The Advantages of Bioresorbable INION® Implants in Traumatology

Design, polymer composition and preliminary results

ANDREI SCRIPCARU[1], NORIN FORNA[1]*, ALEXANDRU BOGDAN CIUBARA[2]*, HOREA RARES CIPRIAN BENEA[3]*, VLAD VERINGA[1], MIHNEA THEODOR SIRBU[4], RAZVAN TUDOR[5], PAUL-DAN SIRBU [1]

[1] Grigore T. Popa University of Medicine and Pharmacy, Faculty Of Medicine, Department of Orthopaedics and Traumatology, Surgical Sciences (II), 16 Universitatii Str., 700115, Iasi, Romania

[2] Dunarea de Jos University, Faculty of Medicine and Pharmacy, Departament of Morphological and Functional Sciences, 35 Al. I.Cuza Str., 800010, Galati, Romania

[3]Iuliu Hatieganu University of Medicine and Pharmacy, 8th Department, Orthopedics and Traumatology Discipline, 47 Traian Mosoiu Str., 400132, Cluj Napoca, Romania

[4]Grigore T. Popa University of Medicine and Pharmacy, Faculty Of Medicine, 16 Universitatii Str. , 700115, Iasi, Romania

[5]Vaslui County Hospital, Department of Orthopaedics and Traumatology, 233 Stefan cel Mare Str. 730006, Vaslui, Romania

Some disadvantages of traditional metallic implants used in orthopedics and traumatology prompted the development of bioresorbable polymer devices.The aim of this experimental study is to emphasize the characteristics of INION® resorbable implants (regarding design and polymers compositions), as well as to evaluate the results when using these innovative implants in two trauma cases. The polymers used in manufacturing INION® devices (Trimethylene Carbonate/TMC; L-Polylactic acid/LPLA; D,L Polylactic acid/ DLPLA; Polyglycolic acid/PGA) degrade in alpha-hydroxy acids, gradually losing their hardness in 18-36 weeks with a complete bioresorption of 2-4 years. The clinical cases demonstrated the advantages of INION® plates (adapted shape, low profile, polyaxial screws, acceptable strength) or pins (allowing the aligmment and fixation of fracture, no migration). Among our patients, we found excellent results concerning the maintaining of primary reduced fracture, active range of motion, minimal pain with improving everyday comfort, no tissue or implant complications. Bioresorbable fracture fixation INION® devices are a viable alternative to traditional metallic implants, offering same significant advantages over them: the avoidance of long-term interference with gliding structures, keeping their strength long enough to support bone healing, no need to remove the implants, less pain, radiolucency, elimination of stress shielding and a lower risk of complications.

Keywords : bioresorbable, polymers, bioresorption, polyaxial screws, stress shielding
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Internal fixation devices in orthopedic surgery such as plates, screws, pins, staples and suture anchors manufactured from stainless steel, titanium or other materials have been used for many years. [1].However, despite their global use, some complications or disadvantages were identified such as longterm migration, deterioration of the osteosynthesis material, reaction to the osteosynthesis material, interference with standard and MRI imaging techniques, stress shielding with bone resorption and weakening, growth restriction in young patients, necessity of elective removal of implants after fracture healing[2-4].

One of the challenges related to medical research is the manufacturing of some biomaterials (biodegradable and bioresorbable) with the necessary characteristics to help with healing of various medical pathologies[2,5].The first biodegradable material used for sutures was collagen which degraded proteolytically and disappeared due to phagocytosis, causing a local inflammation of the tissue [6,7]. Many macromolecular compounds are biodegradable but few of them have the necessary properties to be used as internal bone fixation devices. The most used materials in medical practice due to their excellent biocompatibility with the human body are polyglycolic acid (PGA), polydioxanones (PDS) and polylactic acid (PLA)[8-10].

The characteristic of an *ideal* bioresorbable material must be: reproducible synthesis, versality (amendable to a variety of polymer processing techniques) retaining sufficient strength over the time, no inflammatory reactions that necessitate removal[2].

Bioresorbable implants are increasingly used in trauma, orthopedic and cranio-maxillofacial surgery [2, 3, 11-13]

The aim of this experimental study is to emphasize the characteristics of INION® resorbable implants (regarding design and polymers compositions), as well as to evaluate the results when using these innovative implants in two trauma cases.

Experimental part

INION®bioresorbable plates and pins

The INION® bioresorbable plates and pins are preferable in complex fractures of the proximal and distal humerus, fractures of peroneal malleolus, fractures of the forearm, fractures of the distal radius, knee osteochondral lesions, surgery of the forefoot and hand, fixation of bone grafts or bone substitutes [3, 11, 13-16]. Their characteristics comprise: the possibility to cut the plates at the necessary length and shape depending on the patient's anatomy, the possibility of "low profile" mounting by cutting the heads of the screws, the possibility of inserting some polyaxial screws as well as radiotransparency (fig. 1). [17] The advantages of the bioresorbable plates compared to classic plates are the possibility to be used in the most difficult anatomical cases, they have a low risk of irritation of tissues and allow the complete visualization of the fracture. The polymers used in manufacturing the plates, screws and

* *email : norin.forna@gmail.com; abciubara@yahoo.com; beneahorea@yahoo.com*

pins (Trimethylene Carbonate/TMC;L-Polylactic acid/LPLA; D,L Polylactic acid/DLPLA; Polyglycolic acid/PGA) degrade in alpha-hydroxy acids, gradually losing their hardness in 18-36 weeks with a complete bioresorption of 2-4 years [18,19].

The INION®bioresorbable pins allow the alignment and fixation of fractures (forefoot, wrist or radial head fractures), osteotomies, arthrodeses or bone grafts in the presence of the necessary additional immobilizations (other rigid fixations, cast). Regarding their advantages, the pins do not migrate externally, have a lower risk of infections and are more comfortable for the patients. Although according to biomechanical tests, the Kirschner pins are 16 N (equivalent of 1.6 kg) more firm than the bioresorbable pins, from a clinical point of view, they are similar [18-19].

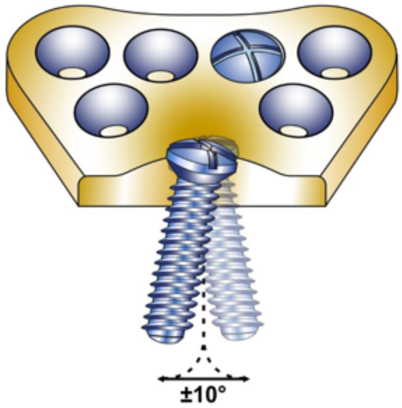

Fig. 1.The bioresorbableINION®plates allow the insertion of polyaxial screws (the screw position can be changed with 10° in any direction inside a solid cone); Adapted image from [18,19]

Synthesis of polymers for application in INION® bioresorbable devices

A polymer is a substance consisting of molecules with a high molecular mass formed from a high number of small identical molecules called monomers [20-21].

The lactic acid (acid 2-hidroxipropionic) is a monomer consisting of 2 enantiomers (L and D), considered to be the monomer with the highest potential in chemical conversions due to the carboxylic and hydroxylic group (fig. 2)[21-24].

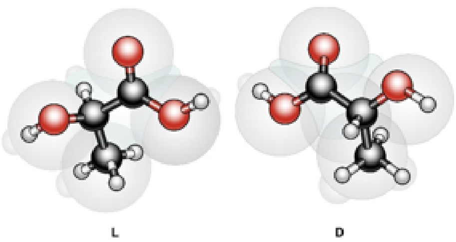

Fig. 2. L-and D- Lactic acid. Adapted image from [21]

Obtaining lactic acid by fermentation differs depending on the bacteria type used. In the heterofermentative process by hexose equimolar quantities of carbon and ethanol are produced while in the homofermentative process via the hexoses metabolism only lactic acid is produced. Due to its features, the lactic acid may protrude through the lipid membrane serving as an energetic sub-layer and may enter in cells via the protein transport system, the monocarboxylate transporter (MCT). [21] In the cell, the lactic acid is transformed in glucose serving as an energetic and protecting layer against the damages generated by the free radicals due to its anti-oxidizing properties [21,23-25]

The polylactic acid is a chiral polymer produced by processing and polymerization of lactic acid monomers and is formed from asymmetrical carbon atoms with a helicoid structure. The term polylactic acid represents a family of polymers: pure poly-L-lactic acid (PLLA), pure poly-D-lactic acid (PDLA) and poly-D,L-lactic acid (PDLLA). Depending on the composition of L-enantiomers, the polylactic acid can be crystalized in three forms (α, β, and γ) [21,26-29] The polymerization process from lactic acid to polylactic acid can be made through different methods including: polycondensation, ring opening polymerization and directly by azeotropic dehydration or enzymatic polymerization (fig. 3)[21,30]

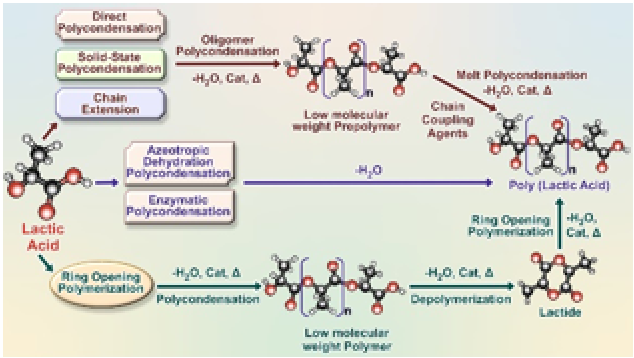

Fig. 3. Synthesis methods for Polylactic Acid .Adapted image from [21]

Properties of polymers

The crystallinity and properties of the polylactic acid largely depend on the stereochemistry and thermal history. The polylactic acid with a content of over 90% pure poly-L-lactic acid (PLLA) tends to be crystalline compared with the amorphous aspect of the polylactic acid with an inferior pure optical content. The melting temperature and the glass transition temperature of the polylactic acid decrease together with the level of poly-L-lactic acid in the composition. The physical characteristics of the polylactic acid such as density, thermal capacity and mechanical capacity depend on the transition temperatures [21, 29, 31-32].

The glass transition temperature is one of the most important parameters since the changes in the mobility of the polymeric chain occur at and over this temperature (T-table 1)[21, 31-33]

Table 1

PROPERTIES OF LACTIC ACID POLYMERS ADAPTED IMAGE FROM [21]

LACTIC ACID POLYMERS	DENSITY (G/CML)	MELTING TEMPERATURE (°C)	GLASS TRANSITION TEMPERATURE (°C)
PLLA	1.290	173 – 178	55 – 80
PDLLA	1.25	120 – 170	43 – 53
PDLA	1.248	120 – 150	40 – 50

Resorption of bioresorbable implants

The degradation of the polylactic acid takes places mainly by hydrolysis after months of exposure to humidity. The breaks of the non-enzymatic chains of the ester links lead to a gradual decrease of molecular weight until the molecular weight of the lactic acid and oligomers allows their metabolization by microorganisms in carbon dioxide and water [21, 34-36].

The materials used in INION® bioresorbable implants are amorphous and degrade in vivo by hydrolysis and later on they are metabolized by the body in CO2 and H2O. The degradation profiles were adapted in order to assure initial stability and then the progressive charging of the bone in order to stimulate regeneration. The implants gradually lose their resistance after 18-36 weeks in vivo with a complete resorption in 2-4 years [18,19].

Clinical cases

Case 1

A 36 years old female with polytrauma and a right distal radius fracture;open reduction and internal fixation with a bioresorbable INION® plate and screws is performed (fig. 4).

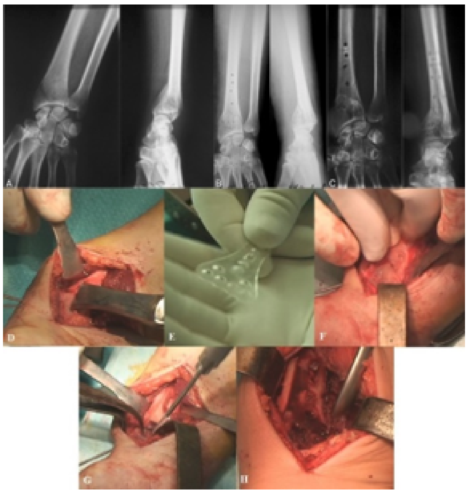

Fig. 4.A-H Osteosynthesis with a INION® resorbable plate for a distal radius fracture A.Initial radiographs of the wrist; B. Postoperative control radiographs with implant radiolucency, good reduction and screw holes visualization; C. Postoperative control radiographs at 3 months; Fracture healing, implant radiolucency and holes visualization D. Intraoperative image with reduced distal radius fracture site; E. Aspect of the INION® bioresorbable plate; F. Intraoperative plate positioning; G - H Insertion of the bioresorbable polyaxial screws;

Case 2

A 18 years old patient with a trauma due to falling from the same level. He is admitted with the diagnosis of bilateral radial head; open reduction and internal fixation with INION® bioresorbable pins is performed on the right side (fig. 5).

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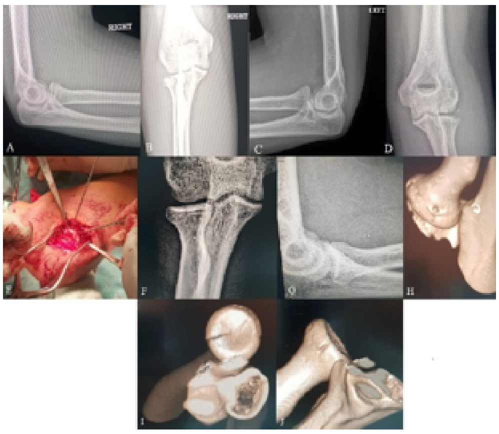

Fig. 5A-J - Osteosynthesis with INION® resorbable pins for a radial head fracture;A - B - Right radial head fracture;C -D -Left radial head fracture;E - Intraoperative image withinsertion of the INION® bioresorbable pins; F -G - Postoperative radiographs with good reduction of the articular fracture and radiolucency of the pins; H - J- Postoperative CT with 3D reconstruction; good reduction and visualization of the tip of the pins

Results and discussions

Among our patients operated with INION® bioresorbable implants, we found excellent results concerning the maintaining of primary reduced fracture, active range of motion, minimal pain postoperative with improving everyday comfort, no tissue or implant complications.

The most common biomaterials used in medical practice due to their excellent compatibility with the human body are polyglycolic acid (PGA), polydioxanone acid (PDS) and polylactic acid (PLA) [8-10].

The crystallinity and characteristics of polylactic acid depends mostly on stereochemistry and thermic history (melting temperature and glass transition temperature) as well as the level of poly-L-lactic acid in its composition. Polylactic acid degradation occurs mainly by hydrolysis after months of exposure to moisture. The fracture of the nonenzymatic chains of ester linkages lead to a gradual decrease in molecular weight until molecular weight of lactic acid and oligomers allow their metabolism by microorganisms into carbon dioxide and water [33, 35-36].

INION® bioresorbable implants made of Trimethylene Carbonate TMC, L -Lactide LPLA and D,L -Lactide DLPLA, degrade in vivo by hydrolysis, subsequently being metabolized by the organism in CO2 and H2O. Degradation profiles were adapted to provide initial stability and then progressive bone loading to stimulate regeneration. The implants gradually lost their resistance after 18-36 weeks in vivo with complete resorption between 2 and 4 years [18-19].

The studies showed the fact that the healing time in case of bioresorbable implants is almost equal with that of the classic implants. With a success rate of 96.88%, besides the excellent biocompatibility with the body, the bioresorbable implants have the advantages that they do not irritate the surrounding tissues, a secondary surgical intervention is not necessary for the ablation of the osteosynthesis material, they allow micro movements at the fracture focus level favoring a faster consolidation and healing. Although the bioresorbable implants are more expensive, the final price is lower compared with classic implants which need two surgical interventions [34,37-38].

Previous experience and a significant learning curve is mandatory for obtaining the best results with bioresorbable implants [3].

At the same time, some complications can be attributed to the bioresorbable implants such as a failure rate of the internal fixation device of 1.2%, an infection incidence of 1.7% and an incidence of the aseptic inflammation which needs surgical drainage of 7.8% [30,37-38].

Today there is a limitation and a low confidence in using biodegradable implants due to their mechanical properties and polymer strength (which are lower than the traditional metallic implants) [5]. In the same time, the interfragmentary compression is not well realized with the miniscrews and biocompatibility is still an insufficient solved problem [5,7].

For sure, the future implant design will overcome the limits of polymer strength [2] and the combination of bioabsorbable implants with therapeutic agents or osteogenic substances will improve the bone healing [3].

Conclusions

From collagen bioresorbable suture wires, the development of bioresorbable and biocompatible materials such as polyglycolic acid (PGA), polydioxanone acid (PDS) and polylactic acid (PLA) represents a medical advancement with use in the healing of different pathologies.

Bioresorbable fracture fixation INION® devices are a viable alternative to traditional metallic implants, offering same significant advantages over them:the avoidance of long-term interference with gliding structures, keeping their strength long enough to support bone healing, no need to remove the implants, less pain, radiolucency, elimination of stress shielding and a lower risk of complications.

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