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Destabilization of the Comminuted Clavicle Shaft Fracture due to Breakage of the Titanium Locking Plate: Biomechanical Analysis

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Abstract

Background: Implant breaking destabilizing the fracture may be caused by its structural defect, inappropriate use, or massive overloads. We present the patient, who broke the plate stabilizing comminuted clavicular fracture at the sixth postoperative week due to the, primarily reported, simple loading of the limb that should not exceeded admissible limits.

Methods: Macroscopic examination excluded its manufacturing defect of an explant, but revealed areas of brittle and fatigue fractures, as well as anterior and inferior bending of its edges. Mechanical analysis proved sufficient material durability. Those findings clearly showed that the plate broke in consequence of repetitive overloads exceeding its durability.

Patient, when acquitted with those results, confessed that the plate broke, while fishing. Moreover, he reported an episode of alcohol overuse that could contribute to implant failure bringing the risk of additional injury.

Results: Biomechanical analysis confirmed that mechanical loads throwing the spinner exceed values adequate for plate breaking. Thus, the real circumstances of the complication seem to be unveiled pointing out to facts that some patients disobey postoperative recommendations to avoid overloading of stabilized extremity, thus participating actively in this type of complications, that they dissemble the real circumstances of the complications, and that they may exhibit risky and irrational behavior.

Conclusion: Basing on the presented case we concluded that in some cases plaster cast immobilization supporting stabilized fracture may be beneficial precluding banned activities and preventing from secondary injuries reducing the risk of postoperative complications.

Level of Evidence: Level III case control study

Keywords: Clavicle fracture; Implant failure; Mechanical overloads; Postoperative recommendations disobey; Insubordinate patient

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Introduction

Implant break off destabilizing the fracture regularly complicates orthopedic procedures. It may be caused by structural defect of an implant, it's inappropriate use, or massive overloads exceeding its strength [1,2]. The first one is casuistic, as producer's quality control effectively excludes defective ones. The second may result from application of an implant dedicated to the bone carrying out much smaller loads than stabilized one, but may also originate from repetitive implant bending adopting it to the anatomical shape of the bone, thus reflecting the technical error during the procedure [3]. The third one - when the healing processes do not support implant's durability and excessive loads are applied over the fracture gap [4,5]. Clinical observations point out that in some cases the third reason occurs and implant failure originates from an excessive limb loads in non-immobilized fractures in early or in un-united fractures in late stages of the healing process [6].

An analysis of the reason of implant breaking usually brings about troubles coming from limited insight into the incident, as patients often dissemble the genuine circumstances that led to the complication avoiding its responsibility. Especially when they do not follow postoperative directions. Moreover, implant failure may also be used for clamor of compensation, bringing

Figure 1: Preoperative x-ray revealing comminuted clavicle shaft fracture with two intermediate bone fragments (arrows).

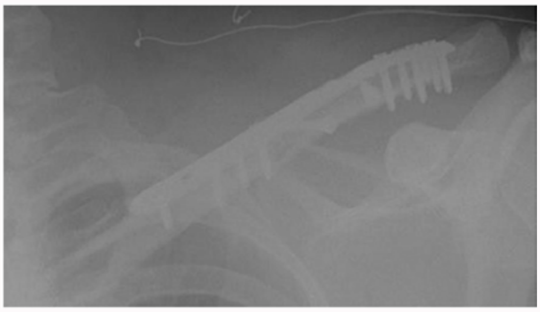

Figure 2: Postoperative X-ray.

about several troubles to the manufacturer, to the hospital, and to the surgeon. Thus, recognizing the reason for implant breakings is of value not only from medical, but also juridical and financial point of view.

We present the patient, to whom the locking plate stabilizing comminuted clavicular fracture broke at the sixth postoperative week due to the primarily reported simple loading of the operated place that should not exceed admissible limit. Since circumstances of the incidence seemed to be ambiguous, material and mechanical analyses of the implant were performed, and anamnesis was reevaluated bringing about conclusions that we found important for other patients subjected to the analogical treatment.

Material and Methods

A 33-years old, athletic male (105 kg body weight, 188 cm height) was operated on due to comminuted fracture of the shaft of the left clavicle (Robinson type II, B2; (Figure 1). Fracture was anatomically reduced and stabilized with 2.8 mm Ti-6Al-4V, precontoured, angle stable, locking plate (System 5.0, ChM, Poland) implanted on its superior surface. Both intermediate bone fragments were additionally fixed with titanium cortical screws (Figure 2). Postoperative wound healed uneventfully and patient was discharged with limb immobilized in shoulder brace for four weeks. After that, patient was referred to rehabilitation, but was recommended to avoid massive physical loads.

At the end of the sixth postoperative week, he reported a sudden pain and noticeable click at the shoulder closing the trunk lid of the car. Performed x-ray revealed broken plate and destabilized fracture (Figure 3). Patient was re-operated and plate was replaced. No any signs or symptoms of infection were noticed both macroscopically at the operation field and in laboratory tests. Again, the postoperative wound healed uneventfully, but patient was discharged with limb

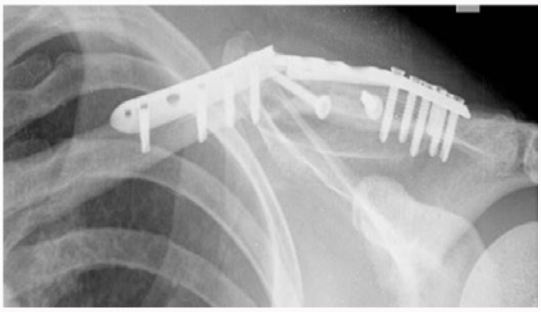

Figure 3: X-ray showing destabilized fracture and broken plate. Proximal aspect of the clavicle rotated anteriorly, superior angulation of the plate fragments.

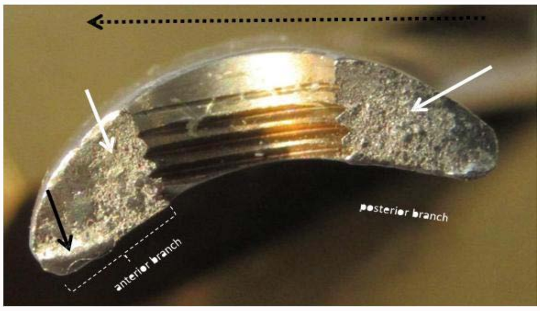

Figure 4: Macrophotograph of the site of break. Dashed black arrow runs from posterior to the anterior surface of the clavicle. Areas of brittle (matt gray, white arrows) and fatigue (darker; black arrow) fracture.

immobilized in plaster cast for four weeks. Afterwards, he was referred to rehabilitation.

Clinical controls and X-rays during the forthcoming 12 months showed properly proceeding regenerative process and restoration of the physiological limb function.

Results

Analysis of an X-ray

Shoulder X-ray in PA position made on readmission showed broken plate at the place of its hole. The fracture was destabilized. Moreover, medial fragment was rotated anteriorly, and the clavicle was angulated superiorly (Figure 3).

Macroscopic analysis of the broken plate

The explant was analyzed macroscopically excluding its manufacturing defect. Under magnification, the areas of brittle and fatigue fractures were identified (Figure 4). Interestingly, fatigue fracture was localized on the inferior part of its anterior branch, and brittle-on the posterior as well as inferior aspect of the anterior branch that was, additionally, curved anteriorly and inferiorly (Figure 5).

Mechanical analysis of the plate

Mechanical properties of Ti-6Al-4V alloy, that is its ultimate tensile strength of ca 960 MPa and yield point of ca 850 MPa, are well known, as it is regularly used for implant's manufacturing. Measuring plate dimensions (length, thickness and width) and the length of the lateral clavicle fragment (serving as a lever) allowed estimating values of admissible loads that, when exceeded, resulted in the break.

Assuming an uniaxial load with driving force acting along the plate, the estimated plastic flow starts at 10 kN, and plate break at 11,4

Figure 5: Inferior bending of the anterior and inferior edges of the anterior branch of the plate (dashed lines). Inferior aspect of the plate.

kN. But it could practically never occur. In vast majority of cases, the clavicle moves in transverse plane forward and backward, bending the plate at its hole and stretching its posterior branch, whereas the anterior one serves as a hinge. Under those conditions, the load of 580 N only is sufficient to break the plate, when acting on the acromioclavicular joint from its posterior aspect. Angulation of the antero-inferior edge of the plate supports this observation pointing out to the directions of loads that resulted in the break (Figure 6).

Moreover, orienting the plate to the patient's body it could also be concluded that the break was caused by a combination of multiaxial loads under stress conditions, resulting from simultaneous effect of tension, bending and torque. It clearly shows that the patient has not respected the post-operative recommendations to avoid overloads.

Carried out theoretical calculations were verified experimentally subjecting the analogical plates to simple tension and bending. They revealed that the permanent deformation begins at the axial load of 7,5 kN, leading to its break at the force of 9,4 kN. But it could never happen, as loads of such magnitudes are unlikely. Nevertheless, simple bending with relatively small force (40 N), but acting over an arm of 90 mm (the distance from the site of break to the clavico-acromial joint), thus producing the moment of the force of 3,6 Nm, are sufficient to initiate the permanent deformation.

In the presented case the most probable loads that resulted in plate break off acted in the transverse plane, stretching the posterior branch of the plate, whereas the anterior branch served as a hinge and plate width as a lever. Under those conditions the moment of the force that deforms permanently the plate was validated to be 12,8 Nm, and it corresponds to that theoretically estimated. Thus, both theoretical and experimental investigations showed that loads of 160 N (for instance raising the weight of 16 kg from the ground) acting over the plate in transverse plane over the shoulder from its posterior aspect, is sufficient to deform it permanently.

Muscle attachments to the clavicle

Characteristic displacement of bone fragments observed on re-admission X-ray could be explained analyzing muscle attachments. While the medial part of the clavicle is elevated by sterno-cleido-mastoid muscle, the lateral one is brought down by the weight of the extremity and tension of the deltoid and sub-scapular muscles. Rotation (anteversion) of the medial bone fragment could only be explained by the strong constriction of the pectoral major muscle that attaches to the antero-inferior surface of the clavicle. Its strong constriction not only lowers the clavicle, but also rotates it anteriorly.

Figure 6: Schematic representation of the process of plate fracture from the superior (left) and postero-anterior views (right). Primarily, mechanical loads acting on the distal part of the plate resulted in brittle fracture of its posterior branch, than anterior one.

Final examination

While preparing the manuscript, the patient was once again questioned for the circumstances of the incidence of destabilization. When acquitted with presented above biomechanical analysis he confessed that the plate broke, while fishing. Throwing a spinner for six hours, once per every thirty seconds, he felt the pain at the clavicle. Moreover, few days earlier he participated in a party drinking much too much of alcohol that resulted in loose of his consciousness. As he knows, any kind of additional trauma occurred during this episode, but it could not be excluded, as some itching at the collar bone was felt the following day.

Assuming a dynamic movements of the unloaded extremity while fishing, that is subjected to the mass of a limb (ca 8 kg of the weight and 66 cm distance from the acromion to the fist) loading of the acromio–clavicular joint with the force of 80 N produces the moment of the force of ca 26,4 Nm (80 N acting over a half of the length of the extremity 330 mm). It is more than twice as much as that sufficient to deform the plate permanently, as our experimental bending test revealed that the plate already bends at the moment of the force of 12,8 Nm. Moreover, dynamics of the movements while throwing the spinner produces some additional moment of the force that, depending on the position of the angler, significantly exceeds those values. Those values are additionally increased by the weight of the spinning rod and the spinner that, albeit relatively light (1,0 to 1,5 kg), but acting over the long arm, contribute to the destructive loads.

Discussion

Fracture destabilizations resulting from implant break offs are common complications that require secondary interventions [7]. They encumber surgeons, hospitals and implants' producers with responsibility for unsatisfactory treatment bringing about the risk of patient's claims. Especially, when secondary injuries impair the healing leading to non-union. But in some cases they may result from intended patient's activity or various unintended events in close-minded individuals that contribute to the incident. Thus, the question, which is in fact responsible for it, remains controversial. Unfortunately, in most cases the real circumstances of the episode remain unknown, posing patient's secret.

Orthopedic implants are constructed to withstand mechanical loads that are usually carried out by unloaded limb. But it does not mean that they have to abide massive overloads. To reduce disadvantageous mass of implanted metal, their dimensions are optimized to transducer loads coming from the limb weight and muscle tension of unloaded extremity only, with some safety margin, basing on the idea that "the sufficient minimum is the best". Thus, their constructions do not allow massive strains bringing about the risk of implant failure, when not abided. Titanium alloys, due to modulus of elasticity comparable to that of a bone, are believed to be the most suitable for plate manufacturing [8]. They were proved to possess the strength sufficient to introduce an early rehabilitation [9].

In vast majority of cases patients obey postoperative recommendations avoiding overloading of the stabilized extremity, and orthotic immobilization for a sufficient period of time helps them to avoid complications. But in some cases patients take off orthoses and perform forbidden activities that result in implant failure or losing. Especially, when they over use alcohol or drugs [10]. The loss of self-control, irrational behavior and risky activities predispose them to additional injuries, bringing about the risk of implant failure [11]. Thus, in this particular group of patients additional protection of fracture instrumentation has to be considered [12]. Even, when alcohol overuses is occasional, as in the described above case.

Secondary injuries and inadequate limb immobilization may complicate fracture stabilizations resulting in implant failure [13]. They usually affect lower extremity procedures, as those undergo far bigger loads than upper ones. But, under certain circumstances, breakings may occur in upper limbs. In analyzed case, repeated and dynamic loads led to the break of the clavicle fracture stabilizing plate clearly showing an undertaking of the physical efforts by the patient disobeying postoperative recommendations.

In the case of clavicle stabilization, previously recommended for a long (up to four weeks) period of time plaster casts are nowadays usually reduced to maximum three weeks orthotic immobilizations, as those were estimated to be sufficient, far more comfortable, and allowing to avoid the risk of joint stiffness and muscular atrophy [14]. The effectiveness and usefulness of orthoses in postoperative fracture management is widely accepted [15]. Nevertheless, the easiness to take them off allow maneuvers overloading an implant and deprive the surgeon's control over the abide of recommendations. Thus, those are risky in unreliable patients, as enable banned behavior. The problem especially arises in mentally ill and alcohol and drug abused persons, since behavior of those is highly unpredictable. But it is also likely that some patients do not accept recommendations, or those recommendations are simply unsuitable due to some reasons. Patients could also provoke complications actively, as those allow them to fix some vital problems (release from the jail, postpone of the case, reprieve of the verdict, or simply obtain the compensation). But it also happens that it is unintended and results from incomprehension of the idea of those recommendations. Thus, profound explanation of the aim of recommendations may improve patient's cooperation.

Herein, we presented the patient, who informed about the results of biomechanical analysis of the incidence confessed that the implant broke while fishing, not primarily reported closure of the car trunk lid. It points out to the fact that patients quite often ignore recommendations and hide the information about the real circumstances of the onset of the complication. Unfortunately, we could not exclude that this confession is not true, as we do not have an ability to verify it. It could be quite often observed that patients verify the durability of stabilizations taking exercises, usually young, physically active ones. Simple push-ups in an individual of described patient's posture load upper limbs with the weight of 40 kg to 45 kg. Analogically, other popular exercises including pull-ups, weight lifting or working with resistance bands overload the limb with forces that are sufficient to break the implant. Those episodes are casuistically brought to date due, because patients do not report those giving imaginary explanations. But insubordinate patients do really exist bringing about problems not seen in regular ones. To avoid those problems the best solution is to enforce them to follow recommendations. In the case of bone fracture limb immobilization in plaster cast is the most reliable solution, as it's taking off is not easy and every intervention is obvious and undeniable on examination, giving an insight into patient's contribution to the complication.

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