Fractographic Analysis of 2.0-mm Plates With a Screw Locking System in Simulated Fractures of the Mandibular Body

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Purpose: The purpose of the present study was to analyze the fractured plates from 2 brands of 2.0-mm locking fixation systems submitted to axial linear load testing.

Materials and Methods: Four aluminum hemimandibles with linear sectioning to simulate a mandibular body fracture were used as a substrate and fixed with 2 fixation techniques from 2 national brands: Tóride and Traumec. The techniques were as follows: one 4-hole plate, with four 6-mm screws in the tension zone, and one 4-hole plate, with four 10-mm screws in the compression zone; and one 4-hole plate, with four 6-mm holes in the neutral zone. The hemimandibles were submitted to vertical linear load tests using an Instron 4411 mechanical test machine. The system was submitted to the test until complete failure had occurred. Next, a topographic analysis of the surface of the plates was performed using a stereomicroscope and an electronic scanning microscope. The samples were evaluated using different magnifications, and images were obtained.

Results: The surface of the fracture analyzed in scanning electron microscopy demonstrated a ductile-type fracture, usually found in the traction test bodies of ductile materials, such as titanium. No evidence of failure was observed in any fracture surface from a change in the structure or composition of the material.

Conclusions: The plates were fractured by a ductile rupture mechanism, as expected, suggesting that the manufacturing of the national brand name plates used in the present study has been under adequate quality control, with no structural changes produced by the manufacturing process that could compromise their function.

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The rigid internal fixation systems with miniplates that were developed by Michelet et al[1] and Champy et al[2] have become the standard treatment for mandibular fractures.[3,4] Because of their high success index, surgeons and patients have been encouraged to use this technology to treat certain afflictions.[5] However, knowing the properties of each material, the functions performed, and the conditions of the location that will

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receive the implant is fundamental to choosing the correct material. This has become a determining factor for the success of the surgical intervention.[6]

In the context of oral and maxillofacial surgery, several fixation systems with plates and screws have been applied to treat facial fractures or for orthognathic and reconstructive surgery. Thus, these fixation systems must be able to meet all the necessary criteria for adequate function and minimizing the risk of osteosynthesis failure.[4,7] However, fractures on miniplates and reconstructive plates have been previously reported[8-12] for both dentate patients, with mandibular defects after tumor resection, and edentulous patients, for which the masticatory force is reduced. In such cases, analyzing the failures would be an important tool to discover or confirm the actual failure process of the material, even when the forces to which they were submitted were known, offering improvements to the material during its manufacturing, design, and finishing process.

The fracture surface records the history of the failure. It contains information on the environmental effects, the quality of the material, and the loads to which the part has been submitted. Thus, fractography has been the main technique used to determine how a material has fractured.[13]

However, information is lacking regarding the cause of failure of the fixation plates and screws used on mandibular fractures, mainly in relation to the fractures of 2.0-mm plates with a screw locking system. These are important considerations, because their use has increased with time, and newer and more advanced manufacturing techniques have been developed. However, failures still occur, with fixation failures due to fracture of the material. In the present study, we performed fractographic analysis using scanning electron microscopy of plates from 2 national brands of a 2.0-mm fixation system with a screw locking system in aluminum hemimandibles with simulated fractures of the mandibular body.

Materials and Methods

HEMIMANDIBLES

The hemimandibles were manufactured of 5052-F aluminum (ASTM B- 209-M-AA) by Tóride (Tóride Indústria e Comércio, Mogi Mirim, São Paulo, Brazil). Their composition was 0.01% copper, 2.35% magnesium, 2.35% manganese, 0.17% chrome, 0.3% iron, and 0.1% zinc, with titanium, boron, zinc, calcium, silicon, tin, vanadium, and lead constituting approximately 0.2%.

The hemimandibles were submitted to sectioning, simulating a mandibular body fracture at the lower premolar and first molar region. They were also perforated according to group and the outer diameter and thread pitch of the screws from each brand. For group I, the hemimandibles had 4 perforations in the tension zone, with 2 holes on each side of the fracture, according to the design of the plate, and 4 perforations in the compression zone, similar to the tension zone. For group II, 4 perforations were made in the neutral zone, similar to the specifications for the tension zone in group I. All perforations completely crossed the body of the substrate. Figure 1 shows the measurements of the hemimandible.

SAMPLES

The samples were divided into 2 groups. In group I, 2 aluminum hemimandibles received a rigid internal fixation system from Tóride (Tóride Indústria e Comércio) and Traumec (Traumec, Tecnologia e Implantes Ortopédicos Imp e Exp, Rio Claro, SP, Brazil). The hemimandible was fixed with a 4-hole straight plate with a screw locking system, no intermediate space in the tension zone, with four 2.0- × 6-mm titanium screws, and another plate in the compression zone, with four 2.0- × 10-mm titanium screws. Five samples from each brand were used. In group II, 2 aluminum hemimandibles with a rigid internal fixation system were used from the same manufacturers. The hemimandible was fixated in the neutral zone with a 4-hole straight plate and a screw locking system, no intermediate space, with four 2.0- × 6-mm titanium holes. Five samples from each brand were used.

According to the specifications from the manufacturers, the plates were composed of grade II commercially pure titanium, and the screws were a titanium-aluminum-vanadium alloy.

BIOMECHANICAL TESTS

The mechanical test was performed using the Instron model 4411 universal mechanical testing machine (Instron, Norwood, MA). A support device for the hemimandibles was manufactured with the equipment to perform the test.

The noncyclical linear load test was performed at a 1-mm/minute speed to apply a progressive load to the system, thus obtaining the load resistance, in Newtons, and the displacement imposed by the test, in millimeters. The load was applied to a fixed point in the distal segment in a region similar to the canine. The machine was calibrated at the initial displacement resistance point imposed by the system. Thus, the 5,000-N load cell was manually leaned against the load application force up to a limit at which the console showed the first load values against displacement in a decimal scale. The system was submitted to the test up to its complete failure, when it lost resistance, and the machine ended the test (Fig 2).

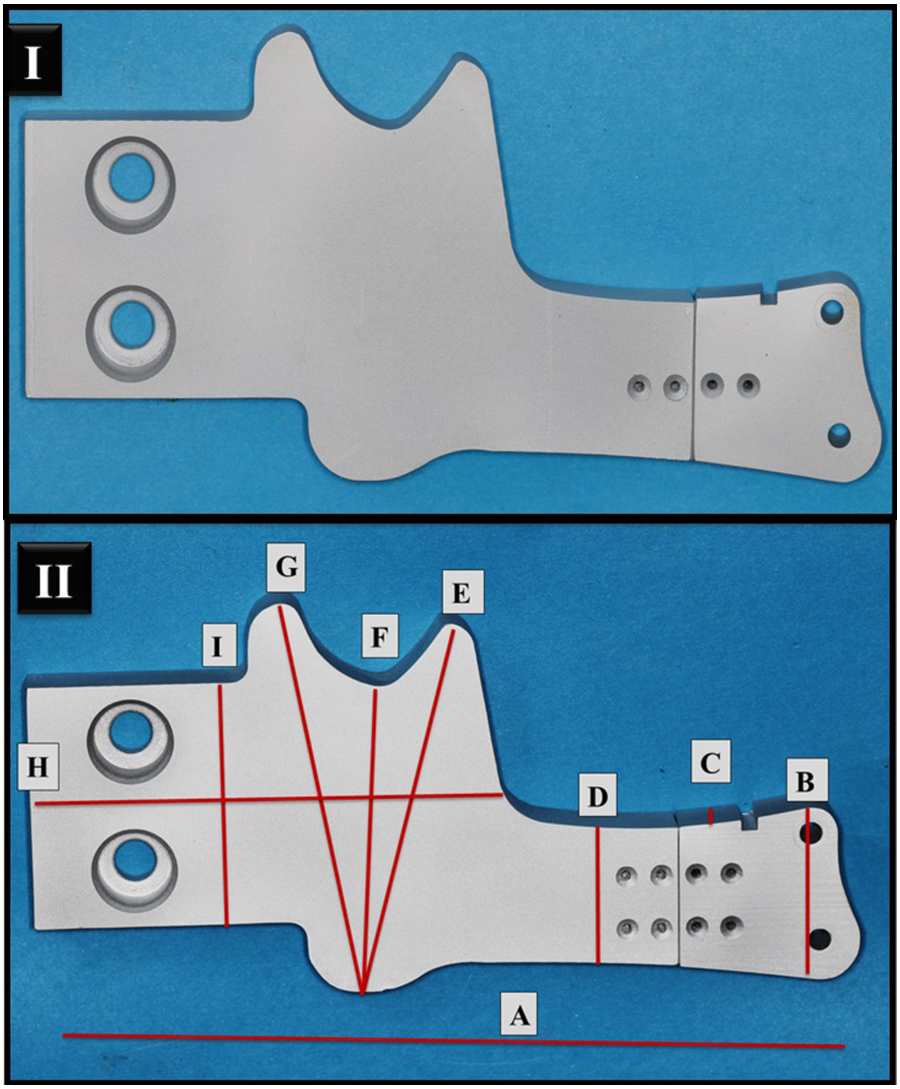

FIGURE 1. Hemimandibles composed of aluminum with 2 larger holes in the posterior region to adapt to the support device and linear osteotomy simulating a body fracture: *A,* total length, 15 cm; *B,* height in the region of the mandibular symphysis, 3.3 cm; *C,* thickness, m 3c; *D,* height in the region of the jaw body, 2.6 cm; *E,* angle to the mandibular coronoid, 7.1 cm; *F,* mandibular angle to the sigmoid notch, 5.7 cm; *G,* height of mandibular condyle to mandibular coronoid; 7.4 cm; *H,* width of the mandibular from anterior to posterior, 8.5 cm; *I,* height of the hemimandible back support, 4.5 cm. *I,* hemimandible from group I; *II,* hemimandible from group II.

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SCANNING ELECTRON MICROSCOPY

The plates were first submitted to a cleaning process of impurities using the Ultramet 2003 Sonic Cleaner Buehler ultrasound (Buehler, Lake Bluff, IL). The topographic analysis of the surface was macroscopically performed using a low magnification stereoscope (stereomicroscope) and microscopically using a Quanta 400-FEI scanning electron microscope (FEI, Hillsboro, OR). The samples were placed in the sample holders with carbon tape, and their surfaces were not directly manipulated by the operator. They were then analyzed under different magnifications. With the purpose of displaying a panoramic view of the surface of the plates, 60× and 80× magnification was used. To obtain more details of the surface, 2,000× magnification was used in the regions of the plate fractures on the right and left sides to analyze the directions, contours, and textures to determine the micromechanism of the fracture.

Results

All the plates were fractured during the test. In 3 experiments from group I, the plates in the tension zone and the plates in the compression zone were fractured in the upper part of the hole to the right of the fracture line. For the other samples, the plates in the tension zone were also completely fractured at the hole to

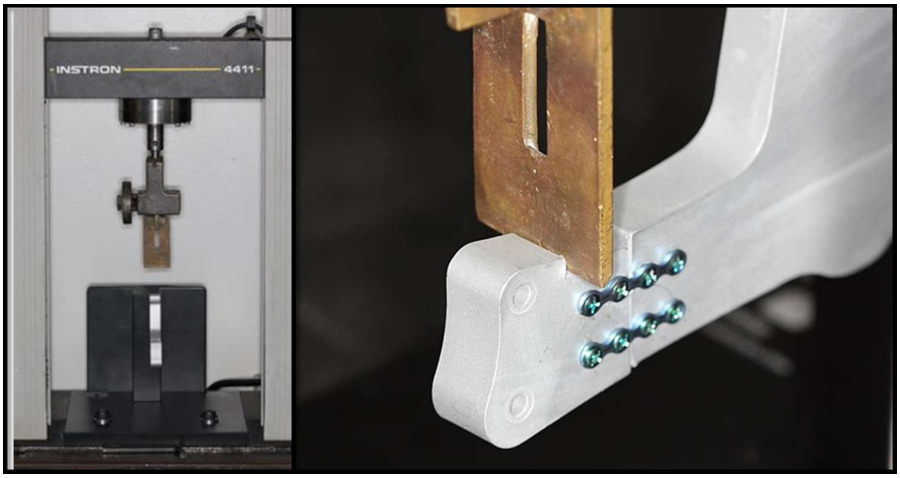

FIGURE 2. Hemimandible from group II subjected to mechanical testing in the Instron, model 4411, universal mechanical testing machine.

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the right of the fracture line. In group II, the 5 plates were fractured in the upper part of the hole to the right of the fracture line (Fig 3).

All the samples were macroscopically analyzed in the stereomicroscope and had a dim and grayish surface with evidence of intense plastic deformation. Because they had all been submitted to the same biomechanical test and had the same behavior, images from 1 sample of each rigid internal fixation commercial company were obtained.

All sample fractures occurred because of ductile overload and were characterized by an alveolar damage micromechanism, as expected for ductile material submitted to a monotonic load to rupture. The fracture occurred from the center of the material to the edges, and no abnormalities were observed regarding the type of fracture in relation to the material and its structure. The analysis of the surface showed hemispherical or parabolic cavities, known as “dimples.”

The images supplied from the scanning electron microscopy have a virtual nature, because what will be seen on the monitor of the device is the transcodification of the energy issued by the electrons (Figs 4, 5). In Figure 4, the analyzed plate was the plate in the tension zone of group I with the Tóride system. The plate fractured in the upper and lower parts of the first link, to the right of the fracture line. In Figure 5, the analyzed plate was fixed in the neutral zone of the mandible from group II with the Traumec system. The latter, owing to the mechanical test to which it was submitted, had only fractured in the upper part of the first link to the right of the fracture (on the left of Fig 2), when the machine recorded a system failure and ended the test.

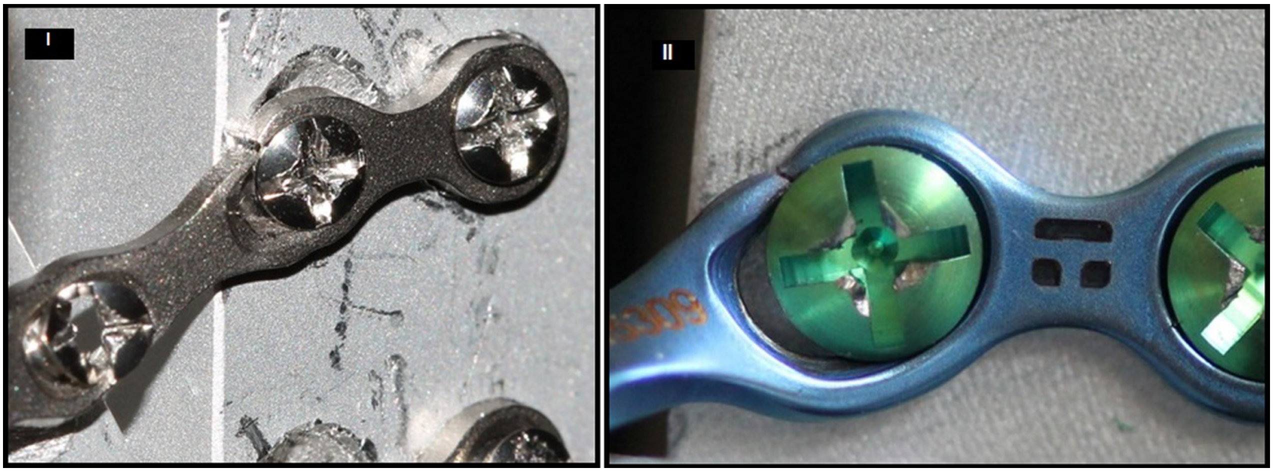

FIGURE 3. *I,* Sample from group I with Traumec brand in which a complete fracture of the plate in the tension zone can be observed and a fracture in the upper part of the link to the right of the fracture line on the plate in the compression zone. *II,* Sample from group II with Tóride brand with a fracture in the upper part of the link to the right of the fracture line.

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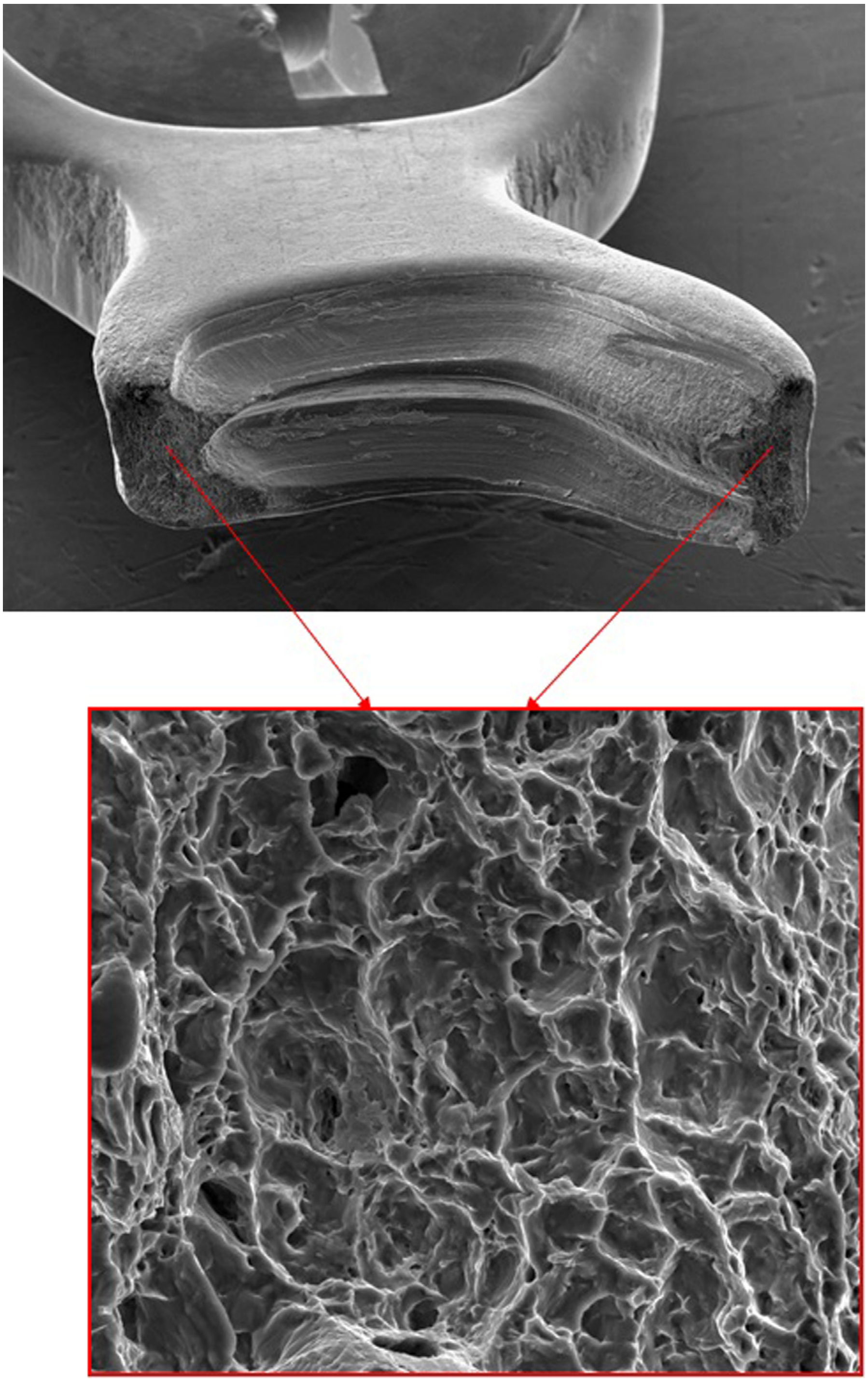

FIGURE 4. Fractographic aspects of the sample from group I with the Tóride brand. *Above,* Fractured plate at 60× magnification. *Below,* Fracture surface at 2,000× magnification.

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Discussion

A structure was considered to have failed on the occurrence of 1 of the 3 following conditions: *1)* when the structure has been rendered completely useless, *2)* when it still could be used, but was no longer capable of performing its function satisfactorily, and *3)* whenever deterioration had occurred making it unsafe to be used.[14] Under any of these situations, the material must be removed, and the failure must be scientifically studied to discover and evaluate the damages and failure process. This will allow the material to be optimized.[14-16]

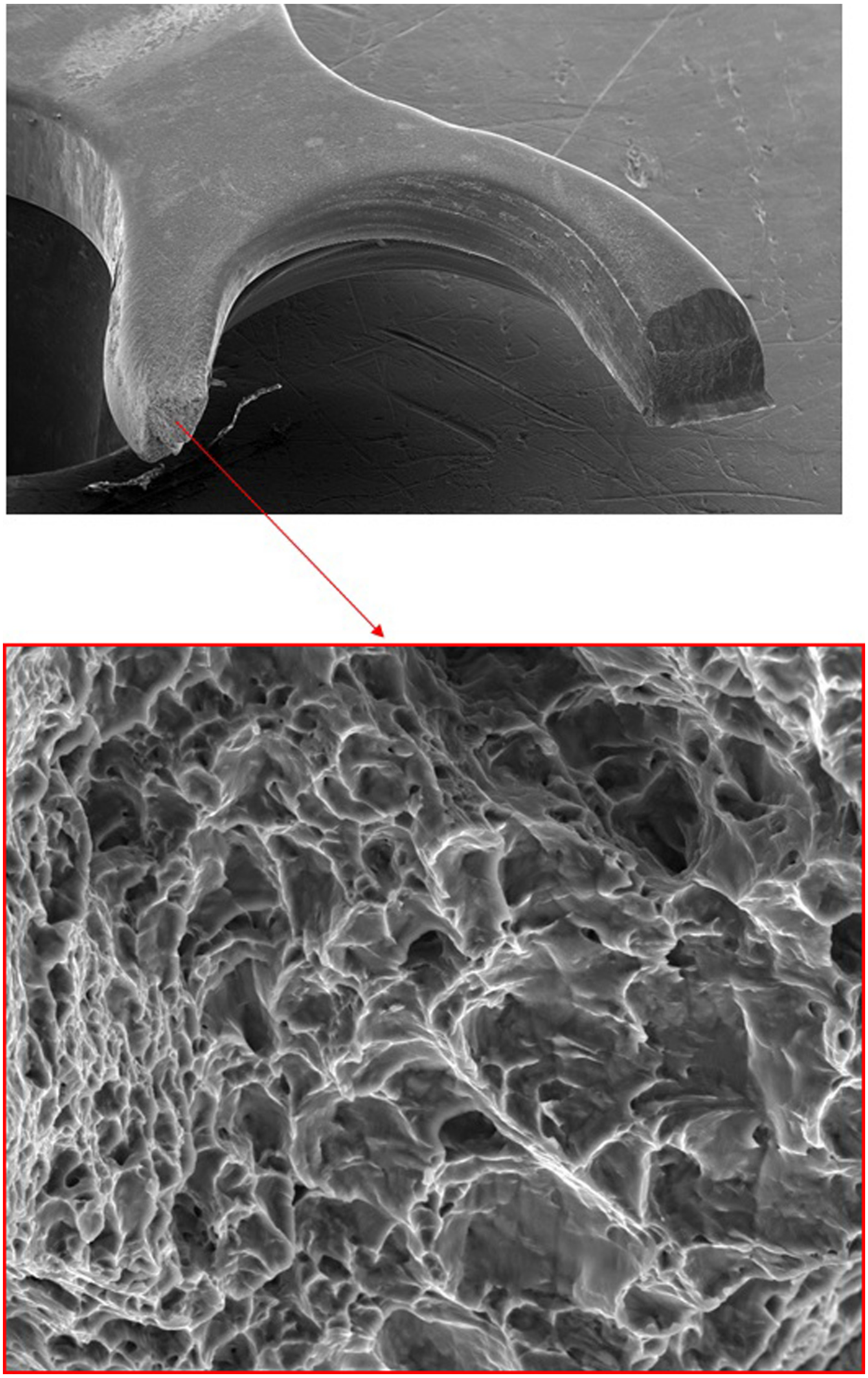

FIGURE 5. Fractographic aspects of the sample from group II with the Traumec brand. *Above,* Fractured plate at 45× magnification. *Below,* Fracture surface at 2,000× magnification.

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Fractography starts with the macroscopic analysis, such as analysis of a surface with up to 10× magnification, which will reveal the initial characteristics of the fracture type—color, brightness, plastic deformation, and the presence of cracks.[15]

The analysis continues microscopically, with the help of an electronic microscope. The *ASM Metals Handbook*[13] reported that the rupture by dimples, such as occurred to the plates we studied, occurs through the coalescing of microvoids. The voids will develop from the effect of an external force in the discontinuities present in the material. This rupture mechanism occurs when the material has been exposed to a greater tension than the peak load of the material, and it is characteristic of ductile materials, such as metals. The fracture will resemble spherical or stretched cavities, depending on the direction of the force applied.

In the present study, the rupture mechanism by dimples occurred as expected, because the forces to which the plates were submitted were known. In a case in which the rupture mechanism was different, changes to the pure titanium structure, the manufacturing of the plate, or the force mechanism itself would be suggested. Thus, our results indicate that the national brand name plates were manufactured with adequate quality control and no structural changes that could have compromised their function.

In the published data, the results of a fractographic analysis for a 2.0-mm locking plate has not been reported. Tucker[17] stated that in cases of an atrophic edentulous mandible in which the 2.0-mm plates had fractured, the miniplates were more likely to have fractured because of fatigue. This will result because, even after reduction of the fracture, the bone contact will still be minimal, and the plate will experience the action of the mandible elevator muscles that cause the superior rotation of the ramus and the suprahyoid muscles that cause anterior and inferior rotation, creating deformation from repetition.

However, Hylander and Johnson[18] added that, owing to the low ductility of titanium, the fracture will occur from the difference in the elastic and plastic deformation between the mandible and the fixation plate, not only from the cyclical loads. Thus, failure occurs, and conventional 2.0-mm plates will fracture within 10 days.

Of the studies in which plate fractures were described,[8-10] only 2 reported the period in which the failure occurred. The period was approximately 30 days postoperatively, suggesting that the failure occurred owing to an excess of load to which it was subjected and not fatigue. However, the plates were not subjected to analysis, and the cause of failure was unknown.

Ellis and Price[19] recommended the use of 2.0-mm locking plates in the case of an edentulous mandible, such as the one used for the biomechanical model in our study, and mainly in the case of an atrophic mandible, in which the use of 2 conventional plates was urged owing to the reduced mandibular height. This type of system offers greater stability to the fracture and has resulted in lower complication rates.

According to Oliveira,[20] the increasing need to improve the reliability of the materials has resulted in several techniques to minimize and/or eliminate failures. These methods and techniques have been intended to increase the probability of a material to perform its function without failure. In the healthcare area, this will be extremely important, because it will avoid complications after installation, reduce the number of second interventions, reduce the hospitalization time, and, consequently, reduce governmental expenditure.

This study achieved its objective of assessing the loads supported by the fixation system and the methodology used was of utmost importance to achieve the results shown. In the present study, an aluminum hemimandible was chosen because of the need to evaluate the resistance of the plate and screw system with no interference from the substrate. Thus, it was necessary to manufacture a hemimandible from a material that would not allow the system to fail by the loosening of the screws in the screw–substrate interface during linear loading, allowing for plate fracture and subsequent analysis. Aluminum also has a low cost and is easily available, factors that influenced our choice to use aluminum to manufacture the hemimandibles.

The results of the present study agree with those from Hegtvedt,[21] who used a stainless steel substrate in his study. Hegtvedt stated that although the biomechanical model did not represent a human mandible in all its aspects, it allowed for the evaluation of the amount of load the miniplates can support before failing. That, combined with fractography and metallography, will allow understanding of the behavior and failure process of the internal fixation material in a clinical situation. Furthermore, failures in samples of polyurethane, the most commonly used material for substrates for biomechanical testing, have been reported by Vieira e Oliveira and Passeri[22] and could interfere with the results.

In Brazil, no specific legislation yet regulates a procedure to notify and investigate failure cases. Thus, no statistical data are available that describe the technical and economic aspects of these failures, the direct and indirect costs related to new operations, the main causes of the failures, and so forth.[23] However, plate fractures, not only for the 2.0-mm plates with a screw locking system, but also for any biomaterial used for treatment, must be analyzed to obtain answers and allow improvement of the materials.

In conclusion, the plates fractured owing to a ductile rupture mechanism, as expected, suggesting that the manufacturing of the plates used in our study was performed with adequate quality control. Also, no structural changes produced by the manufacturing process compromised their function. The fracture of 2.0-mm plates with a screw locking system has been previously described in the literature; thus, these plates need to be analyzed, using biomechanical models, to help improve the fixation system.

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