ESOMAT 2009, 07001 (2009)
DOI:10.1051/esomat/200907001

Application of nanostructural nickel titanium implants with shape memory effect to modern dental practice

V.S. Afonina[1a], N.I. Borisenko[2], R.M. Gizatullin[2], D.V. Gunderov[3], V.S. Kalashnikov[a,1], V.V. Koledov[2], E.P. Krasnoperov[3], V.G. Shavrov[2], V.I. Suslov[3], N.A. Yusov[3]

[1] Moscow State Technical University n. a. N.E. Bauman, 2-nd Baumanskaya, 5, 105005, Moscow, Russia.
[2] Kotelnikov' Institute of Radioingineering and Electronics of RAS, 125009, Mokhovaya 11-7, Moscow, Russia.
[3] «Nano-Dent» Co Ltd, Moscow, Russia

Abstract. The results of clinical treatment of severe periodontal diseases by application of the new functional implants based on nanostructural NiTi alloy with shape memory effect are presented. The nanostructure in NiTi alloy is attained by severe plastic deformation, particularly by equal channel angular pressing. Several new types of NiTi implants are developed, including dental implants (to replace the removed teeth) and trans radix implants (to enforce teeth and to attach teeth to the jaw bone). The surface of nanostructured NiTi implants is covered by the carbyne layer in order to ensure high bio-compatibility. The new treatment procedure is proposed which includes the injection into the jawbone tissue of the mixture based on powdered NiTi alloy. These injection implants will be incorporated into living bone tissue. The result will be the growth of the shell of the new healthy dense bone. The NiTi particles behave structurally similar to healthy bones, i.e. living tissue cells incorporate with them followed by small vessels and nerves. As a result the implants will not be rejected for a long time. The summary results of 3 years' practice of the successful application of these new implantation system in dentistry are presented. The ease of implementation of the new NiTi dental shape memory implants and the ease at which they can be adopted to bone tissue, especially in cases where it's in deficit are highlighted

1. Introduction

One of the most actual problems in modern dentistry is the conservation of teeth in severe periodontal cases which could not otherwise be saved by conventional treatment methods. The conventional titanium dental implants are difficult to be implemented surgically in cases when bone tissue deficit occurs. The conventional titanium implants also can not serve both for tooth enforcement and connecting them to the jawbone. A lot of works have been done in order to introduce in dentistry and in other fields of medicine the different types of tools and implants taking advantage of the unique properties of NiTi alloy with shape memory effect (SME) [1].

The subject of the present paper is to propose the new NiTi alloy based implantation system including the several new types of dental implants, and injection implanted gel-composites. The nanostructured NiTi alloy produced by equal channel angular pressing (ECAP) is used as basic material of implants' design due to its biocompatibility, outstanding mechanical and functional properties [2]. The series of the original implants with SME includes the dental implants (DI) to replace the absent teeth and trans-radix implants (TRI) to enforce and to connect reliably the teeth to the jaw's bone. The heterophase NiTi powder based gel-composite implants for injection treatment of severe dental deceases and implantation procedures, and the special tools and methods of their applications for the treatment and implantation are the parts of the system too.

The goals of the new implantations technology: the best adaptation of the parodontium to implantations; preventing the DIs and TRIs from rejection; the conservation of those teeth which were recommended for deleting by conventional treatment methods; the healing and prophylaxis of parodontosis.

2. Dental implants

The series of dental implants (TAL®) is used in the proposed system in order to replace the absent teeth as well as to reinforce the weak ones and to connect them to the jaw bone. This provides salvage of the most of the teeth recommended previously for removal. A principle of work of dental implants is based on the application of SME. All the TAL implants are made of nanostructured TiNi alloy, with the surface of implants being covered with the layer of carbyne or linear-chain carbon in order to ensure their high bio-compatibility.

[a]email: sunny_shadow@list.ru

For example TAL-1 is TRI i.e. implant which is to be implanted through the tooth root (radix) into the jawbone. The implant has the in-bone part and the outer part. The in-bone part is in the form of wire made from

Fig. 1. Series of TAL® implants made from nanostructured NiTi with SME covered by LCC surface layer. (a) TRI TAL – 1; (b) and (c) DI TAL 2 and TAL 3; (e) implant – distractor TAL 4, (c) DI TAL – 5.

nanostructured NiTi alloy with SME covered by carbyne layer. The outer part of the implant has screw on which the artificial tooth should be installed.

The process of TAL-1 TRI implantation consists of 4 steps. On the first step the inner part of the implant is to be bent in the austenite state in accordance with the configuration of the specific bone of the patient (see Fig. 1a). On the second stage it is given a straight form in martensite state in cold alcohol or liquid nitrogen. On the third stage the straight channel is produced through the tooth radix into the jaw bone. As a conclusion, the TAL-1 is easily implanted into the straight channel, with the tooth being enforced and reliably attached to the bone due to implant's bending at the temperature of human body. The special procedures of the bone healing and enrichment can be done preliminary using NiTi containing gel-composite in severe cases.

The DIs TAL-2 and TAL-3 (Fig. 1 b,c) are used in order to replace the absent teeth. They have several advantages: SME elements, detachable construction with the ability to bear different constructions of artificial tools and suprastructures; the complimentary NiTi SME ring, which serves as fixing element changing its form after implantation at the temperature of human body.

The distractor TAL-4 (Fig. 1 d) have been designed for enlargement of narrow jawbones. It is to be temporary introduced in to the slit into narrow bones in combination with gel-composite. The distractor serves to apply the reactive force for the sufficiently long time in order to initiate growth and enlargement of the bone. The common effect of 3-4 weeks action of the TAL-4 distractor is several millimeter growth of the jawbone.

The distracting-injecting device TAL-5 (Fig. 1 e) is used to treat and to enlarge the jawbone before the implantation of DIs TAL-3 or TAL-3. It gives possibility to activate screw-distractor and to inject gel-composite into bone during the preliminary preparation of the bone to implantation.

The TAL implantation series is very simple in usage and has small number of components, but each of the component is supplied in many individual dimension-types and fits the jaw bone region where it is to be implanted. The implants take advantage both of the outstanding mechanical and functional properties of

nanostructured NiTi alloy with SME and of the effect of the biofunctional properties of the new gel-composite. The series of implants can serve to save the weak teeth and to replace of the absent ones in a great variety of severe periodontal cases.

3. Nanostructured NiTi

The nanostructured NiTi alloy produced by ECAP is the basic material for the TAL implants design. The commercially available NT-10 alloy for medical applications produced by "MATEX" Co Ltd (Moscow, Russia) have been used for nanostructuring. The ECAP have been done at 400 C at 8 runs [2]. The nanostructuring helps to attain very high strength and functional properties of the alloy, in particular the record values of ultimate stress (up to 1500 MPa), yield point, reactive stress produced by SME, reversible deformation. Nanostructuring of TiNi grains results in changing of martensitic transformation temperature. We can choose required temperature, for example 36,6 C, of martensitic transformation of TiNi implants with SME by regulating grain size.

We outline the property of "functional inflexibility" which is treated as higher reactive force produced by nanostructured alloy then coarse grained one at the same reversible strain under the load. This property is of especial favor when designing the dental implants and devices, because at the same time the elastic element with SME can be done thinner and smaller and produce a greater force at heating. This is very important for example in TRI implants construction intended to be implanted into thin or weak jawbone. The "functional inflexibility" can be explained by the nanostructure formation as well as the enhanced reliability of the nanostructured NiTi alloy. But if the greatly enhanced reliability is usually attributed to restricted dislocations propagation in the nanograin structure, we think, that functional inflexibility of the alloy with same determined pseudoplastic deformation is due to enlarged integral surface of grain boundaries. These boundaries can play the role of "reinforcing ribs" producing the higher reactive force at the same reversible strain.

Due to record functional properties and mechanical reliability, high stability of the properties, durability, corrosion resistance, and biocompatibility the nanostructured NiTi alloys produced by ECAP are recognized like new generation of TiNi alloys with unique properties for medical application. More information about functional properties of nanostructured TiNi alloy is given in the works [3,4].

4. Carbyne coverage

The series of TAL implants have biocompatible carbyne coverage. Carbyne is linear-chain carbon that has sp3-hybridization of monatomic fibers. Carbyne is elastic across the fibers and it is harder than diamond along them. The protein molecules and water molecules can integrate between carbon fibers. Carbyne is extremely hydrophilic. The carbyne coverage prevents implant rejection and improves their integration because relief of the coverage is complementary to tissue cells. In contrast to other types of coverage it does not corrode when SME appears, thereby it prevents emission of Ni from implants into organism. Due to its elasticity it does not collapse under stress. The carbyne's properties are described in several works [5,6].

5. Medicinal gel-composite

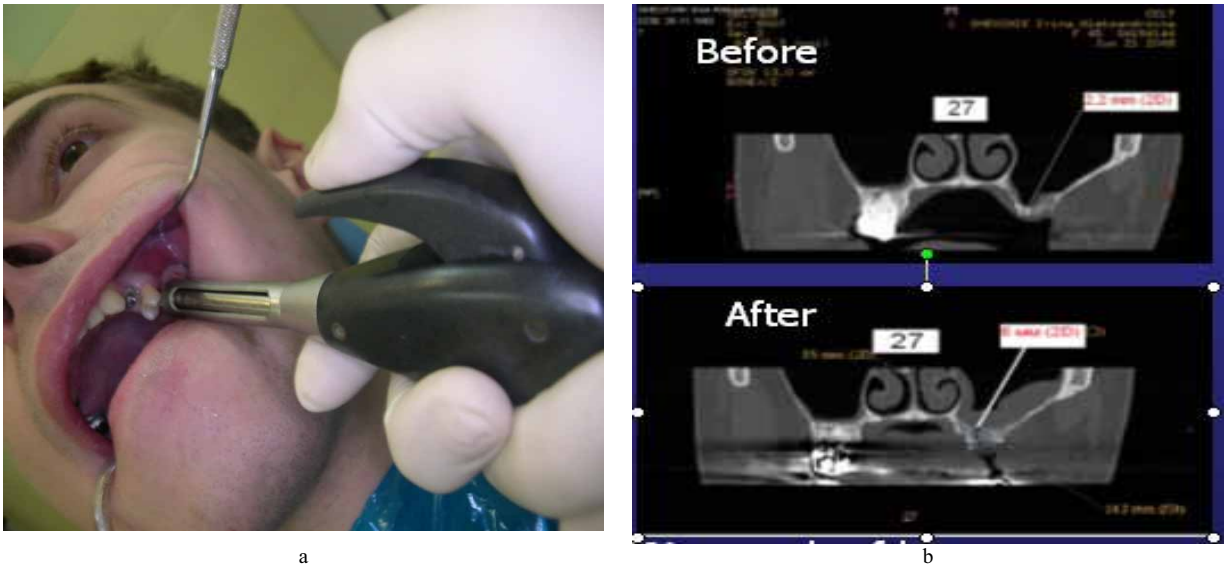
One of the key elements of the proposed implantation system is the gel-composite based on powdered NiTi for injection implantation into jawbone. The powdered NiTi is used in medicine because it exhibits elastic properties similar to bone, does not require bone grafting techniques and appears to offer long-term fixation, biofunctionality and biocompatibility. Previously the powdered NiTi has been examined in animal studies and has been shown to be an excellent substrate for osteogenic cell integration, has demonstrated resistance to both *in vivo* surface corrosion and nickel ion release and has been shown to be a non-sensitizing, nonirritating and non-toxic biomaterial [7,8].

We propose the new variant of the powdered NiTi medical application in the form of bioinorganic gel-composite. The non organic part of the composite is the mixture of powdered NiTi and nanoparticles of silver. The organic part of the composite is patient's blood plasma. After mixing under ultrasound action the resulting gel-composite is injected into the bone by means of special injector (see Fig. 2 a).

The gel-composite can serve for bone strengthening, so far as solid particles of NiTi create a frame for a new bone, both in connection with DI implantation or not. The factors of growth of blood plasma are immobilized on particles of NiTi as well as on Ag nanoparticles. The NiTi particles remain in the zone of injection because they are bound with proteins. Thereafter they form bioinorganic structure which we call "Phoenixon". This structure can belong to any tissue: bone tissue, connective tissue, where the process of regeneration take place in zone of injection of heterophase implant. Several weeks after the injection, the TiNi powder is appears spread within the bone tissue in the way it could enhance tissue strength to typical stress. Thus

a resistant biologically functional system is generated, appearance of which could be a guaranty of the DI or TRI long-term survival rate and absence of parodontosis.

The standard tests were conducted on biosafety *in vitro* with the help of primary culture human cells of TiNi-Ag composite in the concentration at least 10 times higher then that of used for reconstruction of jawbones. The proved chronic toxicity of TiNi-Ag composite was not revealed.



a b

Fig. 2. Injection of Ni-Ti containing gel-composite.

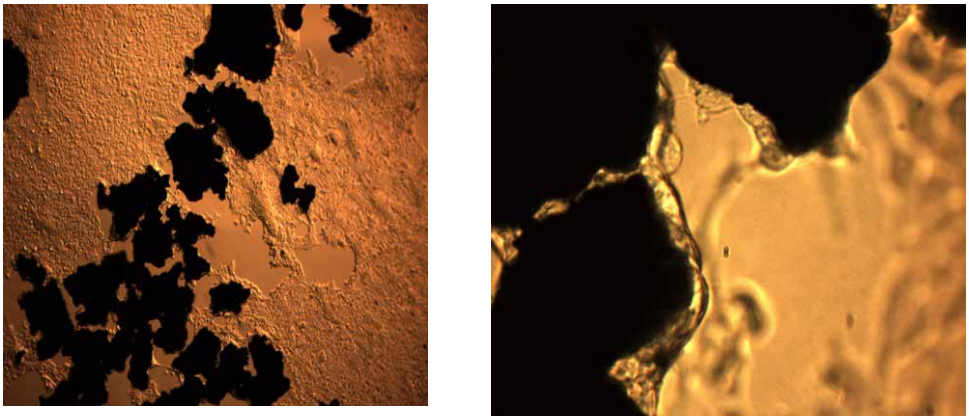
So, NiTi - Ag composite is a safe and biocompatible. The role of Ag nanoparticles in the action of gel-composite is that Ag do not cause burn of the tissue, but destroy bacteria, whereas bacteria generate colonies that can't resist to destruction of bacterium cell' membrane by Ag particles.

Standard tests *in vitro* of NiTi particles have showed their good biocompatibility with living cells of human lever. Photo on Fig. 3 demonstrate that living cells not only survive on the particle surface, but tend to change their place from standard bio-neutral substrate to the Ni-Ti particles' surface. The use in combination of the nanostructured TiNi implants with gel-composite gives the optimum integration of the DIs or TRIs into the living tissue, and the resulting bioinorganic structure of the tissue is the most functional.

6. The experience of the treatment with the application of new implant system

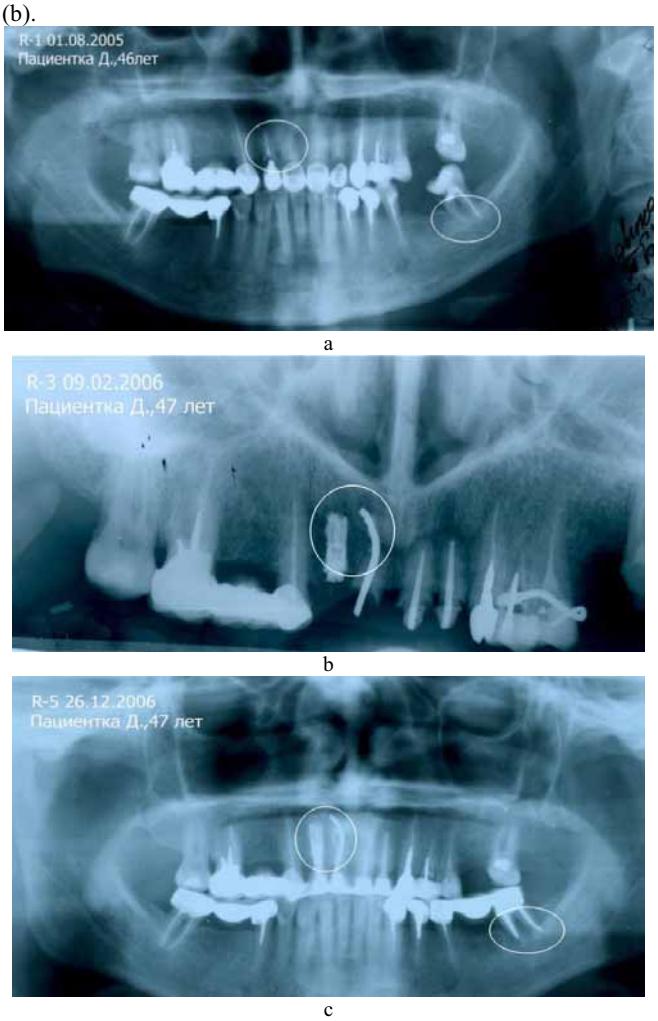
We report on the results of three years practice of the severe periodontal cases treatment be application of the heterophase implantation system, including series of TAL implants made from nanostructured NiTi alloy with SME and heterophase gel-composite injection implants. The gel-composite injection is usually undertaken before DI or TRI implantation in order to strengthen and enlarge the jawbone. The effect of thin jawbone treatment by gel-composite is demonstrated by XR tomograms on Fig. 2 b. The region of thin jawbone is shown before and 30 days after the injection of gel-composite. The almost threefold growth of the bone from 2,2 mm to 6,0 mm is seen, which is quit reasonable for the NiTi implant installation. The gel-composite can be applied not only as complementary procedure before the DI or TRI implantation, but is rather effective in treatment of parodontosis, periodontitis and other severe periodontal cases.

The results of complex application of DI, TRI and gel-composite are shown on the series of XR photographs on Fig. 4 a-c. The initial state of the case is shown on Fig. 4 a. The two teeth are to be treated, with one of them having broken root being replaced by DI, but another being enforced and saved by implantation of TRI. The results of the DI and TRI implantations are shown immediately after the operation on Fig. 4 b. The successive treatment with gel-composite injections has led after 2 years to a stable position of the implants, dense and functional jawbone. The evolution of the bone tissue after gel-composite treatment is illustrated by XR images on Fig. 5. The R1 image shows the state of the bone tissue after TRI implantation. The bone is rarified. R2 reflects the result of gel-composite treatment 2 years the after implantation. The NiTi particles stay in the region of interaction of the living tissue and metallic implant. The result is the formation of functional bioinorganic composite which we call "phoenixon".



a b

Fig. 3 The biological tests on bio-adaptability of the powdered NiTi *in vitro.* The photos show that the culture of living human lever cells not only survive in contact with NiTi (a), but tend to change the place from standard biocompatible substrate to particles surface (b).



a b c

Fig.4. The results or the treatment of Patient D, 46 years. R 1 - before treatment . b) R 2 - immediately after the TRI and DI TAL-3 implantations. The bone is rarefied. The gel-composite is applied. c) R 3 - 2 years after treatment. The bone is dense and functional.

After 3 years of the new system clinical application it was proved the survival rate of 93.4% for all implants and the tendency towards rise of the survival rate is positive. Due to SME after implantation and effectiveness of gel-composite treatment of the bone tissue of the patient the ease of implantation is achieved in cases of jawbone deficit. The multiple cases of severe parodontosis treatment proved efficiency of the gel-composite injections, including those cases where no DIs have been implanted or the traditional titanium implants needed adaptation and enrichment of the jaw. In all of these cases no signs of DI and TRI rejections after long time operation have been observed.

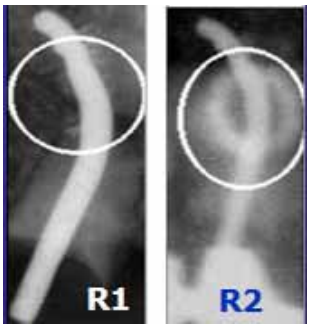


Fig.5. The conservation of the tooth and healing of the jawbone by combination of TRI TAL-1 and gel-composite injection implantations. R1 – The bone is rarefied around the TAL-1 implant installed. R2 – 2 years after the implantation followed by the injection of gel-composite into the bone near the implant. The dense region on R2 near the TRI TAL-1 is recognized like new bioinorganic functional structure "phoenixon", with the bone around being dense and reinforced.

7. Conclusion

New heterophase implantation system for severe periodontal diseases treatment was proposed. The system comprises of the series of new DIs and TRIs made from the nanostructured NiTi alloy with SME, as well as the injection implants – powder Ni-Ti based gel-composites and the tools and methods of the treatment. The linear chain carbon coverage is applied on the surface of DIs and TRIs to insure better biocompatibility. The nanostructured Ni-Ti alloy have been obtained by ECAP and have demonstrated the strongly enhanced mechanical reliability together with enhanced functional properties which allows at the same time to enhance the reliability the of the implants and to diminish the overall size of the implants which in turn gives the opportunity of the easier installation and adaptation especially in cases when the jawbone is in deficit. Another component of the system is the injection implanted gel-composite based on powder NiTi, which is to be used both for adaptation of implants and enrichment of the jawbone before and after the DI implementation and for solitary use for parodontosis treatment. The system includes all the tools and procedures necessary to perform the treatment. We report the experience of 3 years of successful practice of the application of the new implantation system to severe periodontal cases, including adentia, parodontosis, periodontitis etc. It's effectiveness in clinical conditions was demonstrated. It is shown that application of the new system not only improves survival rate of implants, but also allows savage of those teeth that were recommended for deleting by traditional methods.

Acknowledgment

The authors greatly appreciate fruitful discussions with professors V.E.Gunter, G.P.Ter-Asaturov, L.P. Sokov, E.L.Sokov, S.L.Sokov, O.L.Hasanov, S.N.Kulkov, B.I.Beletskiy, L.N.Gurfinkel, L.P.Istranov, S.D.Prokoshkin, M.I.Scherbakov.The work is supported by FASIE Government Contract No 8188.

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