ASSESSMENT OF STRUCTURE OF PLATE IMPLANTS USED IN MANDIBULAR OSTEOSYNTHESES

OCENA STRUKTURY IMPLANTÓW PŁYTKOWYCH STOSOWANYCH DO ZESPOLEŃ ŻUCHWY

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ABSTRACT

Titanium plate implants used in osteotomy and osteosynthesis of mandible were studied. These medical procedures are planned and their goal is shortening or extending the ramus of mandible. Material used for manufacturing of miniplates – titanium and its alloys – is a basic biomaterial. In this paper, we present results of macro- and microscopic examination of mini plates made from technically pure titanium – grade 2. These are typical implants used in mandible osteosynthesis. Straight 4- and 5-hole plates and partially open 6-hole plate were investigated. Structural analysis was conducted on used plates – removed from patient's body after completion of treatment or in result of plate fracture during treatment. Comparative microstructure examination of brand new, unused plates was also conducted.

Keywords: plate implant, microstructure, SEM

STRESZCZENIE

Przedmiotem badań były tytanowe implanty płytkowe stosowane do zabiegów osteotomii i osteosyntezy kości żuchwy. Zabieg taki jest zabiegiem planowanym, mającym na celu skrócenie lub wydłużenie gałęzi kości żuchwy. Materiał stosowany do wytwarzania minipłytek, tytan i jego stopy, jest podstawowym materiałem z grupy biomateriałów używanych do produkcji implantów. W pracy przedstawiono wyniki badań makro- i mikroskopowych mini płytek wykonanych z czystego technicznie tytanu – grade 2. Były to typowe implanty stosowane do osteosyntezy kości żuchwy. Przebadano płytki proste 4 i 5 oczkowe, oraz płytkę częściowo otwartą 6 oczkową. Analiza strukturalna została przeprowadzona na płytkach używanych – usuniętych z ciała pacjenta po zakończeniu leczenia, lub na skutek pęknięcia płytki w czasie trwania leczenia. Wykonano także badania porównawcze dla takich samych płytek nowych.

Słowa kluczowe: implant płytkowy, mikrostruktura, SEM

1. Introduction

Even though the mandible is a bone characterized by high strength, due to its peculiar anatomical location and to the fact that it is not shielded by other bones, mandible bone fractures amount to two thirds of all the fractures of the facial bones [1]. The osteosynthesis of bone fragments, consisting of setting and then uniting them by means of plate implants, is the procedure most often applied in cases of mandible fractures. Miniplates are also used in the operative treatment of morphological defects of the mandible. When selecting a material for the implant one should consider, among other things, the material/surrounding tissue interaction and the mechanical properties of the material [2]. Titanium is one of the most commonly used metals for plate implants. Owing to improved processing this biomaterial has suitable mechanical properties and is well tolerated in the tissue environment. Nevertheless, such implants sometimes undergo damage before the treatment ends [3]. Therefore it is vital to determine the causes of this damage [4]. By examining the material's structure one can acquire much valuable information about, e.g. material defects and changes which arose in the manufacture of the plate or during its preparation for the operation. By carrying out micro- and macroscopic examinations of the fractured surfaces one can determine the causes of the cracks [5].

The aim of this work was to carry out studies of the structure of the material of selected implants used in the osteosynthesis of human mandible bone fragments.

This paper presents investigations of implants removed from a patient before the end of the treatment because of damage making further treatment impossible. The patient was subjected to reoperation.

2. Object of examination

The implant geometry must take into account the anthropometric features of a wide population of patients [6, 7]. Also attempts are made to miniaturize metallic implants in order to enhance the therapeutic effect and prevent any increase in adverse body reactions. When selecting a biomaterial for the implant one should take into account the latter's biotolerance in the tissue and body fluid environment.

Straight plates with 4, 6, 8 or 16 holes and branched plates in the shape of the letter Y, X or L are most often used. The thickness of the plates used in the osteosynthesis of fractures and in the treatment of cranial-mandibular dysfunctions is usually about 0.9 mm.

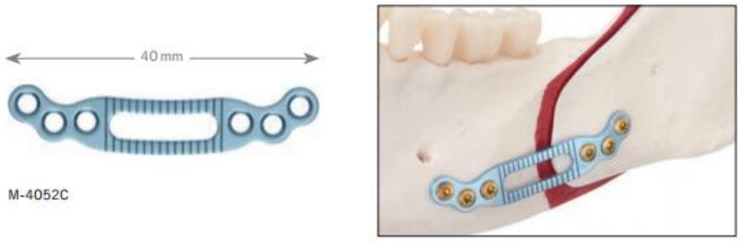

Fig. 1. Sagittal split plates [8]

Fig. 2. Application of investigated plates [8]

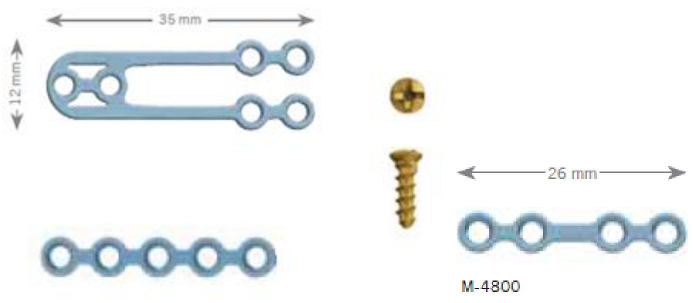

Fig. 3. Investigated elements [8]

The objects of the examination were plate implants used in osteosynthesis of mandible bone fragments. Two partially open six-hole plates, one straight five-hole plate and three plate fixing screws (ultimately selected from seventeen such screws) were subjected to microstructure examinations and microhardness tests. All the investigated elements came from one patient with osteosynthesized mandibular rami.

Directly before implantation the plates were bent in order to fit them to the shape of patient's bones. The plates were removed from the patient's body before the end of the treatment because they had fractured. The material from which the plates and the screws were made was commercially pure titanium. According to the implant manufacturer specifications, the investigated plates are made of commercially pure titanium grade 1 or 4. The screws are made of titanium grade 4. The chemical composition of the titanium grades and their mechanical parameters are presented in tables 1 and 2.

Tab. 1. Chemical composition of standardized titanium for implants, acc. to [9]

<table>
<tr><td>Ti grade</td><td>N</td><td>C</td><td>H</td><td>Fe</td><td>O</td><td>Al</td><td>V</td><td>Ti</td></tr>
<tr><td>Grade 1</td><td rowspan="2">≤ 0.03</td><td rowspan="3">≤ 0.08</td><td rowspan="3">≤ 0.015</td><td>≤ 0.20</td><td>≤ 0.18</td><td rowspan="3">absent</td><td rowspan="3">absent</td><td rowspan="3">rest</td></tr>
<tr><td>Grade 2</td><td>≤ 0.30</td><td>≤ 0.25</td></tr>
<tr><td>Grade 4</td><td>≤ 0.05</td><td>≤ 0.50</td><td>≤ 0.40</td></tr>
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Tab. 2. Mechanical properties of selected grades of commercial titanium [10]

Ti grade	Condition	$R_{m\ min}$, MPa	$R_{p0.2\ min}$, MPa	A_5, %
1	annealed	240	170	24
2	annealed	345	230	20
4	annealed	550	440	15
4	deformed	680	520	10

3. Methods of examination

Macroscopic and SEM (ang. *scanning electron microscope*) examinations of the plate implants and the screws were carried out. Both the inner surface and the outer surface of the implants were examined in order to identify the macroscopic surface damage.

The macroscopic examinations of the fractures and the inner and outer surfaces were carried out prior to SEM examinations. Specimens were prepared for SEM microscopy. After their mounting, grinding, and polishing the specimens were subjected to etching using the Kroll reagent (a solution of 40% HF and 65% HNO_3) applied to the fractured surfaces [11]. The duration of the reaction of the surface with the reagent amounted to 60 seconds. After etching the microstructure of the investigated elements was examined under a Nikon ECLIPSE MA200 microscope using x100, x200 and x500 magnifications.

4. Examinations and their results

The aim of the macroscopic examinations was to evaluate the degree of damage to the surface of investigated elements. Both the specimen's surface, which had been in contact with the bone, and its surface, which had been in contact with soft tissues (see fig. 4−7), were examined. Extensive mechanical damage, sustained probably during implantation, was found on the outer side of the plate implants. Whereas the inner side was only slightly damaged. Also damage caused by the interaction between the plate and the plate fixing screws was visible on the plates.

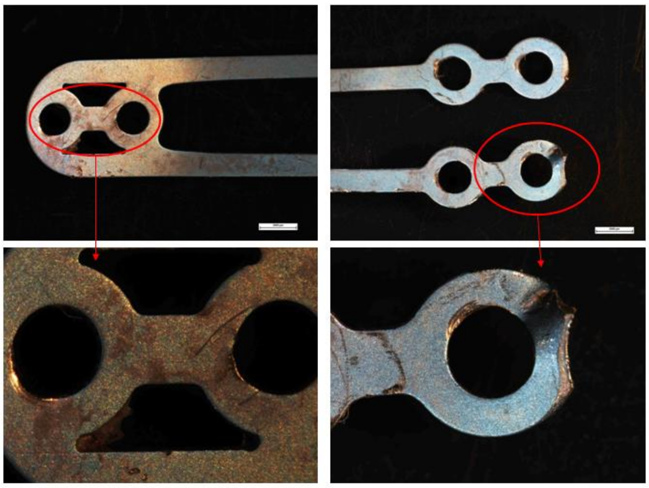

Fig. 4. Inner side of plate 2

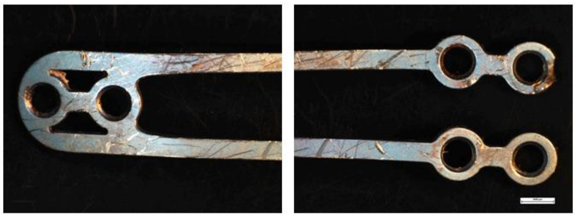

Fig. 5. Outer side of plate 1

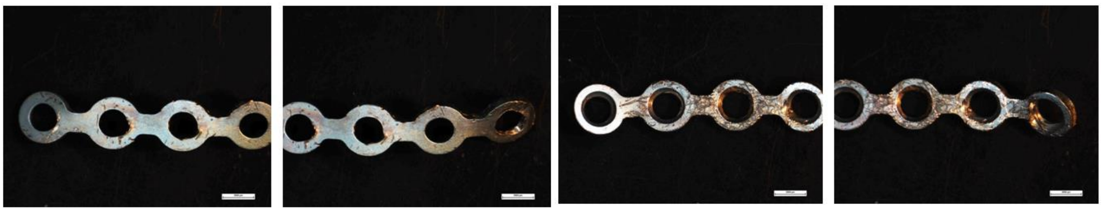

Fig. 6. Inner (A) and outer (B) side of straight plate

Fig. 7. Plate fixing screws

The macroscopic examinations revealed extensive mechanical damage. The damage on the outer side of the plate implants was much more extensive, probably resulting from the implantation operations. Whereas on the inner side, which had been in contact with the bone, the damage to the material was slight. The miniplates also showed damage resulting from the interaction between the plate and the fixing screws.

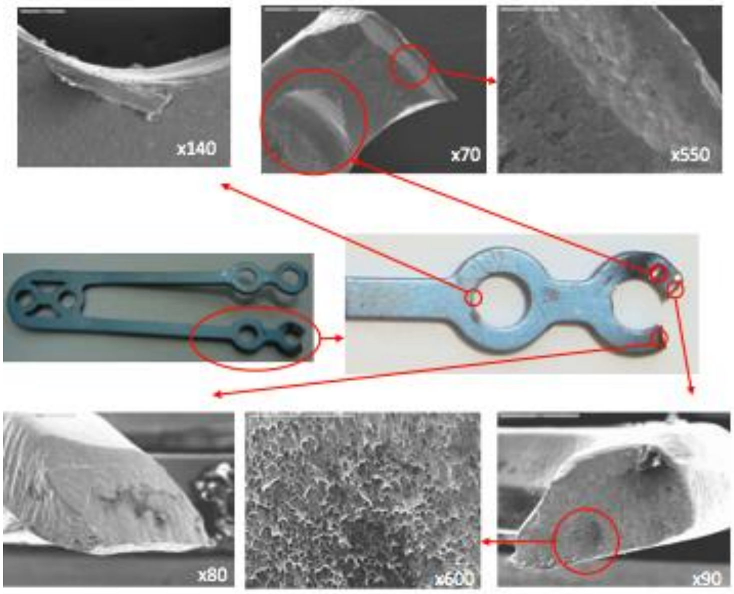

Fig. 8. Image of plate fractured surfaces; damage to surface having contact with patient

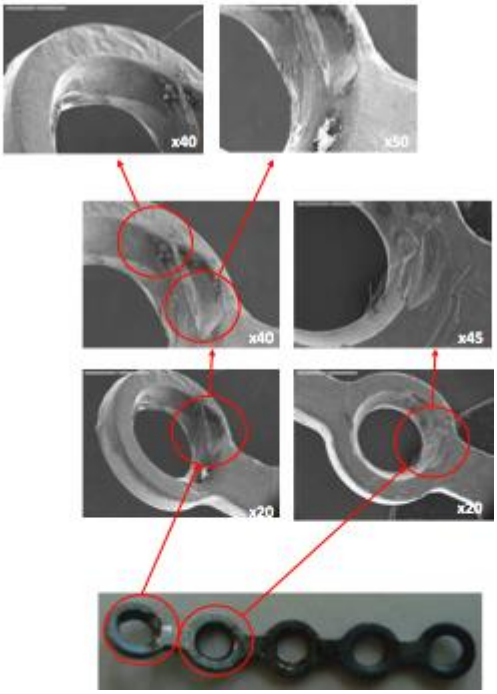

Fig. 9. Deformations of plate outer surface

The surfaces of the plates and the fractures were also examined using a scanning electron microscope. The image of the fractured surfaces suggests that the fracture occurred as a result of mechanical damage caused by a cut with a sharp tool and subsequently propagated. The result is shown in the photographs (see fig. 8, 9, 10). A plastic fracture, a parting shear fracture and a surface defect (probably caused by either an improper implant manufacturing process or by plastic deformations of the material (resulting in microcracks on the implant surface) are visible.

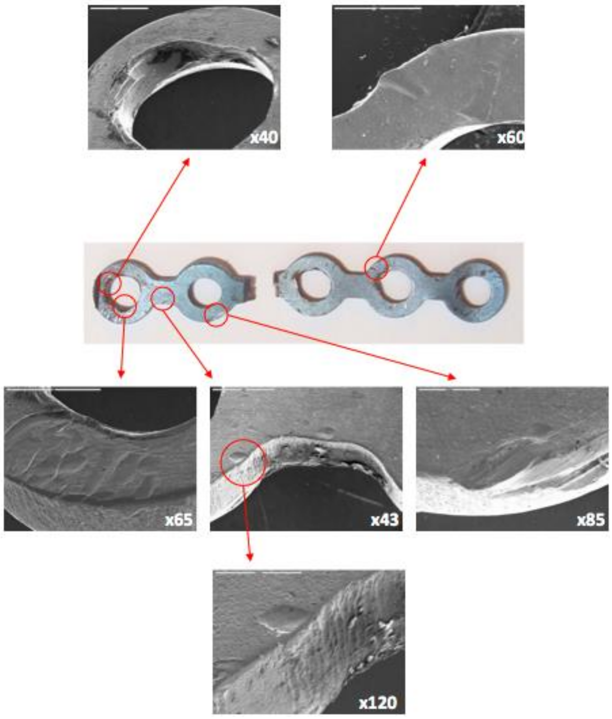

Fig. 10. Deformations of inner surface of straight plate

Because of the considerable mechanical damage visible on the outer surface of the plates, the inner surface of the implants, which was in contact with the patient’s bone, was subjected to microstructural examinations. Both the areas deformed by bending the plate and the undeformed areas were examined. Figure 11 shows the structure of the implant area fitted to the shape of the patient’s bone, with marked microtwins representing a dislocation mechanism of plastic deformation. Twinning is visible inside grains as rectilinear boundaries. Microtwins occur more numerously in places subjected to greater plastic strains [12]. No twins were found to be present in the areas in which the plates had not been shaped.

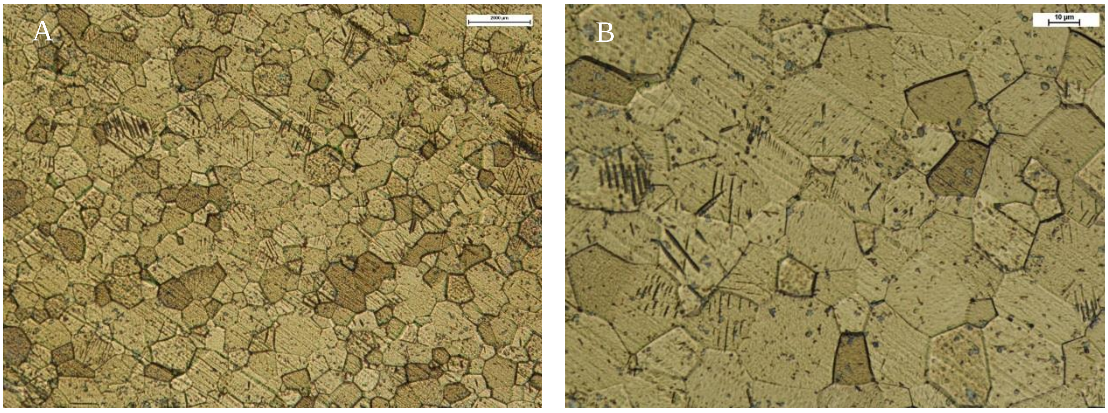

Fig. 11. Deformed area of plate implant, magnification: A – x200 and B – x500, LM, visible microtwins

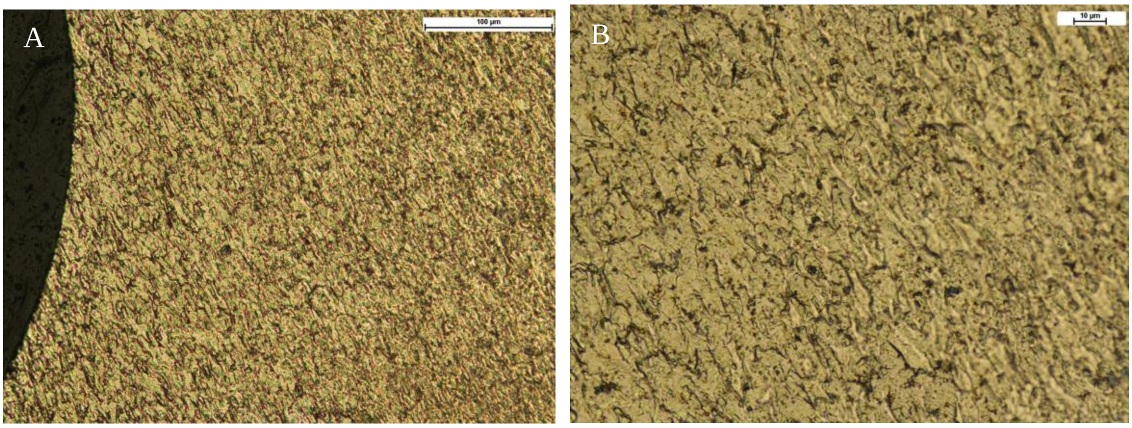

Fig. 12. Microstructure of screw made of commercial titanium in magnification (A) x200 and (B) x500, LM.

5. Discussion

The macroscopic examinations of the surfaces show that the plates used in mandible osteosynthesis underwent extensive mechanical damage, probably during implantation. The use of the product not in conformity with the manufacturer instructions, such as multiple bending of the plates or their mechanical damage, can result in defects in the material’s structure or on its surface, leading to cracking and ultimately to the failure of the element. Small pitting corrosion centres were noticed on the plate implants acquired for the investigation. But since the implants were subsequently sterilized, the analysis of the corrosion sites became impossible. Plate damage in the form of marks left by screw heads near the holes indicates improper interaction between the screws and the implants or errors made during the implantation of the plates. The photographs of the plate implant fractures show that the fracture was not a progressive process. It occurred abruptly as a result of the overloading of the improperly preoperatively prepared element.

Despite the manufacturer assurances, the microstructure of the fractures of the screws (see fig. 10) does not resemble the typical microstructures of commercial titanium. A comparison of this microstructure with the titanium microstructures found in the literature suggests that the structure of the screws resembles the microstructure of titanium alloys containing molybdenum [13]. However, the chemical composition analysis did not clearly corroborate this suggestion.

Fractures of plate implants are a serious clinical problem making it impossible to continue the treatment. Therefore it is vital to determine the causes of the cracking and the conditions in which it occurs. Moreover, reoperations constitute an additional burden for the patient’s body and generate higher costs. A series of material tests are conducted to determine the causes of the damage and to prevent it in future.

The investigations described in this paper did not show any errors at the implant production stage. The plate implants were damaged, and consequently fractured, probably as a result of the operations performed before and during (screwing in the screws fixing the implant to the mandible bone) the operative procedure.

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