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# Fracture Analysis of the Orthopedic Plates used in Joining of the Lower-Limb Bones

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**Abstract.** Breakage of the orthopedic plates that join the fractured bones of the lower-limb can cause major problems in healing treatment of the patients. Augmentation of the necessary medical treatment, prolongation of the healing duration and medical cost enhancement are a few problems caused. An investigation on the root of such failures is beneficial to prevent such disasters. Consideration was given therefore to 100 patients hospitalized in Imam Reza Hospital, Kermanshah, I.R. Iran. Lower limb examinations showed 6 broken plates, 1 broken rod and 1 broken nail. All broken samples were characterized by atomic absorption spectroscopy (AAS), scanning electron microscopy (SEM) and energy dispersive spectroscopy (EDS) techniques. Cyclic loading was revealed as the main source of the undesirable problem. Marginal incentives were also identifiable; some of them were: (a) large static and dynamic loads, (b) patient's premature movements, (c) presence of inclusions in the plates and (d) porous plates made by rare incompetent manufacturers.

**Keywords:** Orthopedic plates, fracture, fatigue, lower limb bones

## 1. INTRODUCTION

Implants are constantly exposed to static and dynamic loads. The magnitude and type of them depend on the activity of the patient. The amount of the forces can reach to twice or more the body weight in lower limbs. So the orthopedic plates that are used in the mentioned organs such as femoral and tibia bones to repair them should have sufficient strength. Despite that they also must transmit the loads to the host tissue preventing the stress shielding phenomena [1]; the most of the forces are sustained by the plates because of their more stiffness than the host bones [2-5]. Stainless steel (St.St.) or titanium (Ti) and it's alloys are the usual materials used in manufacturing of the orthopedic plates. According to the appropriate mechanical properties, high corrosion resistance and reasonable price, the austenitic stainless steel 316L is one of the most applicable one [6-8].The plates are screwed to the fractured bone to immobilize the two parts of the bone in a suitable anatomical position [9].

Failure of bone plates before bone fracture healing or after it is one of the severe complications after bone fracturing [2] that makes the patients painful. Increasing static and cyclic loads, corrosion, infection, improper installation or incorrect selection of plates by the surgeon and patient earlier moving before the prescribed time [10] are the factors that increase the probability of plate's fraction. Study on fatigue resistance is also essential in all cases according that the implants are the load bearing ones which must tolerate cyclic loads [11]. Identifying the active mechanisms in fracturing process of them could be helpful providing the proper solutions for their optimal utilization and reducing the number of fractured bone plates. In this study, it is focused on the reasons of fracturing of orthopedic plates used in lower limbs. For this purpose some the fractured plates have been characterized using micro and macrographs of them with view pointing of their other features.

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## 2. MATERIALS AND METHODS

In this study, 100 bone implants (16% of them was native (Iranian) ones) logged from lower limbs bones in Imam Reza hospital of Kermanshah were studied. The broken ones (6 bone plates and 1 rod and 1 nail) were characterized to analyzing the reasons of the fractions. The specifications of the samples and the owner patients were summarized in Table 1.

At the first, the specimens were cleaned in a solution of Acetone and Ethanol through ultrasonic method in order to separating the surrounded tissue from the fracture surfaces. Then the broken samples were investigated by macroscopic and microscopic fractography. The recent study was done by using scanning electron microscope (SEM) (VEGA, TESCAN, Czech Republic) equipped with an EDAX analysis. In order to detect microscopic structure of the fracture surfaces, an engraving solution including 6 parts of HCL and 4parts of HNO3 was used. The chemical compositions of the implants were determined through emission spectrometry (ASS) (FUNDARY MASTER, Germany).

2 of the plates (samples 3 and 4) were also examined through hardness test (HEKERT, Germany) by Rockwell method under an applied force of 150Kgf.

**Table 1:** specifications of the broken implants and the owner patients

| | Patient | | | | | implant | | |
|---|---|---|---|---|---|---|---|---|
| Code | Gender | Age (yrs) | Weight (Kg) | implantationtime(Month) | Anatomical Location | Materials | Type | Manufacturer |
| 1 | Male | 24 | 102 | 1.5 | Femor | Steel | LCP | Iran |
| 2 | Male | 19 | 80 | 18 | Tibia | Steel | LCP | Other |
| 3 | Male | 29 | 83 | 6 | Femor | Steel | DCP | Iran |
| 4 | Male | 22 | 70 | 12 | Femor | Steel | DCP | Other |
| 5 | Female | 36 | 67 | 12 | Femor | Titanium | LCP | Other |
| 6 | Male | 22 | 70 | 18 | Femor | Titanium | LCP | Other |
| 7 | Male | 24 | 83 | 10 | Femor | Steel | Nail | Other |
| 8 | Female | 61 | 50 | 24 | Femor | Ti-6Al-4V | Rod | Other |

## 3. RESULTS

The macroscopic images of the broken Plates (samples 1-6) are shown in Fig.1. Sample 3 and 4 are LCP (Locked Compression Plate) and the rest ones are DCP (Dynamic Compression Plate). Results of ASS analysis showed that the samples no.1 to 4 are made of stainless steel, code 5 and 6 is made of Titanium. According to fig.1, one can find that all the plates have been broken from the holes embedded on them. The cross sections of them at the mentioned areas are more minimum than the besides. Therefore the applied stresses reach to a maximal magnitude.


**Figure 1.** Six investigated plates with cut parts for SEM analysis of failure surface; samples A) 1, B) 2, C) 3, D) 4, E) 5 and F) 6.

The SEM images of the fracture cross sections are observed in figures 2 (plates) and 3 (Nail and Rod). Fatigue effects are evident in all the samples (Fig. 4)

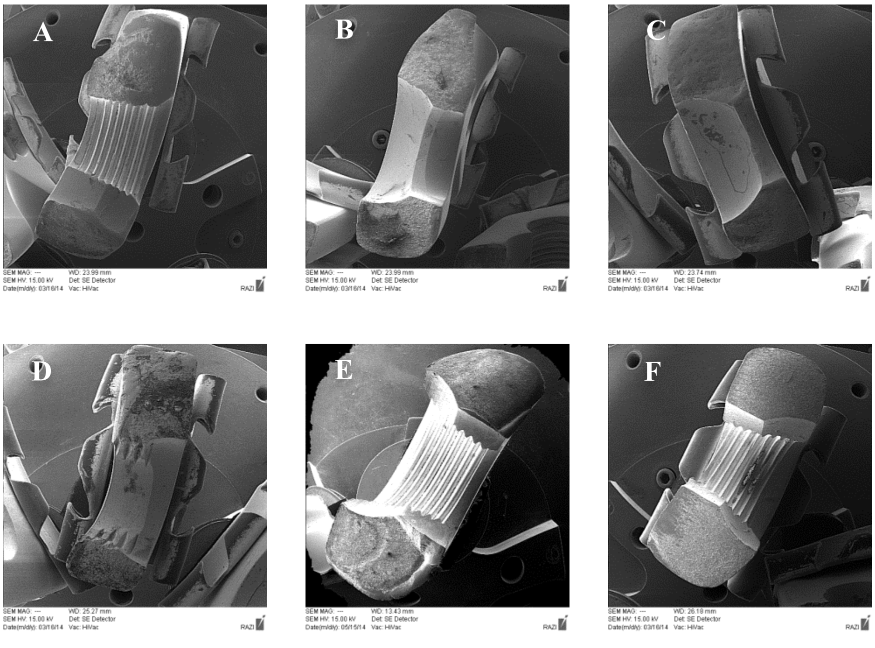


**Figure 2.** SEM images of the fracture cross sections of the samples: (A) 1, (B) 2, (C) 3(D) 4(E) 5 and F) 6.

Hardness of sample 1 and 2 was respectively reported 28 and 25 Rockwell C that belongs to the $Cr_2O_3$. The passive layer is due to the high activity of Chromium and thus its high tendency to oxidation, which leads to the appearance of stainless steel and its biocompatibility feature [12].

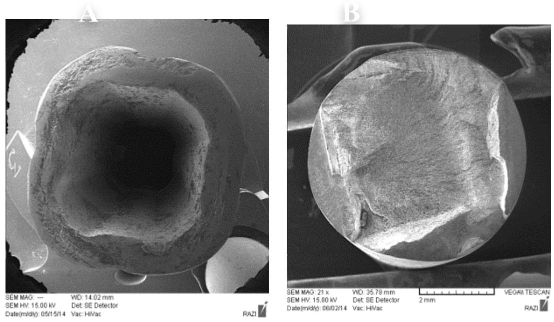


**Figure 3.** SEM images of the fracture cross sections; sample (A) 7 and (B) 8.

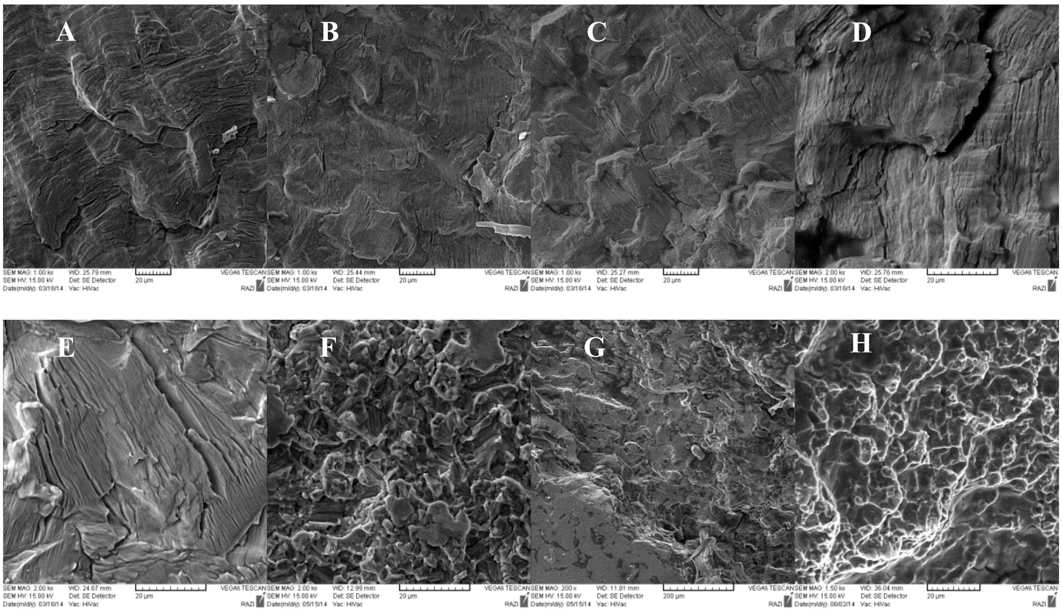


**Figure 4.** SEM images of samples (A) 1, (B) 2, (C) 3, (D) 4, (E) 5, (F) 6, (G) 7 and (H) 8.

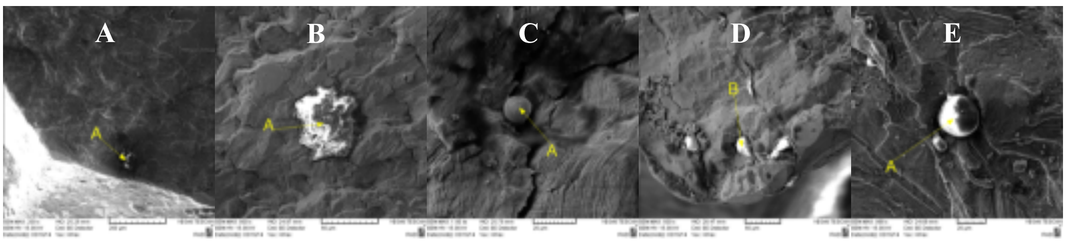


**Figure 5.** SEM images of samples (A) 2, (B) 3, (C, D) 4 AND (E) 6 (inclusions are shown by arrows).

Some Inclusions are shown in fig.5. Irregular inclusions in samples 2 and 3 and spherical ones in samples 4 and 6 are evident. These inclusions are crack origins due to their different hardness.

## 4. DISCUSSION

The Fatigue phenomenon is obvious in all the steel plates (samples 1-4). Parallel coastlines in forms of concentric arcs could be seen on the fracture surfaces (Fig. 2). The lines are signs of slow crack growth caused by cyclic loading. Loads influencing plates within the body is a combination of static and cyclic loads that cause 3-dimensional systems of stress [13]. Those were applied to 2 or more times higher than the patient's weight in the lower limbs. For example, sample 1 belongs to a 102 Kg patient. His high weight caused to the LCP failure in a short time about 1.5 months.

Fatigue cracks usually begin from the irregularities of surface where bending or torsion loadings create a high stress resulted from stress concentration [13]. Finally, the cross section decreases in a way that the sudden fracture occurs. Due to the lower shear strength of Ti compare to St.St. it was expected that the fracture sections of St.St. plates with more numbers of coastlines and fracture more flexible than the Ti ones. It was confirmed in micrographs in fig.4.

Designing factors of an implant that cause stress concentration could result premature failure of them [14]. For example, the stress concentration around the holes made them appropriate regions to break. It was obvious in all the bone plates (fig.1). The least cross section around the embedded holes and the junction points of them with screws are the main reasons. They lead to the mechanical fatigue and electrochemical reactions respectively [6, 15]. It also could be seen that the brilliance and polish of the plate was removed due to corrosion (fig.1).

In LCP samples, the fixed angles of the screws transform the shear stresses to compressive ones [16] that reaches out of their tolerance at cyclic loadings and fracture happened at the screw locking area which body fluids penetrate in the holes and screw junction areas; difference of the ions density between adjacent areas with cyclic loading led to fatigue corrosion [17].

Plates can break due to metallurgical defects (non-metallic inclusions, porosity, etc.) or mechanical phenomena [13]. Stress concentration regarding to inclusions could accelerate the germination and propagation of cracks in the structure. Also, the microscopic holes observed in the fracture cross section could be due to forces imposed during the deformation process. Inclusions and porosities in the fracture areas of plates are evidences for a weak production process [18]. Inclusions are evident in sample 2, 3, 4 and 6 (fig.5).

Inclusions near the surface or on the surface have a really negative effect on fatigue properties compared to the ones that are inside. Oxide inclusions due to low formability and their non-hemispherical shape are one of the important origins of crack germination as the Sulfide inclusions are the least important [18]. Non-metal inclusions reduce hardness and tolerance limit of fatigue. The final fracture occurs when micro cracks are interconnected at inclusions areas and get propagated.

According to the history of the patients which they told, it is determined that the owners of samples 2, 3 and 6 began to walk earlier than the due date because of their jobs. The high activity in the period of fracture healing time could be an important parameter that contributed to the fracture. Certain diseases, taking certain medications, smoking and opiates consumption are the major marginal parameters that could affect bones fusion and implants breaking. Smoking, hookah smoking and opiates consumption by the owner of samples 3, 1 and 6, participated in the implants failure procedure.

About sample7, elderly, osteoporosis, heart disease and consumption of certain medicines are influential. Finally, the wrong surgical techniques and improper selection of the implant related to the type of fracture could be the reasons for the fracture of the implant (sample 8) (fig.3). Surgeon had used nail instead of orthopedic plates for the mentioned patient. As the fracture occurred at the distal part of Femur, stress concentration due to mechanical loads was applied on to the distal part of nail and caused its failure. Some narrow smooth areas could be seen clearly in fig. 3 that noticed the fatigue initiation [14]. Presence of narrow smooth zone at the edges of the fracture cross sectional of samples 5,6 and 8 is the sign of large static stress according to their materials. The determination of crack origin is difficult to determine exactly in the similar cases [14].

## 5. CONCLUSION

According to the present study, large cyclic loads are the main reasons to premature fracture of the lower limbs bone plates. The smooth narrow zones on the fractured cross section surfaces of the samples show the performance of fatigue phenomenon. The areas are clearer in Ti implants. The steel plates could tolerate more cyclic loadings than Ti ones. Some agents such as high static loads, moving ahead of the due time prescribed by the physician, corrosion smoking, poor design, inclusions and porosity due to poor material manufacturing process accelerates fatigue led to plate failure.

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