.2. Studies of the author



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Registry number: DEENK/542/2025.PL  
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Candidate: István Lampé

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### List of publications related to the dissertation

1. Hajdu, P., **Lampé, I.**, Rácz, R., Biri, S., Csik, A., Tóth, F., Szalóki, M., Hegedűs, V., Dombrádi, Z. R., Varga, I., Csarnovics, I., Kókényesi, S., Beke, D. L., Hegedűs, C.: Optimized Size and Distribution of Silver Nanoparticles on the Surface of Titanium Implant Regarding Cell Viability.  
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3. **Lampé, I.**, Marton, S., Hegedűs, C.: Effect of mixing technique on shrinkage rate of one polyether and two polyvinyl siloxane impression materials.  
*Int. J. Prosthodont.* 17 (5), 2004.  
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List of other publications

4. Gruper, Y., Wolff, A. S. B., Glanz, L., Spoutil, F., Marthinussen, M. C., Osičková, A., Herzig, Y., Goldfarb, Y., Aranaz-Navaliches, G., Dobeš, J., Kadouri, N., Ben-Nun, O., Binyamin, A., Lavi, B., Givony, T., Khalaila, R., Gome, T., Wald, T., Mrazkova, B., Sochen, C., Besnard, M., Ben-Dor, S., Feldmesser, E., Orlova, E. M., Hegedűs, C., **Lampé, I.**, Papp, T., Felszeghy, S. B., Sedlacek, R., Davidovich, E., Tal, N., Shouval, D. S., Shamir, R., Guillonneau, C., Szondy, Z., Lundin, K. E. A., Osička, R., Prochazka, J., Husebye, E. S., Abramson, J.: Autoimmune amelogenesis imperfecta in patients with APS-1 and coeliac disease.  
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*Magyar. Radiol.* 66 (1), 11-14, 1992.

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## 11. Keywords

dental implants, silver nanoparticles, mucositis, peri-implantitis, antibacterial effect, hydrophilicity, cell viability, titanium, shrinkage of impression material

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## 13. Appendix

The Department of Biomaterials and Prosthodontics, Faculty of Dentistry, University of Debrecen and the ECRIS working group of the Hungarian Academy of Sciences Nuclear Research Institute have had a close working relationship for years. The first joint publication was published in the Journal of Electrical and Electronic Engineering in 2009.

The technologies used here have been applied in our work related to several dental fields, one of which is the development of a surface with antibacterial silver nanoparticles.

The basic concept of our work is determined by the following observations: The use of dental titanium implants is becoming increasingly widespread, and the experience can be traced back to several decades. These experiences also show that a significant part of the implanted implants are affected by inflammatory processes around the implant, which in extreme cases can lead to the loss of the implant and the restoration anchored on it. From a dental perspective, it would be important if the implant surface had antibacterial properties, because it could thus play a role in the prevention of these inflammatory processes.

The work brought new results from both the physical and dental sides, I believe that I was able to provide a comprehensive overview of the topic only together with the presentation of the work of my co-author Péter Hajdu PhD. During our joint work, our physicist colleagues produced the titanium surface configurations based on the biological aspects determined by the dentists. The physicist working group examined the physical properties of the surfaces, while the dentist working group examined the biological properties. The scientific work and the use of the results were carried out in accordance with the attached approved “Shared Use” statement.