DOI 10.1007/s10527-019-09894-0
Biomedical Engineering, Vol. 53, No. 2, July, 2019, pp. 137-141. Translated from Meditsinskaya Tekhnika, Vol. 53, No. 2, Mar.-Apr., 2019, pp. 43-46.
Original article submitted June 25, 2018.

Strength Characteristics of the Bone–Implant–Bone System in Midshaft Clavicular Fracture Osteosynthesis

B. Sh. Minasov[1], Sh. F. Yakupov[2]*, R. R. Yakupov[1], A. R. Bilyalov[1], M. M. Valeev[1], T. B. Minasov[1], T. R. Mavlyutov[1], M. I. Nagimov[3], and I. I. Garipov[1]

A method of surgical treatment of midshaft clavicular fractures and a compression interlocking nail for osteosynthesis of the clavicle were developed. Strength characteristics of various bone–implant–bone systems in osteosynthesis of midshaft clavicular fractures were compared. It was shown that none of the tested fixation techniques provides stability under conditions of axial loading comparable to that of an intact clavicle. The developed design can be recommended as a method of choice for osteosynthesis of midshaft clavicular fractures, as it demonstrated strength characteristics comparable to those of other systems.

Introduction

Clavicular fractures are among the most frequent injuries (2.6-4% of all skeletal injuries). Midshaft fractures constitute 69-82% of all clavicular fractures [1-4]. Such fractures most often occur in young and middle-aged persons leading an active life. The abundance of surgical techniques for clavicular osteosynthesis often makes it difficult to select the most appropriate surgical procedure, which is indicative of the absence of a "gold standard" technique. An overview of the literature and orthopedic practice showed that plate osteosynthesis and intramedullary nails are especially frequently used for surgical treatment of clavicular fractures. According to the majority of specialists, the resistance to the start load determines the mechanical interactions in the bone–implant–bone system. Therefore, it is of special interest to compare the characteristics of the implants widely used in orthopedic practice [5-11].

The goal of this work was to carry out a comparative analysis of the characteristics of bone–implant–bone systems for different surgical techniques of osteosynthesis of midshaft clavicular fractures.

Materials and Methods

Groups of cadaver clavicle specimens with midshaft fractures were studied. The clavicles were experimentally fractured using an identical procedure and consolidated using different techniques of osteosynthesis. In the experiment, the specimens were randomized as to the osteosynthesis technique. A group of specimens with intact clavicles was also included in the study. The experiments were performed in cadaver models of the same age and sex and with similar anthropometric characteristics. Bone–implant–bone specimens were randomly selected for bench tests under conditions simulating actual mechanical causes of fracture. The Instron 1185 universal testing frame was used. The specimens were deformed in three planes: horizontal (along the clavicle axis, with the acromial extremity facing upward and the sternal extremity facing downward), frontal (from top downward), and sagittal (anteroposteriorly). Each system was subjected to dosed loading at a rate of 2 mm/min until complete destruction. The results of the tests were plotted as load (N) vs. time (s).

A technique for surgical treatment of midshaft clavicular fractures and an interlocking compression nail were

[1] Bashkir State Medical University, Ministry of Health of the Russian Federation, Ufa, Russia.
[2] Ufa Municipal Clinical Hospital No. 13, Ufa, Russia; E-mail: tr_shamil@mail.ru
[3] Institute for Metals Superplasticity Problems, Russian Academy of Sciences, Ufa, Russia.
* To whom correspondence should be addressed.

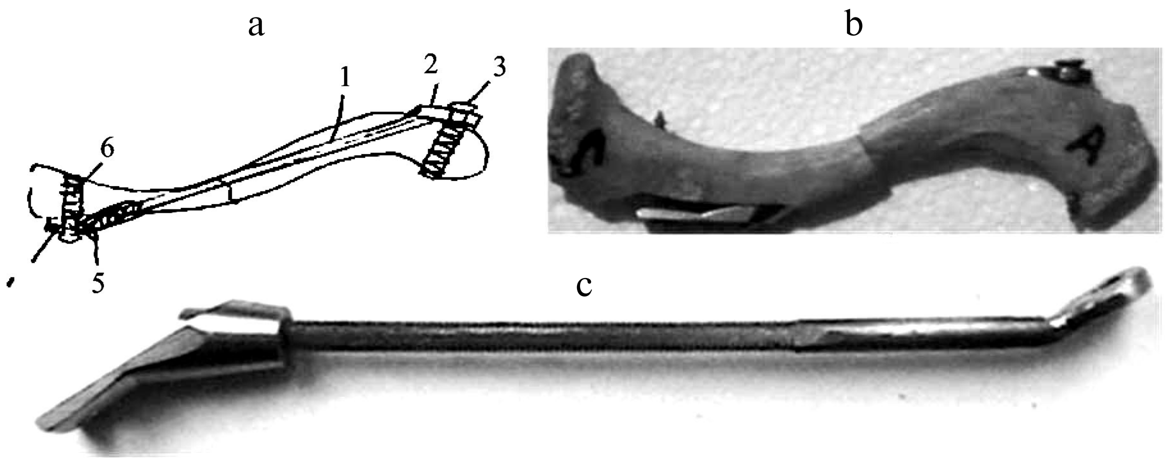

Fig. 1. Interlocking compression nail: a) schematic; b) after osteosynthesis in cadaver model; c) top view.

developed and patented (Utility Patent No. 2281786, March 25, 2005, and Utility Patent No. 2345730, February 10, 2009). The implant for intraosseous osteosynthesis is an interlocking compression nail 1 with a round cross section. The nail is threaded at one end. Its other end 2 is extended and flattened and has a screw (3) hole in it. The implant has two removable parts: a rectangular metal plate 4 with a screw (6) hole in it and a compression nut 5. A two-diameter tube is soldered to the removable plate. The tube is threaded inside to fit the threaded end of the nail 1, which has the shape of a truncated cylinder at an angle of 90° with respect to the flattened end of the nail (Fig. 1). This does not allow the nail and the plate to move with respect to each other.

The strength characteristics in the horizontal plane along the axis of the clavicle were studied in the following groups of specimens:

1) specimen with intact clavicle;
2) specimen with a reconstruction plate 1.2 mm thick;
3) specimen with a reconstruction plate 2.3 mm thick;
4) specimen with the developed interlocking nail;
5) specimen with an LCP plate;
6) specimen with a thick Bogdanov's nail (3.5 × 4.5 mm);
7) specimen with a Bogdanov's nail (2 × 3 mm).

The strength characteristics in the frontal and sagittal plane were studied in the following three groups of specimens:

1) specimen with the developed interlocking nail;
2) specimen with a straight plate for clavicular osteosynthesis;
3) specimen with a reconstruction plate 2.3 mm thick.

The results of the bench tests were recorded using an ADC providing automated recording of time, velocity, and load force. Maximum peak values of the load resistance, duration of effective load resistance, critical points of failure of the system, magnitude of decline of interfragmental stability, and the pattern of stress decrease were measured.

Results

In bench tests of the bone–implant–bone systems and the intact bone, maximum peak strength under horizontal loading along the clavicle axis was observed in the group of intact bone specimens (group 1). These specimens were destroyed at a mean load of 2600 N. Maximum peak load resistances achieved using the tested standard techniques and certified implants were as follows (Fig. 2):

– group 2 (2.5-mm reconstruction plate) – 1520 N;
– group 3 (4-mm reconstruction plate) – 1730 N;
– group 4 (the developed interlocking nail) – 2450 N;
– group 5 (LCP plate) – 2480 N;
– group 6 (Bogdanov's nail 2 × 3 mm) – 1010 N;
– group 7 (Bogdanov's nail 3.5 × 4.5 mm) – 1260 N.

The longest resistance time was exhibited by specimens osteosynthesized using the LCP plate. These remained stable for 817 s of the test. Shorter resistance times were observed in specimens fixed using reconstruction plates and the developed nail. Specimens with Bogdanov's nails had the shortest resistance times.

In the case of top-to-bottom loading in the frontal plane, maximum peak strength was observed in the group of specimens with the developed nail (673 N). Specimens with the straight plate and the reconstruction plate exhib-

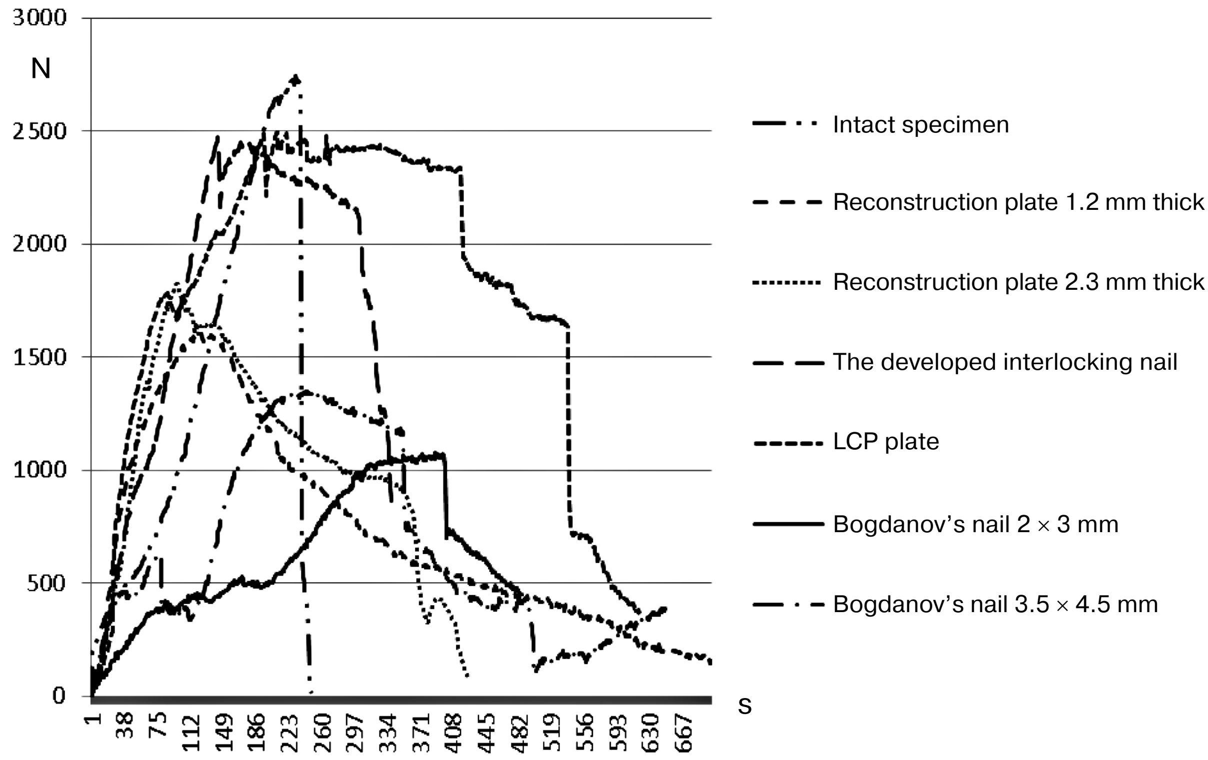

Fig. 2. Strength characteristics of the bone–implant–bone system in osteosynthesis of midshaft clavicular fractures under horizontal loading along the axis of the clavicle.

Fig. 3. Strength characteristics of the bone–implant–bone system in osteosynthesis of midshaft clavicular fractures under top-to-bottom loading in the frontal plane.

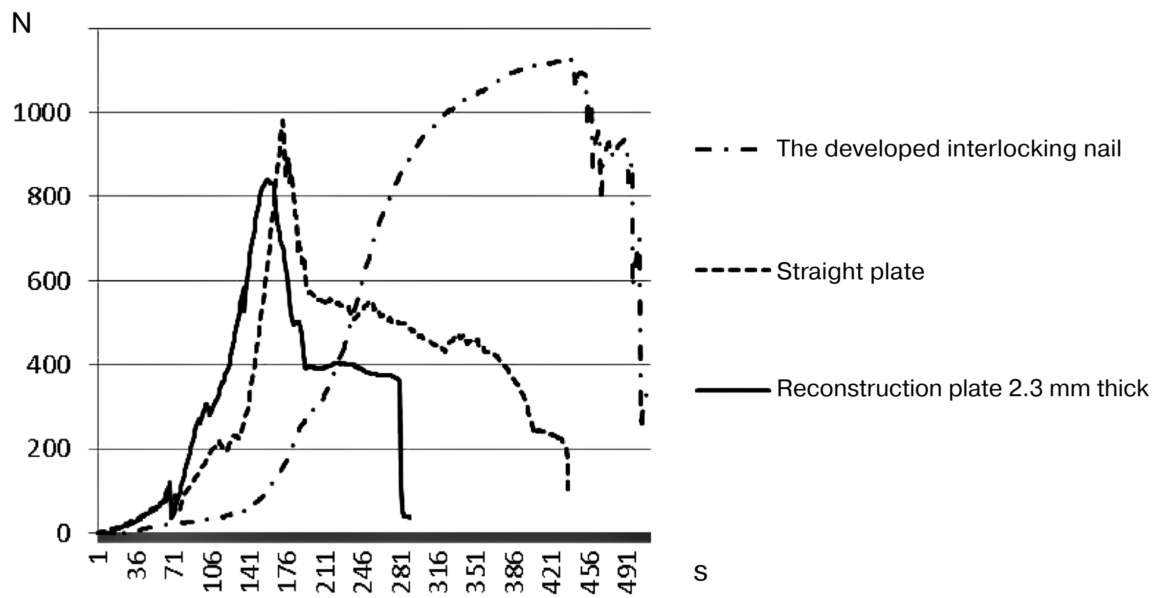

Fig. 4. Strength characteristics of the bone–implant–bone system in osteosynthesis of midshaft clavicular fractures under anteroposterior loading in the frontal plane.

ited lower peak strength values: 607 and 188 N, respectively. The longest resistance time was exhibited by specimens with plate osteosynthesis (as compared to specimens with the developed nail) (Fig. 3).

In the case of anteroposterior sagittal loading, maximum peak strength was exhibited by specimens with the developed nail (1126 N) as compared to those with the straight plate (981 N) and the reconstruction plate (840 N). The resistance time was longer in the case of intramedullary as compared to plate osteosynthesis (Fig. 4).

Comparative analysis of maximal values of axial load resistance showed that plate osteosynthesis and nailing using the developed nail provided comparable results. Maximal resistance time was exhibited by specimens with the LCP plate.

In the case of top-to-bottom loading in the frontal plane, specimens with the developed nail exhibited higher peak values of resistance, while the resistance time was longer in specimens with plated fractures.

Bench tests in the sagittal plane (anteroposterior loading) showed that specimens with the developed nail exhibited higher peak values of resistance and longer resistance times.

Evaluation of the initial characteristics of the bone–implant–bone system stability in osteosynthesis of midshaft clavicular fractures made it possible to determine the critical points of failure of the system. The obtained data can be used for improving the implant performance.

Conclusions

Bench tests of the bone–implant–bone system in midshaft clavicular fracture osteosynthesis showed that the tested techniques do not allow the mechanical strength of the intact bone to be achieved.

Evaluation of the system behavior under axial loading revealed an instantaneous stress drop in intact specimens, while in bone–implant–bone systems the decrease in stress was, in the majority of cases, gradual.

The developed interlocking compression nail can be recommended for osteosynthesis of clavicle shaft fractures. Tests showed that the developed nail provides strength characteristics comparable to those achieved using other techniques.

Knowledge of the range of performance characteristics of an implant allows its service life to be evaluated, facilitating thereby selection of the optimal osteosynthesis technique. It may prove to be a key factor in providing effective surgical treatment. The functional rehabilitation program and the load regimen should, in turn, be adjusted to the selected osteosynthesis technique.

REFERENCES

1. Airapetov, G. A., Zagorodnii, N. V., Volna, A. A., Vorotnikov, A. A., and Panin, M. A., "Medical care management for patients with midshaft clavicular fractures: Current state of the problem of con-

servative and surgical treatment and its possible solutions," Med. Vestn. Sev. Kavkaza, **8**, No. 2, 42-44 (2013).

2. Zagorodnii, N. V., Airapetov, G. A., Volna, A. A., and Grigor'ev, V. V., "Anatomical substantiation of a new access point for clavicular osteosynthesis," in: Proc. Congress Traumatology and Orthopedics in the Capital City: Present and Future, May 14-16, 2012 (Moscow), p. 48.
3. Labronici, P. J., Santos Filho, F. C. D., Reis, T. B., Pires, R. E. S., Junior, and A. F. M., Kojima, K. E., "Are diaphyseal clavicular fractures still treated traditionally in a non-surgical way?," Rev. Bras. Ortop., **52**, No. 4, 410-416 (2017).
4. Ahrens, P. M., Garlick, N. I., Barber, J., and Tims, E. M., "The clavicle trial: A multicenter randomized controlled trial comparing operative with nonoperative treatment of displaced midshaft clavicle fractures," J. Bone Joint Surg. Am., **99**, No. 16, 1345-1354 (2017).
5. Martel', I. I. and Darvin, E. O., "Treatment of closed clavicular fractures by various osteosynthesis techniques," Gen. Ortoped., No. 4, 5-8 (2011).
6. Skoroglyadov, A. V., Ivkov, A. V., and Shneiderov, M. V., "Intramedullary clavicular osteosynthesis," Vestn. RGMU, No. 3, 22-25 (2013).
7. Beidik, O. V., Tonin, M. S., Levchenko, K. K., Karnaev, Kh. S., Nemolyaev, S. A., and Litvak, M. B., "Biomechanical computer simulation of osteosynthesis techniques," Gen. Ortoped., No. 4, 89 (2007).
8. Shchurov, V. A. and Darvin, E. O., "Dynamics of the functional state of patients treated for a clavicular fracture by transosseous osteosynthesis," Travmatol. Ortoped. Ross., No. 1, 87-92 (2013).
9. Fuglesang, H. F-S., Flugsrud, G. B., Randsborg, P. H., Oord, P., Benth, J. Š., and Utveg, S. E., "Plate fixation versus intramedullary nailing of completely displaced midshaft fractures of the clavicle: A prospective randomised controlled trial," Bone Joint J., **99-B**, No. 8, 1095-1101 (2017).
10. Langenhan, R., Reimers, N., and Probst, A., "Intramedullary stabilisation of displaced midshaft clavicular fractures: Does the fracture pattern (simple vs. complex) influence the anatomic and functional result," Z. Orthop. Unfall., **152**, No. 6, 588-595 (2014).
11. Fritz, E. M., van der Meijden, O. A., Hussain, Z. B., Pogorzelski, J., and Millett, P. J., "Intramedullary fixation of midshaft clavicle fractures," J. Orthop. Trauma, **31**, No. 3, S42-S44 (2017).