Properties of biocomposite on the “bone-to-carbon nano implant” border

George Sh. Golubev¹, Michael B. Rodin¹, and Vladimir A. Irkha^{2,}*

¹Rostov State Medical University of the Ministry of Healthcare of the Russian Federation, 344022 Rostov-on-Don, Russian Federation

²Platov South-Russian State Polytechnic University (NPI), Novocherkassk, Russian Federation

Abstract. Novice carbon nanostructural material was investigated to estimate its integration to the bone tissue. Wedge osteotomy of a femur bone performed in experimental circumstance on 26 white rats (control=6, experiment=21). Wedge-shaped ($h=4$ mm, $r=3$ mm, $\alpha=12$) implants were crafted from carbon nano-structural material and used to fill bone's defect. Rats withdrew from the experiment in 3 months. Mechanical properties of the “bone-wedge-bone” block evaluated by the 3-point bending test. Field emission scanning electron microscope used to investigate biocomposite at the bone-to-implant border. The microelements distribution in the samples measured with energy dispersive X-ray analysis. Biomechanical properties of bone-to-implant biocomposite depend on clinical features of consolidation. Anyway, the toughness (T) of bone-to-implant zone is worse than bone-to-bone regenerate significantly ($T_{\text{contr}} = 56.97$ MPa, $T_{\text{exp}} = 47.68$ Mpa, Welsh p -value = $2.689e-07$). No Ca, or P reveals in the body of implants. The quality and the thickness of the biocomposite on the bone-to-implant border predetermine clinical results of bone substitution. The absence of microelements inside the body of implants confirms that the implant structure is too subtle. Increasing porosity of material and creation of transverse channels can improve bone conduction and scaffold quality of carbon nano-implants.

1 Background

Replacement of fractured bone is the challenge in orthopaedic surgery. The amount of bone grafting procedure is second after blood transplantation in the modern world. Autografts are the current gold standard for bone defects replacement in approximately 58% of the bone grafts used. Allografts are an alternative to autografts. They account for 34% of the current bone grafting. These procedures have a lot of restricting factors such as limited bone stocks, donor or recipient site morbidity, fractures of the grafts and others [1].

The new bone substitution materials are results of mixing biomaterials, ceramics, and nanomaterials. Main demands for new biocomposites are: easy to manufacture; offer desired properties and improved healing rates without causing any adverse effects; mechanical rigidity; quick bone conduction or bone integration [2].

* Corresponding author: irkha.vladimir@gmail.com

Carbone implants have more than 20 years history of application in orthopedic surgery. It seems that the new generation of carbon nanomaterials have good prospects to produce implants for bone defects substitution.

This research performed to estimate “carbon nano-implant to bone” biocomposite when substituting bone defects.

2 Material and methods

Wedge osteotomy of a femur bone performed in experimental circumstance on 26 white rats (control = 6, experiment = 21). Experiment approved by Ethic council of Rostov State Medical University and followed demands of European Convention [3], [4]. Wedge-shaped ($h=4$ mm, $r= 3$ mm, $\alpha=12^\circ$) implants were crafted from carbon nanomaterial (Carbon nanostructural implants by TY 9398-001-30422885-2014. Certificate of accordance № POCC RU.HM41.H01487 valid since 30.11.2017 to 30.11.2020, № 0071740. Manufacture NanoTechMed Plus, Russia).

A femur bone osteotomy performed. Left or right side for osteotomy chose randomly. At controls osteosynthesis performed after osteotomy. At experimental animals, wedge-shaped defect substituted with carbon wedge. Any case osteosynthesis performed with compression by shape-memory brackets. Rats were withdriven from the experiment in 3 months. The “bone-implant-bone” samples prepared for consequent investigations.

Mechanical properties of the “bone-wedge-bone” blocks evaluated by 3-point bending test. Both ends of resected 20 mm “bone-implant-bone” cylinder rigidly fixed on the table of testing machine ПЭМ-0,1 (“Metrotest” Ltd., Moscow). Central part loaded till fracture between implant and bone occurred.

Morphological estimations were carried out with the field emission scanning electron microscope Zeiss Crossbeam 340. The microelements distribution in the samples were measured with energy dispersive X-ray analysis with the use of Oxford Instruments X-Max 80. Samples were coated with a thin layer of carbon.

Descriptive and nonparametric statistics were used to compare results of the investigation (R version 3.4.3; Rstudio, Version 1.1.453 – © 2009-2018 RStudio, Inc.).

3 Results

The experiment’s data is shown in the table (refer to Table 1).

Table 1. Results of double-side femur-bone osteotomies

R.no	Gender	Weight, g	Eside	Type	Compl	Consolid	Tou, MPa
1	2	3	4	5	6	7	8
I	m	363	R	E	0	Consolid	46,05
II	m	490	R	E	1	Nonun	3,22
III	m	300	R	E	0	Nonun	1,18
IV	m	337	R	E	1	Consolid	51,52
V	m	375	R	C	0	Consolid	55,81
VI	m	371	R	E	0	Consolid	48,73
VII	m	302	L	E	0	Consolid	48,62
VIII	m	239	R	E	0	Nonun	0,86
IX	m	420	L	E	0	Consolid	45,30
X	m	219	R	E	0	Consolid	45,83
XI	m	356	L	E	1	Nonun	0,43

XII	m	530	L	E	0	Nonun	0,97
XIII	m	358	R	E	0	Consolid	50,88
XIV	m	330	R	E	0	Nonun	5,26
1	2	3	4	5	6	7	8
XV	m	346	L	E	0	Consolid	50,23
XVI	m	334	L	E	0	Consolid	45,94
XVII	m	330	R	E	0	Consolid	48,09
XVIII	m	340	R	E	0	Nonun	51,84
XIX	m	345	L	E	0	Consolid	46,80
XX	m	350	L	E	0	Consolid	48,94
XXI	m	338	R	E	0	Consolid	46,80
XXII	m	338	R	C	0	Consolid	56,89
XXIII	m	343	L	C	0	Consolid	60,11
XXIV	m	339	L	C	0	Consolid	56,89
XXV	m	357	R	C	0	Consolid	56,67
XXVI	m	359	L	C	0	Consolid	55,49

Comments: R.no – animal’s ID; Gender – aminal’s gender; Weight – animal’s weight, g; Eside – “experimental” side; Type – E(xperiment), C(ontrol); Compl – purulent complication, 1 – if Yes, 0 – if No; Consolid – X-ray, consolidation; Tou – sample’s toughness, MPa

The toughness of zone between implants and bone fragments depends of clinical features of consolidation (mean Tounonun = 9.10 MPa, Touconsolid = 50.82 MPa, Welsh p-value = 0.001, where Tounonun – toughness of non-united “bone-to-implant” samples, Touconsolid – toughness force of clinically consolidated samples, the square of side plane of implant was 0,01118 sm2).

Comparison between toughness at control and experimental cases shows significant differences between them (Tcontr = 56.97 MPa, Texp = 47.68 Mpa, Welsh p-value = 2.689e-07).

Detailed visualization of bone to implant border shows interposition of connective tissue between these two objects (refer to Fig.). The thickness of connective tissue layers depends of union or non-union status of the sample.

Fig. 1. Bone to implant border (B – bone, I – implant, b – bone to implant border). On the left: sample 2, full consolidation. On the right: sample 4, nonunion.

Ca2+ and P distribution in thickness of an implant used to estimate penetration of bone tissue. These characteristics for sample 9 are shown in Figure 2.

Fig. 2. Sample 9. Distribution of Ca^{2+} (blue, on the left) and P (green, on the right).

Discussion

The data received enable to suppose that the quality and the thickness of the biocomposite zone on the bone-to-implant border predetermine clinical results of bone substitution. Integration of bone to implant in the investigated cases takes place in a very thick layer. Moreover, the absence of microelements inside the body of implants confirms that the implant structure is too subtle. Increasing porosity of material and creation of transverse channels can improve bone conduction and scaffold quality of carbon nano-implants. This hypothesis confirmed by data published [5], [6]. Carbon nanomaterials must be investigated thoroughly to resolve some known issues: increasing callus formation inside and over implants; improving the visibility of these radiolucent materials.

References

1. R. Yunus Basha, S. K. Sampath, M. Doble, *Mater. Sci. Eng. C*, **57**, 452 (2015)
2. X. Shen, L. Chen, X. Cai, T. Tong, H. Tong, J. Hu, *J. Mater. Sci. Mater. Med.*, **22**, 2, 299 (2011)
3. G. Alemanno, Council Decision, **2002**, July 2002, 538 (2003)
4. "European convention for the protection of vertebrate animals used for experimental and other scientific purposes," *Cets*, 170, 123 (1986)
5. D. J. Hak, C. Mauffrey, D. Seligson, and B. Lindeque, *Orthopedics*, **37**, 12, 825 (2014)
6. M. Chua, C. K. Chui, *J. Mech. Behav. Biomed. Mater.*, **44**, 164 (2015)