Foundation for Cardiac Surgery Development
im. prof. Zbigniewa Religi

Artificial Heart Laboratory

TiN diffusive layers applied as athrombogenic surface for cardiac implants: heart valves, rotary blood pumps

Foundation for Cardiac Surgery Development
Heart Prostheses Institute
Artificial Heart Laboratory

INTERNATIONAL SCHOOL OF CARDIAC SURGERY
INTERNATIONAL SCHOOL OF SOLID STATE PHYSICS
ERICE, 2015

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Diffusive layers developed in so called glow discharge plasma potential:

nitriding layer
$TiN+Ti_2N+\alpha Ti(N)$

oxynatriding layer
$TiO_2+TiN+Ti_2N+\alpha Ti(N)$

TECHNOLOGICAL STAND FOR GLOW DISCHARGE SURFACE LAYER PRODUCTION DEVELOPED BY MATERIAL ENGINEERING DEPARTMENT OF WARSAW TECHNOLOGICAL UNIVERSITY

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$TiN+Ti_2N+\alpha Ti(N)$
$TiO_2+TiN+Ti_2N+\alpha Ti(N)$

- ✓ **High adhesion to the surface (diffusive character)**
- ✓ **High biocompatibility with fibroblasts, osteoblasts and blood**
- ✓ **High surface hardness and wear resistance**

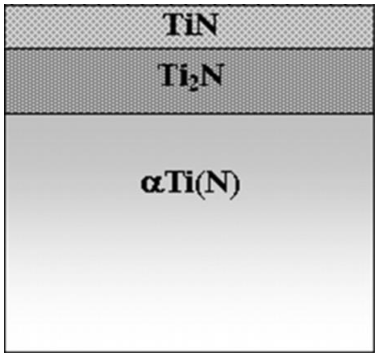
[8] Wierzchoń T., Czarnowska E., Krupa D. ISBN: 83-7207-477-1, Warszawa (2004);
[9] Okrój W. "New technologies for medical applications: studying and production of carbon surfaces allowing for controllable bioactivity" S.Mitura, P.Niedzielski, B.Walkowiak, Wydawnictwo Naukowe PWN, pp. 199-206, Warszawa (2006);
[10] Zhang F., Zheng Z., Chen Y., Liu X., Chen A., Jiang Z. Journal of Biomedical Materials Research v42, pp. 128 – 133 (1998);
[11] Wang X.,, Zhang T. Surface and Coatings Technology, V. 128-129, pp. 36-42 (2000);

$TiN+Ti_2N+\alpha Ti(N)$
$TiO_2+TiN+Ti_2N+\alpha Ti(N)$

↓

minimization of thrombogenicity risk during long term utilization and providing durability of cardiac implants (heart valves, rotary blood pumps etc.)

$TiN+Ti_2N+\alpha Ti(N)$

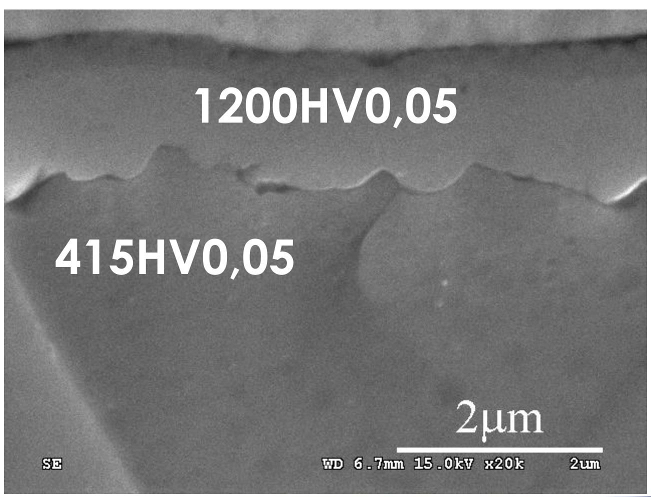


Process parameters:

T = 700ºC

t = 4 hours

p = 2,5mbar



$TiO_2+TiN+Ti_2N+\alpha Ti(N)$

<u>1st phase: nitriding</u>

T = 680ºC, t = 4 hours

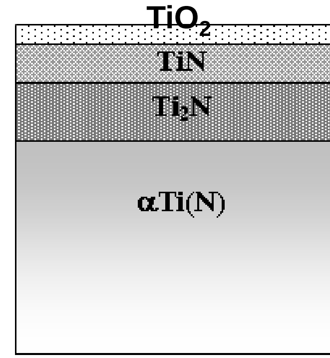
p = 3mbar

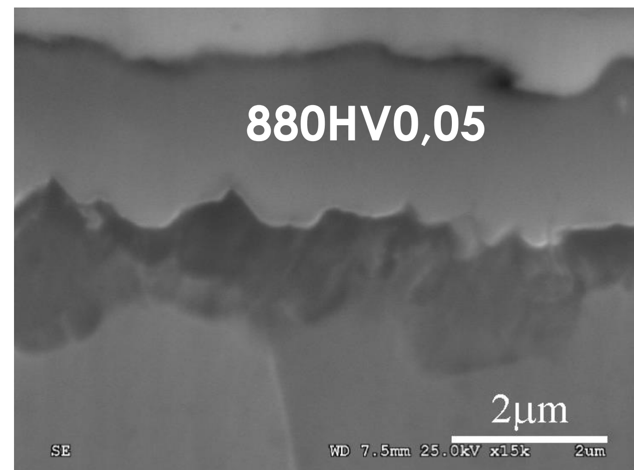
<u>2nd phase: oxidation</u>

T = 710ºC

t = 30 min.

p = 3mbar





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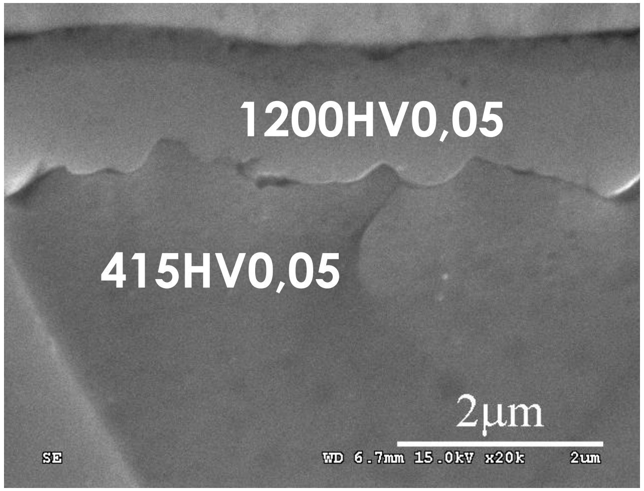
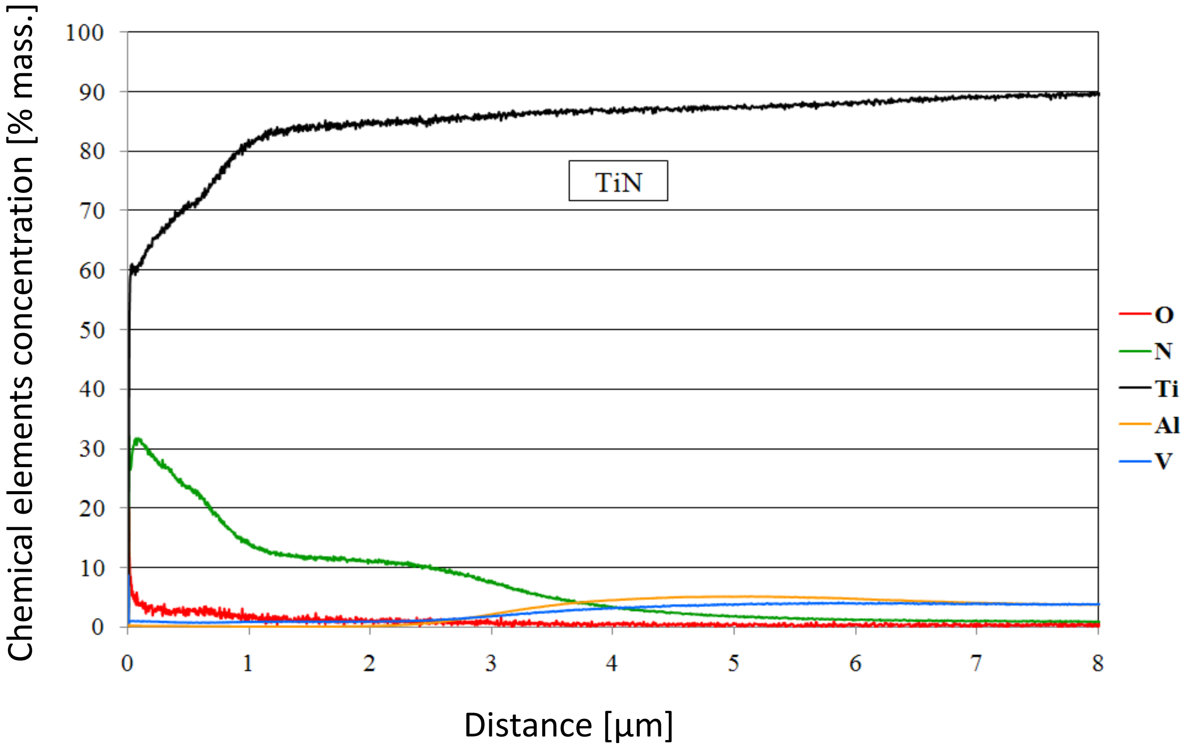
$TiN+Ti_2N+\alpha Ti(N)$

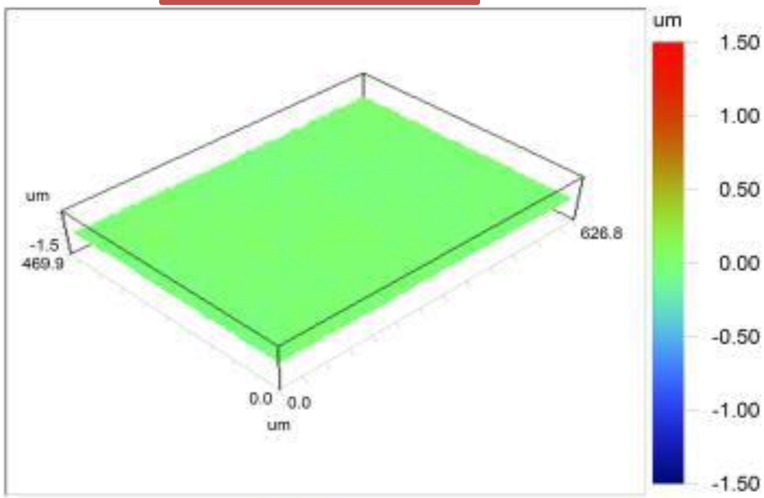


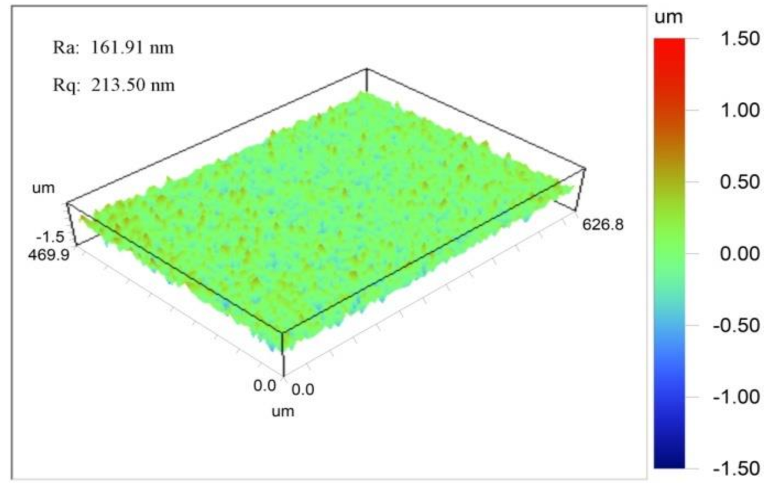
GDOS chemical analysis

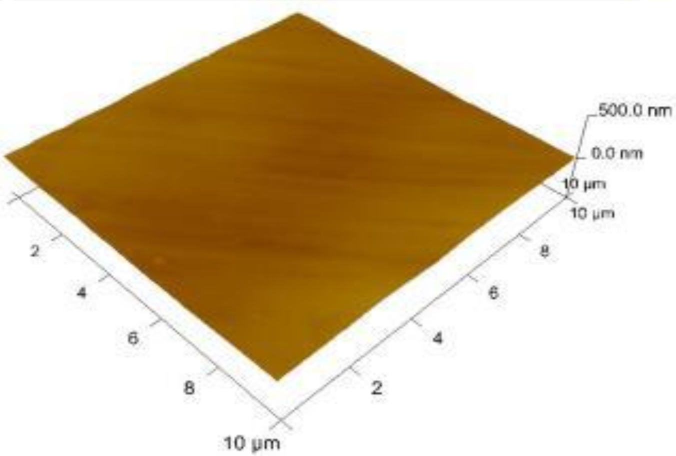


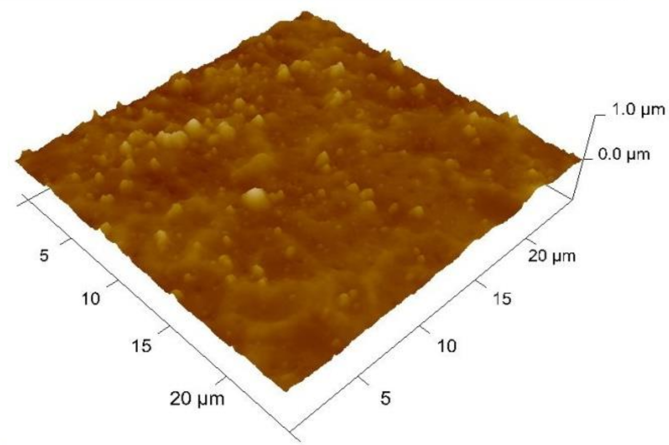
Ti6Al4V

$TiN+Ti_2N+\alpha Ti(N)$

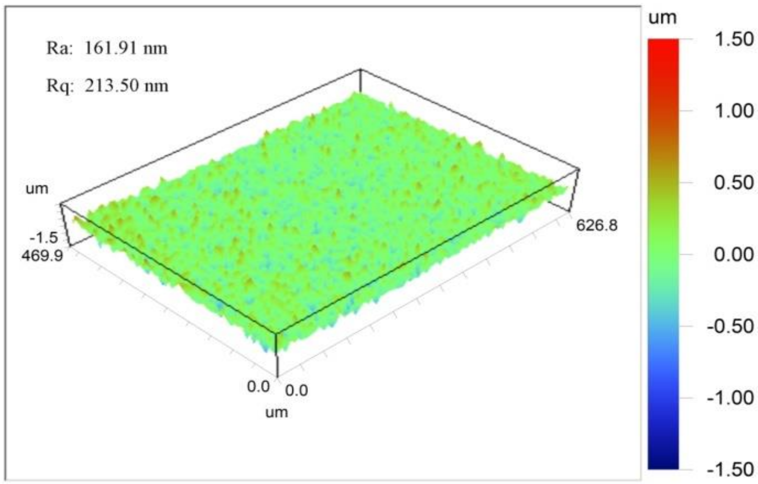


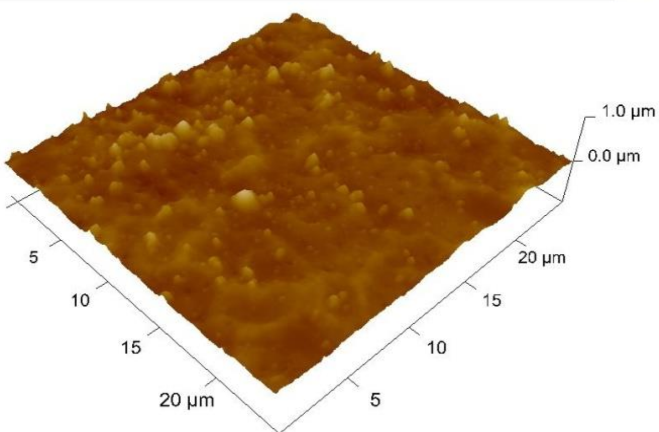




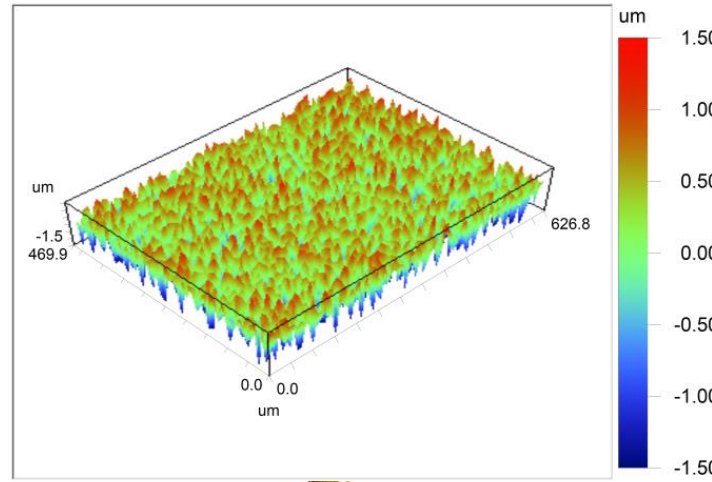


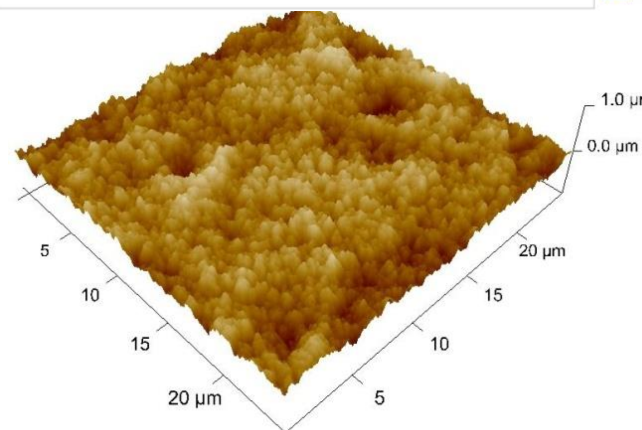
TiN+Ti_2N+αTi(N)





TiO_2+TiN+Ti_2N+αTi(N)





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$TiN+Ti_2N+\alpha Ti(N)$
$TiO_2+TiN+Ti_2N+\alpha Ti(N)$

Homogenous surface structure and topography

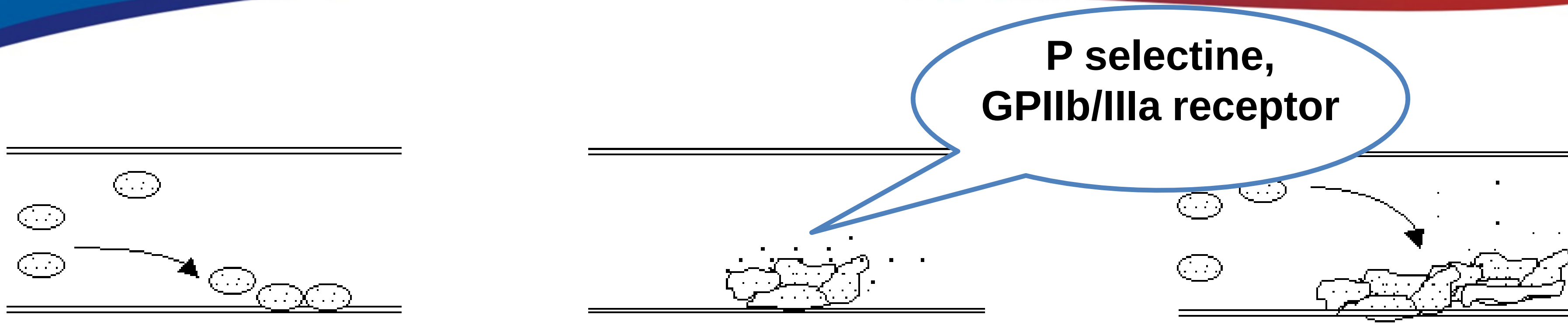
Possibility of surface topography control during the process

High hardness

Very good wear resistance

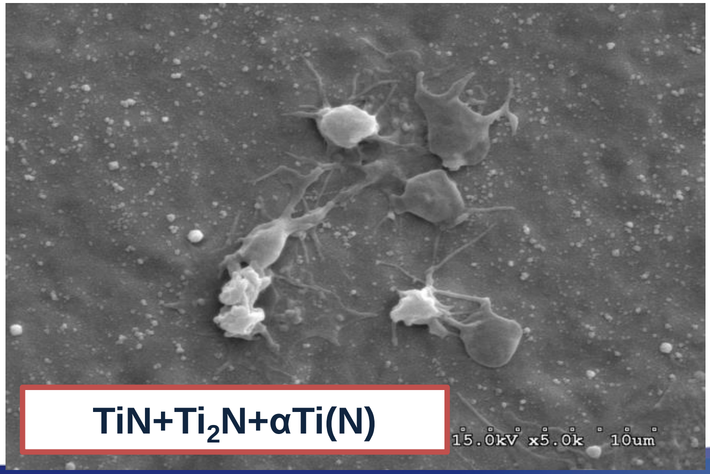
High corrosion resistance

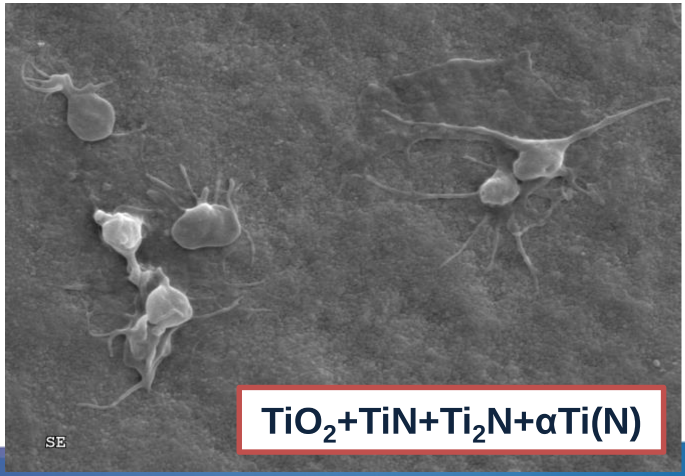
[18] Borowski T., Sowińska A., Ossowski M., Czarnowska E., Wierzchoń T. Engineering of Biomaterials, Rytro (2009);
[19] Ossowski M., Borowski T., Wierzchoń T. Inżynieria Materiałowa, v. 30, nr 5, pp. 294--297 (2009);
[20] Brojanowska A., Kamiński J., Ossowski M., Wierzchoń TOchrona przed korozją, nr 4-5, pp. 135-139 (2008);



PLATELET ADHESION | **PLATELET ACTIVATION** | **PLATELET AGGREGATION**

Static contact with blood - 2 hours of incubation





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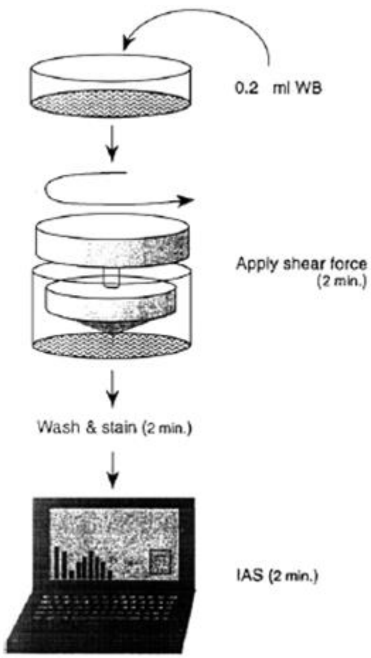
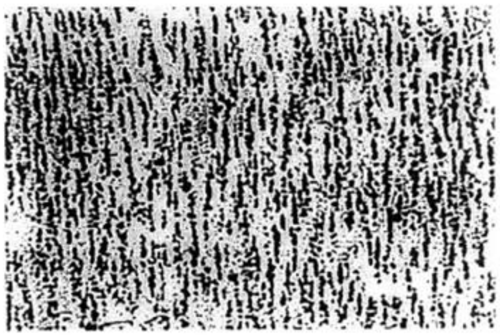
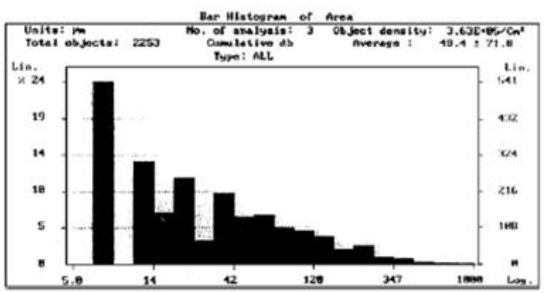
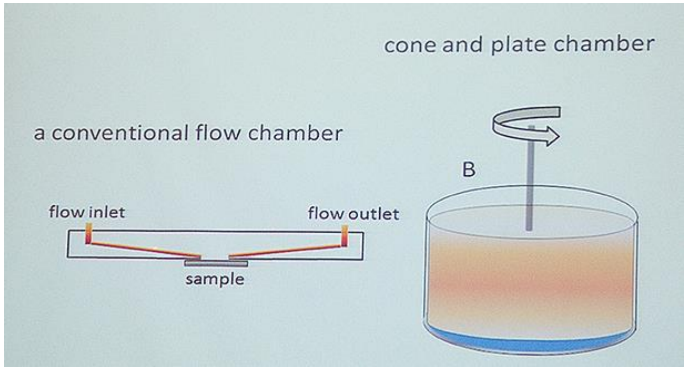
Dynamic contact with blood – shear stress model

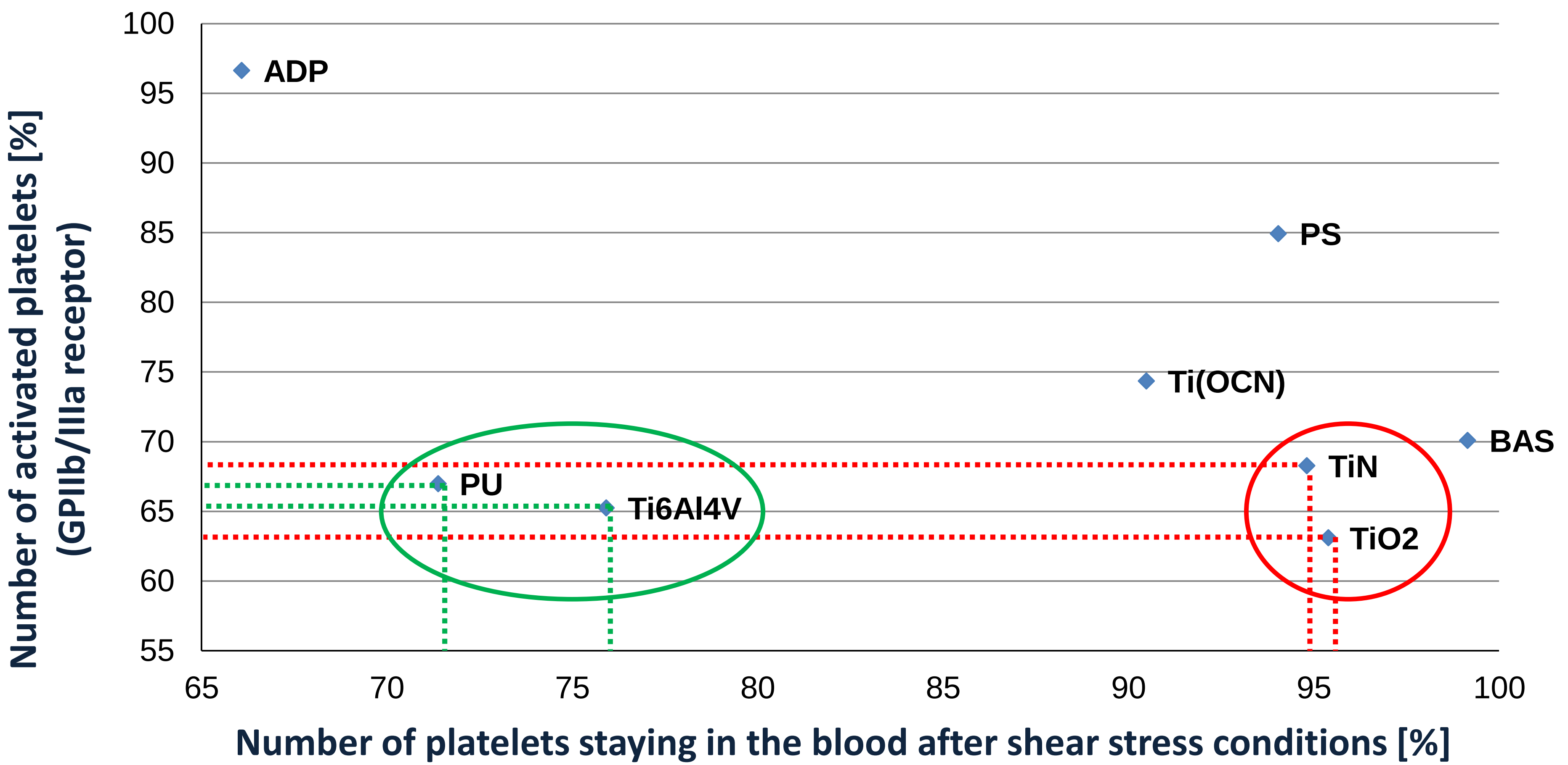




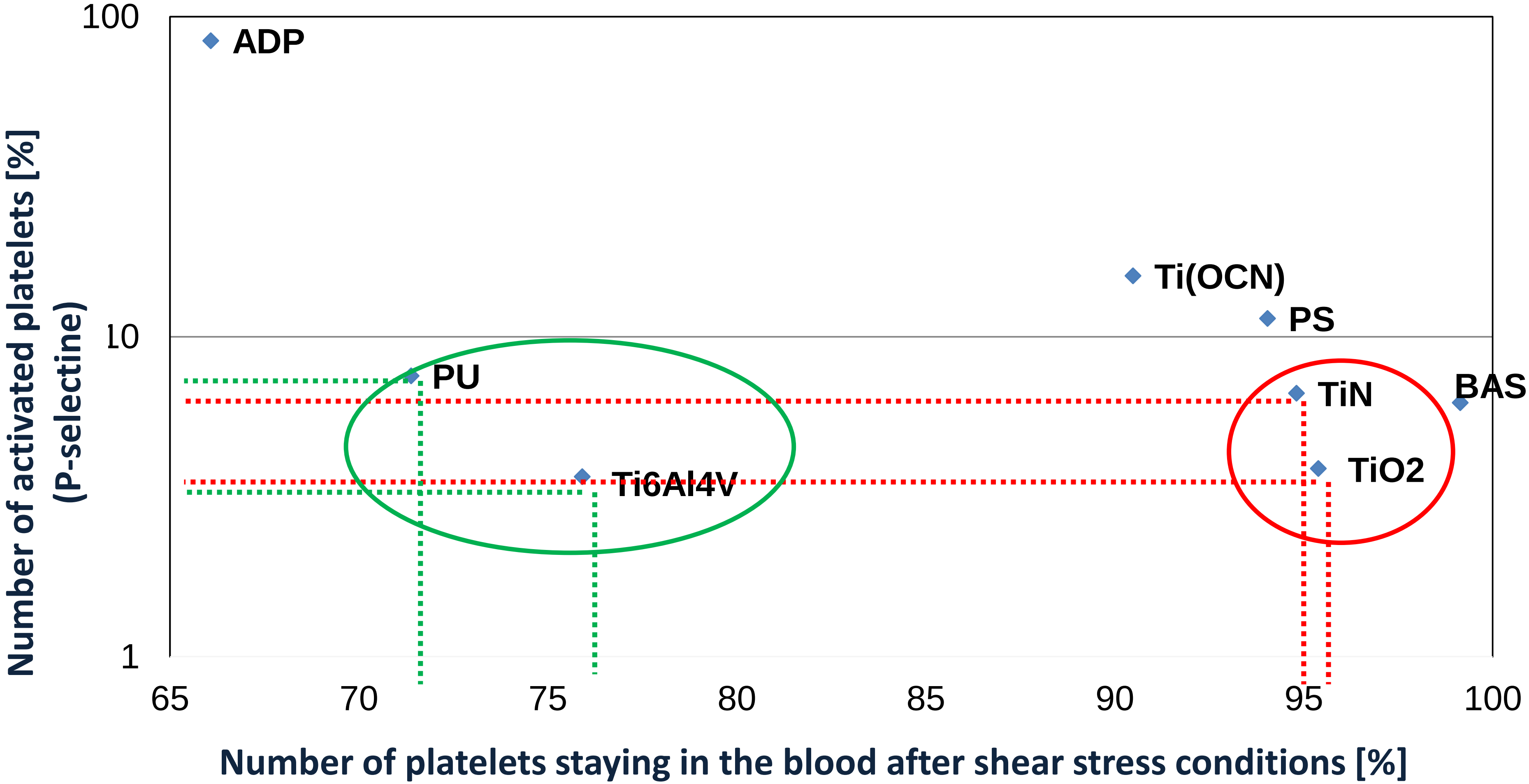




Impact-R

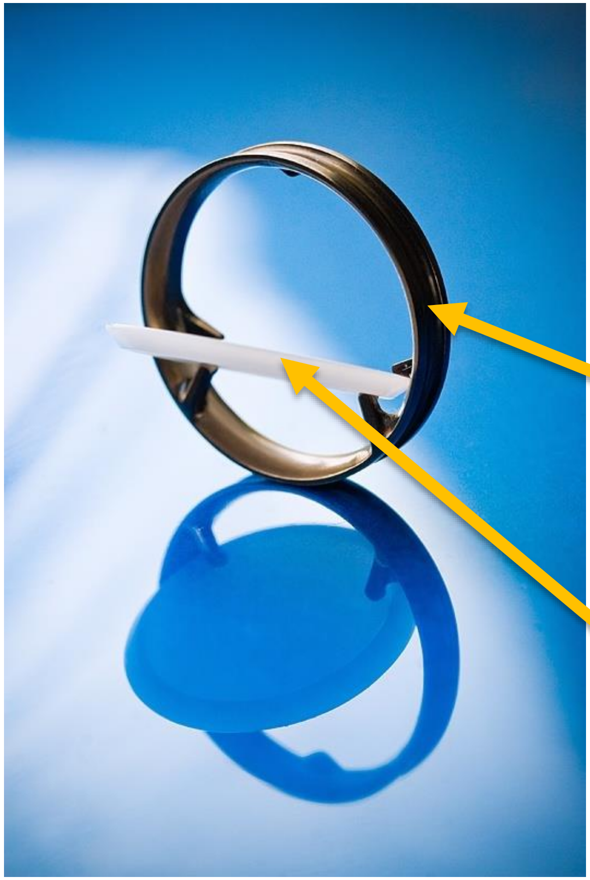


M.Gonsior, et al. Engineering Biomaterials t. 14, no 102, s. 15-22, 2011; M.Gonsior et al. Material Engineering no 3 (175) rok XXXI, 2010; M.Gonsior et al. Engineering Biomaterials 89-91 Volume XII 2009; M.Gonsior et al. Proc. of Biomaterials Conference: „Advancing Biomaterials in Africa", 2009, Pretoria, South Africa.



M.Gonsior, et al. Engineering Biomaterials t. 14, no 102, s. 15-22, 2011; M.Gonsior et al. Material Engineering no 3 (175) rok XXXI, 2010; M.Gonsior et al. Engineering Biomaterials 89-91 Volume XII 2009; M.Gonsior et al. Proc. of Biomaterials Conference: „Advancing Biomaterials in Africa", 2009, Pretoria, South Africa

$TiN+Ti_2N+\alpha Ti(N)$ / $TiO_2+TiN+Ti_2N+\alpha Ti(N)$ application



Original Polish Tilting Disc Valve

[Moll J.J. patent USA 4.661.106, 1987;
Moll J.J. patent USA 4.725.275, 1987]

Valve house: **Ti6Al4V with $TiN+Ti_2N+\alpha Ti(N)$ / $TiO_2+TiN+Ti_2N+\alpha Ti(N)$ layers**

Valve disc: **PEEK OPTIMA polymer**

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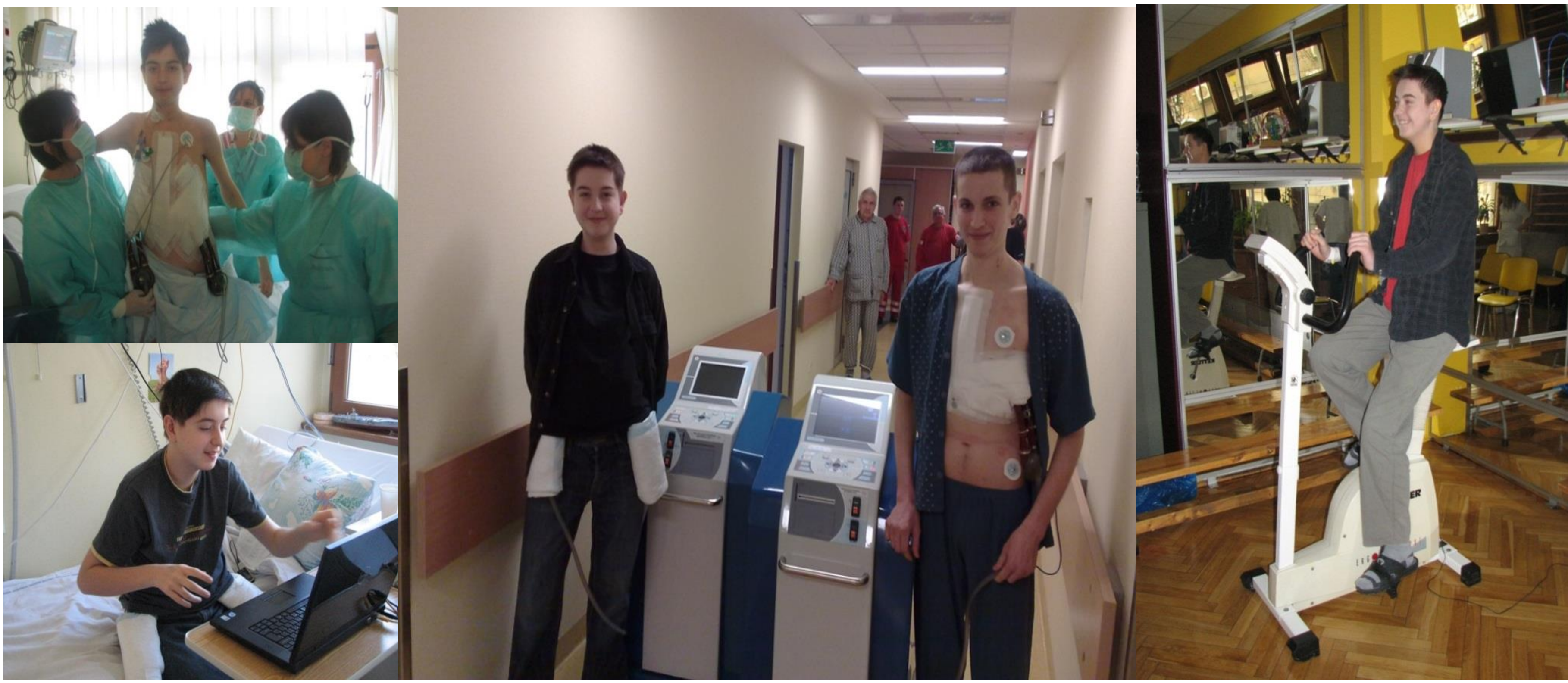
Polish extracorporeal ventricular heart assist device POLCAS

First implantation: 1995
Clinical trials: 1995 - 2000
Clinical utilization: 2000 - 2013

TOTAL IMPLANTS:
323 patients



The longest assistance toward heart transplantation: BiVAD=12; LVAD=13 months, SCCS Zabrze: 2009 -2010

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The longest heart assistance toward heart regeneration;
LVAD = 23 months; SCCS Zabrze, 2011 -2013

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New Polish extracorporeal heart support system

RELIGA HEART
SYSTEMY WSPOMAGANIA SERCA

Technological Department –
ReligaHeart EXT production

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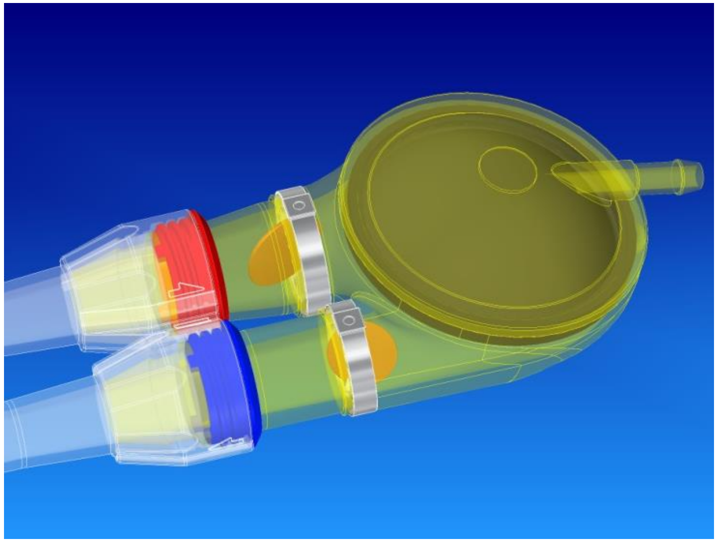
ReligaHeart EXT VAD

- Volume 70 ml and optimized blood chamber construction
- New membrane system with lower profile
- New generation innovative biocompatible PU with modified surface structure (DSM Biomedical USA).
- New tilting disc valves type Moll
- Special cannulas protection system
- Modern technological process of pump elements manufacturing
- Automatized pump assembling process

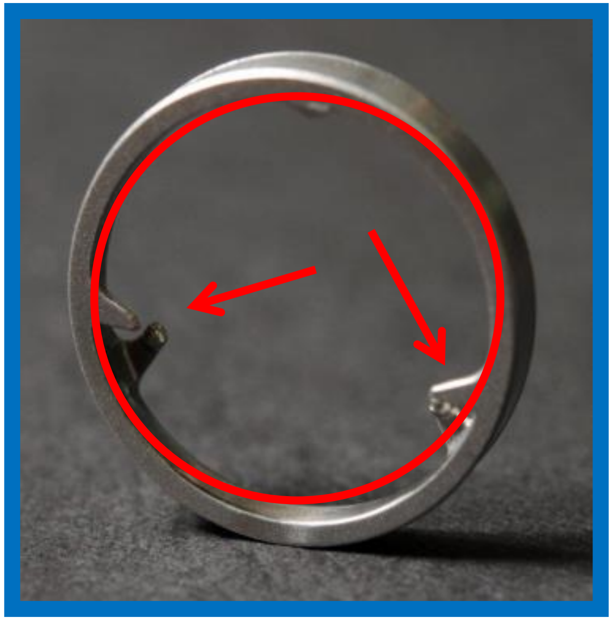


Valves used in POLCAS system

Valves used in ReligaHeart EXT system

Sorin

Medtronic Hall



Moll

Tilting disc Moll Valves with surface engineering

- Inlet valve: size 20 mm
- Outlet valve: size 24 mm
- Ring: Titanium TiN coated
- Disc: PEEK Optima Carbon coated

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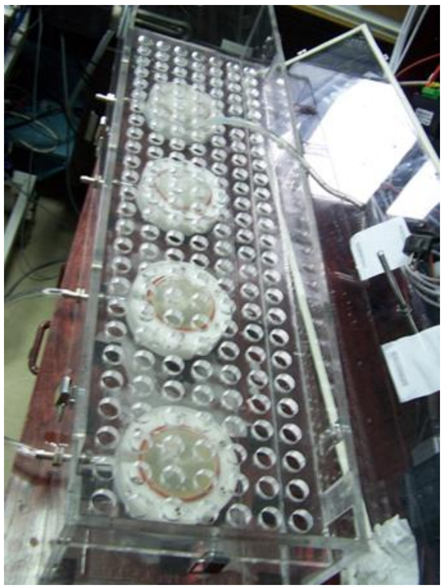
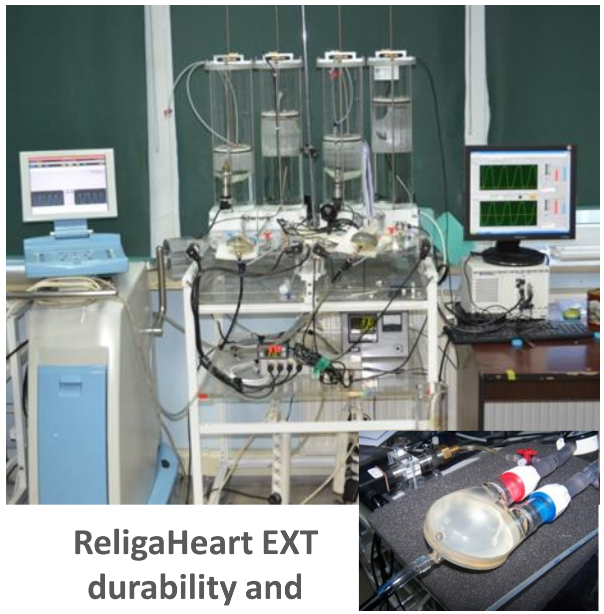
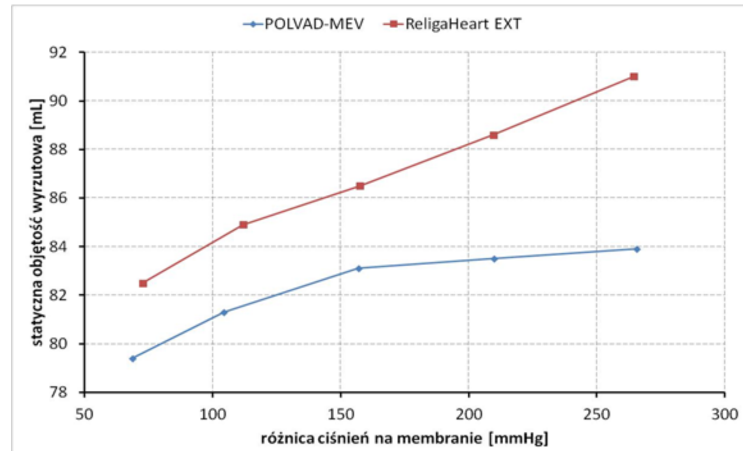
ReligaHeart EXT - Preclinical laboratory examinations



Membrane durability testing



ReligaHeart EXT durability and hydrodynamic testing



ReligaHeart EXT hydrodynamic properties

- 35 millions membrane work cycles = 340 days of 70 bpm stable work
- 10,5 millions RH EXT device workcycles = over 100 days of 70 bpm stable work
- Increasing both: static (+5%) and dynamic (+23%) stroke volume
- No deformations nor damages of PU pump elements, neither the valves

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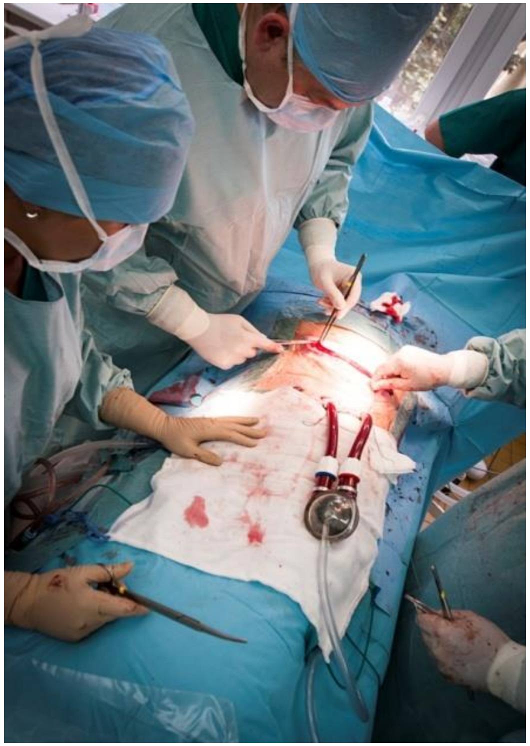
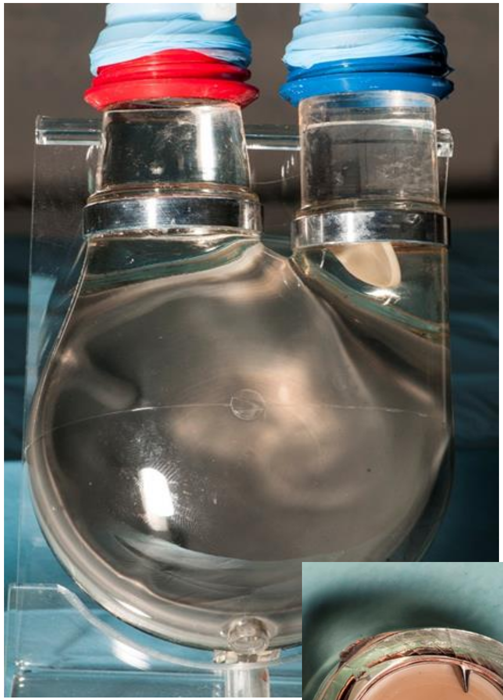
ReligaHeart EXT - Preclinical animal study





- 7 animals
- Up to 30 days investigations
- Warfarin, Aspirin clinical protocol treatment

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I PHASE

II PHASE

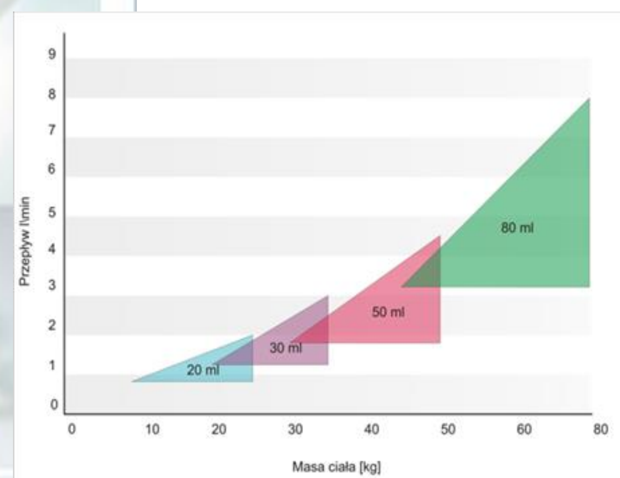
2 clinical applications → I Phase report to Ethical Committee approval → 8 clinical applications

Adverse events and risk evaluation

Effectiveness of heart support using ReligaHeart EXT system

ReligaHeart EXT system usage during over 1500 hours of exploitation confirmed the proper safety of the system

Development of pediatric pulsatile VAD – ReligaHeart PED



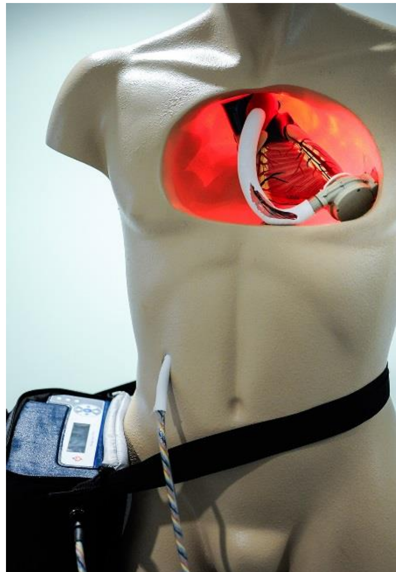
$TiN+Ti_2N+\alpha Ti(N)$ / $TiO_2+TiN+Ti_2N+\alpha Ti(N)$ application

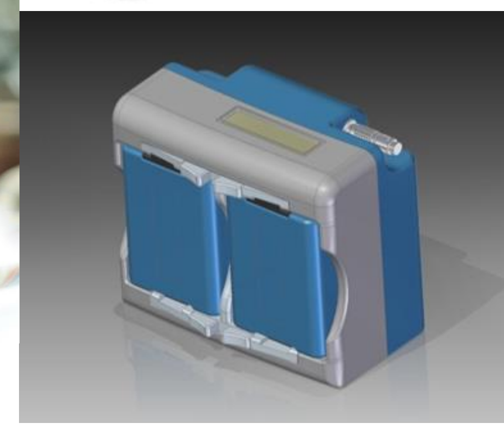
ReligaHeart ROT

Polish left ventricle implantable rotary pump

- low profile impeller, suspended in the middle of pump house, with symmetric gap between pump house and impeller, of 0,15 mm nominal distance each side;
- the jointly acting static magnetic and hydrodynamic forces are used for impeller suspension, while rotating with speed varied from 2000 to 5000 rpm.

- Centrifugal LVAD
- Contactless suspended rotor
- BLCD double motor
- Battery powered
- Remote control
- Long distance communication





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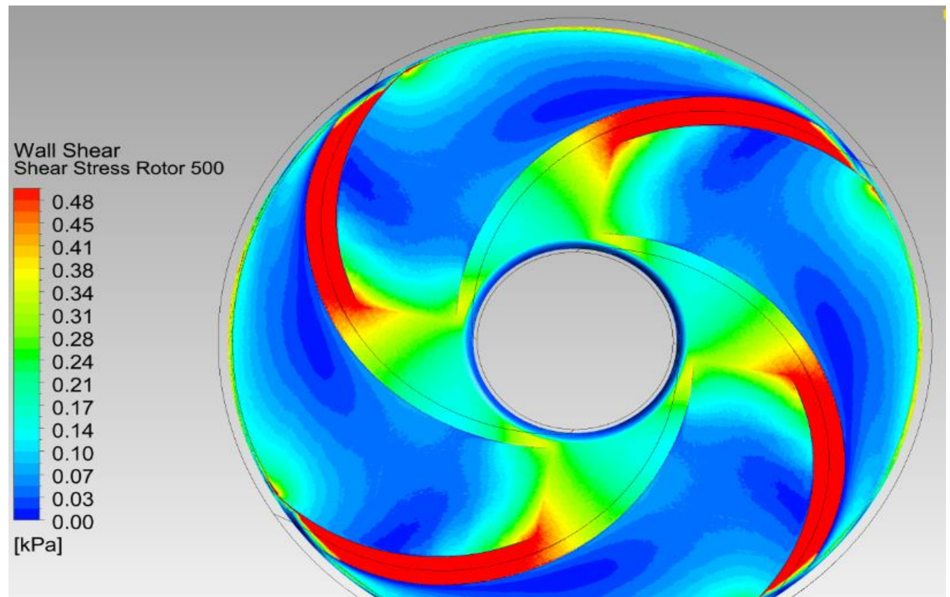
Shear stress in hydraulic bearings area numerically determined for impeller rotation speed of 3000 rpm



The numerically determined wall shear stress produced on the hydraulic bearing blade elements surface (bearing inlet, bearing lifting surface, bridging surface) showed the shear stress values varied from 0,00 to 0,048 kPa. The shear stress exceeding 0,2 kPa level occurred only on small area of bearing bridging surface.

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The physical model for blood rotating with different rotational velocity over a biomaterial surface

Disk to chamber bottom distance:
0,05 - 0,30mm
Disk rotation speed: 500 - 5000 rpm.
Controlled blood flow: 1 - 15 ml/min.

The shear stress exposed thrombocytes activity was determined.
Platelet activation was investigated using flow cytometry.

The biomaterial surface after blood contact was evaluated using fluorescent and confocal microscopy.

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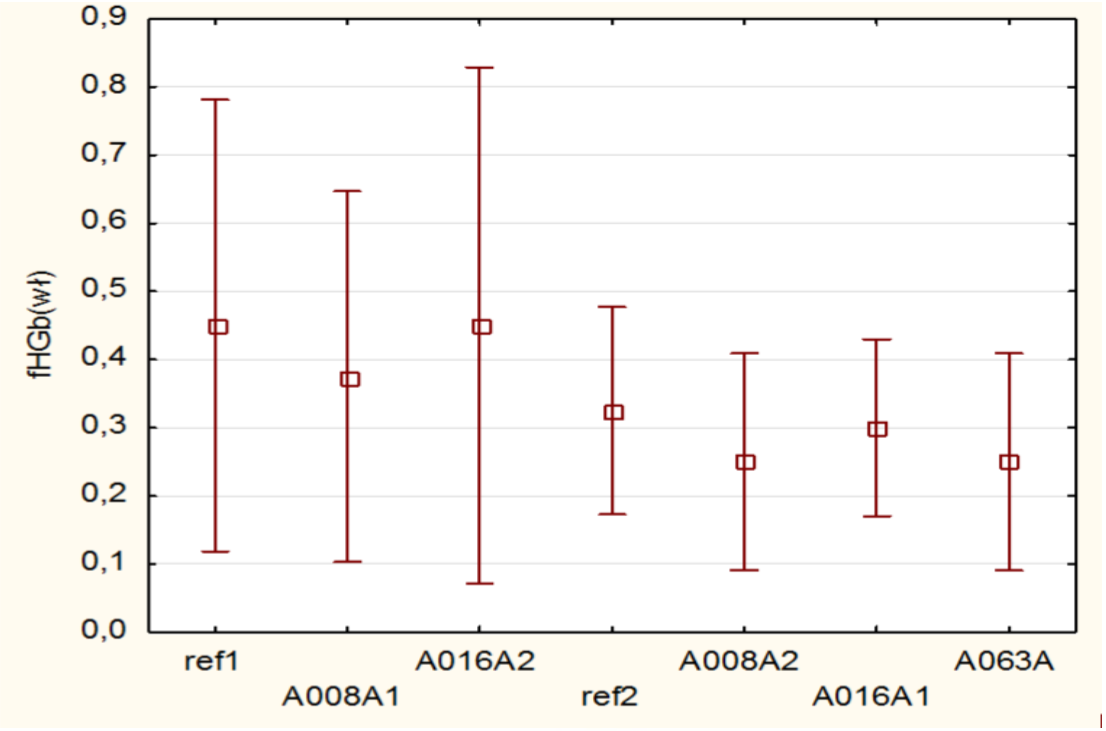
Free haemoglobin level reported in blood after single exposure to high shear stress, produced experimentally by different TiN modified titanium Grade2 surfaces

- ref1, ref2 – Titanium Grade 2 reference samples, roughness 0,08µm;
- A008A1 – TiN layer (created at cathode potential) with Ra=0,08µm;
- A016A2 – TiN layer (created at cathode potential) with Ra=0,16µm;
- A008A2 - TiN layer (created at plasma potential) with Ra=0,08µm;
- A016A1 – TiN layer (created at plasma potential) with Ra=0,16µm;
- A063A - TiN layer (created at plasma potential) with Ra=0,63µm



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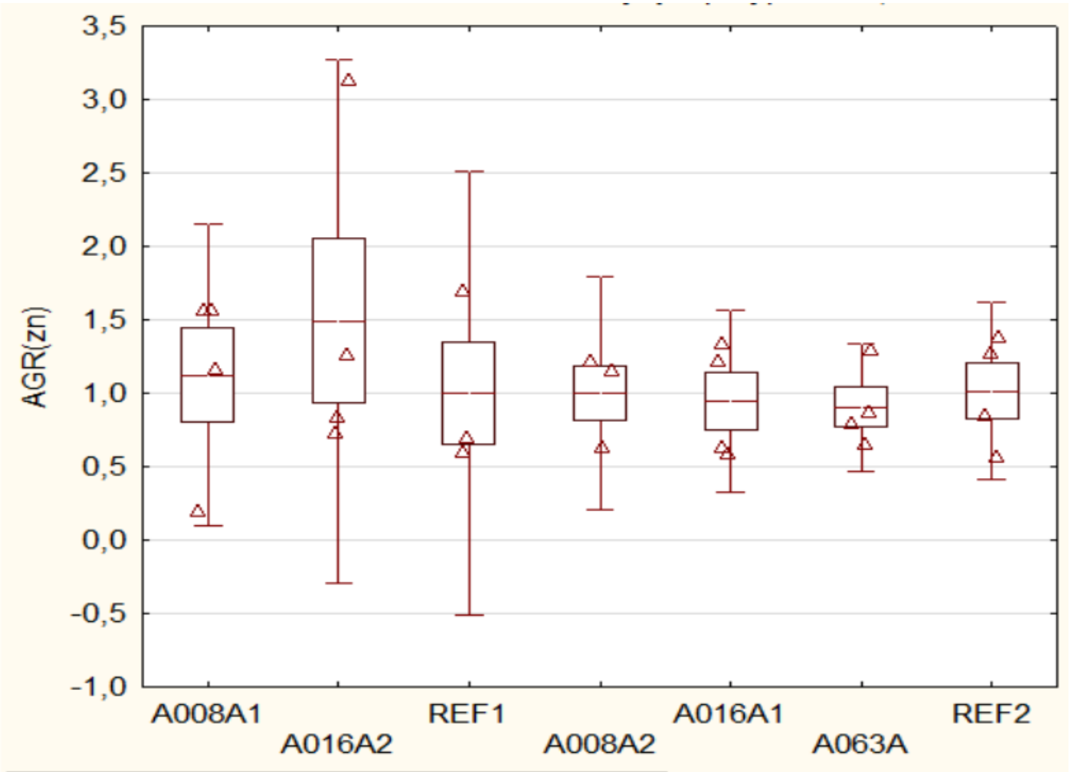
Platelets aggregation level reported in blood after single exposure to high shear stress, produced experimentally by different TiN modified titanium Grade2 surfaces

- ref1, ref2 – Titanium Grade 2 reference samples, roughness 0,08µm;
- A008A1 – TiN layer (created at cathode potential) with Ra=0,08µm;
- A016A2 – TiN layer (created at cathode potential) with Ra=0,16µm;
- A008A2 - TiN layer (created at plasma potential) with Ra=0,08µm;
- A016A1 – TiN layer (created at plasma potential) with Ra=0,16µm;
- A063A - TiN layer (created at plasma potential) with Ra=0,63µm



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The thrombogenicity and hemolytic examinations results analysis demonstrated that diffusive $TiN+Ti_2N+\alpha Ti(N)$ layer produced on titanium surface does not cause erythrocytes damage and platelets adhesion in the dynamic high shear stress conditions.

The developed glow discharge process at plasma potential has allowed to produce diffusive TiN micro-layer on titanium, with controlled surface topography in micro and nano-scale level.
The several microns thick diffusive TiN layers were produced on the different rotary blood pup elements: rotors and blood pump house.
The roughness of TiN layers showed homogeneity on whole modified surface, despite the complex blood pump element's shape.



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Conclusions

Results obtained promise good properties of new developed $TiN+Ti_2N+\alpha Ti(N)$ layers for application in blood contacting elements of heart valves and particularly rotary blood pumps, where blood velocity and shear stresses are very high and increase the risk of thrombosis.

Future steps

The validation of the obtained results will be performed in further laboratory and biological experimental investigations of the ReligaHeart ROT prototype equipped with developed impeller suspension system, with rotor and pump house blood contact surfaces modified of TiN layers, created by glow discharge at plasma potential.

- ✓ In vitro long term work tests
- ✓ In vitro acute thrombogenicity tests with the fresh animal blood
- ✓ In vivo trials

Thank you for your attention

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