

Original article

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Impact of telescopic intramedullary rodding on the growing tibia: an experimental study

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Abstract

Introduction Telescopic intramedullary osteosynthesis (TIO) is used in children with osteogenesis imperfecta and other diseases accompanied by frequent fractures and deformities of long bones due to pathological bone tissue featuring reduced strength properties. **Purpose** In an animal experiment to study the growth characteristics of an intact tibia under conditions of intramedullary reinforcement with a telescopic rod. **Material and methods** A non-randomized controlled study was conducted on 4 animals (puppies, littermates) that underwent TIO of the right limb tibia with a telescopic titanium rod (outer diameter of 4.2 mm) at the age of 5 months. X-ray parameters (length of the tibia, angles of inclination of the articular surfaces, telescoping magnitude) were studied before surgery, on the day of rod placement, and after the end of spontaneous growth of the segment (7 months after surgery). The contralateral left tibia served as a control, and its X-ray parameters were studied at the same time-points. **Results** Transphyseal reinforcement with a telescopic rod caused growth retardation with loss of length in only one case out of four (8 mm or 4.8 % of residual growth). In other cases, no difference in the length of the tibias of the right and left lower extremities was found. Eccentric insertion of the transphyseal rods into the posterior third of the distal epiphysis (due to the natural anatomy of the canine tibial shaft) formed an angular deformity during growth: a significant increase in the distal anterior and lateral tibial angles of the operated limb compared to the intact limb. The amount of divergence of the parts of the rods was, on average, 11.3 mm. There were no cases of migration of intramedullary rods or loss of fixation of threaded sections in the epiphyses. **Conclusion** Under experimental conditions, the slowing down of longitudinal bone growth is not a constantly observed effect. Titanium telescopic rods are not prone to blocking during the limb growth or to losing the position of the threaded parts in the epiphyses. The eccentric passage of the rods through the growth zones causes angular deformities in the course of growth of the segment.

Keywords: telescopic intramedullary osteosynthesis, osteogenesis imperfecta, experimental study

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INTRODUCTION

Currently, the problem of choosing methods for correcting limb deformities in children with osteogenesis imperfecta and other systemic diseases accompanied by reduced bone strength remains relevant both in Russia and abroad. To eliminate these pathological conditions, variants of transphyseal intramedullary osteosynthesis are often used [1-3]. The effectiveness of such technologies is due to the fact that the reinforcing intramedullary fixator acts as an internal splint during the entire period of growth and prevents formation of new deformities [4-6].

The elastic transphyseal reinforcement proposed by Metaizeau [3] is not the leading method for use in children with osteogenesis imperfecta. However, this technique is indicated for small transverse bone diameters, with complete obliteration of the medullary cavity and small diameters, when the rods are inserted subperiosteally, as well as for correcting forearm deformities [5, 7, 8].

Our experimental study of the effect of this method on the growth of a segment under the conditions of imitation of preventive reinforcement revealed a loss in the magnitude of residual growth from 1 to 5.4 %, as well as a violation of the formation of radiographic joint angles in eccentric insertion of elastic rods through the growth zones [9]. Telescopic intramedullary osteosynthesis (TIO) is the most common technique and shows the best results in clinical conditions, where one part of the rod slides inside the other in the course of the natural limb growth [10-12]. However, experimental studies on the effect of a telescopic rod on the growth of a reinforced segment have not been carried out so far. Therefore, it is necessary to study the features of the formation of the epiphyses in the reinforced segments, the longitudinal limb growth and to assess the risks of developing angular deformities.

Purpose In an animal experiment, to study the growth characteristics of an intact tibia under the conditions of intramedullary reinforcement with a telescopic rod.

MATERIALS AND METHODS

A non-randomized controlled study was conducted on four healthy outbred litter dogs. The experiments started when the animals reached the age of 5 months; the weight of the puppies was 9.6 ± 0.8 kg.

All surgical procedures were performed in the operating room by one surgical team. General anesthesia was intravenous administration of sodium thiopental in the recommended doses.

In this experiment, TIO of the right tibia (experimental limb) was performed with a titanium rod (telescopic intramedullary rod; registration certificate No P3H2017/6876 dated 10.07.17, developed by Metis LLC, Tomsk; manufactured at Osteosintez LLC, Rybinsk; made of titanium alloy VT-6; GOST 19807-91). Both parts of the rod (inner and outer) were introduced through the proximal metaphysis by parapatellar approach under radiographic control. The diameter of the rod was selected in advance; as in all the cases the minimum diameter of the medullary canal along the epiphysis was 5–6 mm, 4.2-mm rods were used in all animals. Canal reaming was not performed in any case. The height of the threaded part of the inner and outer components was compared in advance (X-rays) with the height of the corresponding epiphyses of the tibia. If necessary, the threaded part was shortened prior to sterilization of the rod. Also, the outer part of the rod was shortened in beforehand. Osteoperforation in the proximal epiphysis was performed with a 4.5-mm awl. After the inner part was inserted and screwed into the distal epiphysis, the outer part was inserted and screwed into the proximal epiphysis. Then, after X-ray control, the excessive inner part protruding above the tibial plateau was cut off. Soft tissues were sutured in layers. In the postoperative period, the animals began to move bearing weight on the operated limb within 2-3 days.

The follow-up period was 210 days after the surgery. At the end of the experiment, the biological age of the animals was 12 months.

To achieve the objective of the study, radiography of the right and left legs was taken in frontal and lateral projections using the VEP X Technology Premium VET system (Spain) with subsequent analysis of X-rays at the stages: immediately before the experiment (control point D0, corresponding to the preoperative period), immediately after the operation (D1) and 210 days after the start of the experiment (D210). For performing radiography, the technical shooting conditions were of the same type: voltage on the tube was 44-46 kV, current strength was 2.5-3.2 mA, and focal length was 97 cm.

To study the outcomes of the experiment, we measured (Fig. 1):

- tibia length in the lateral radiograph;

- magnitude of the superposition of the parts of the rod (inner in the outer one, cm and %);
- mechanical medial proximal tibial angle (mMPTA) [13];
- mechanical lateral distal tibial angle (mLDTA) [13];
- mechanical posterior proximal tibial angle (mPPTA)
- mechanical anterior distal tibial angle (mADTA)
- location of the rods at the level of the physes relative to their median axes in the sagittal and frontal planes (on the radiographs of each view, the epiphyses were divided into three parts and the location was determined, respectively, in the middle, lateral, or medial third or in the middle, anterior, or posterior third of the epiphysis).

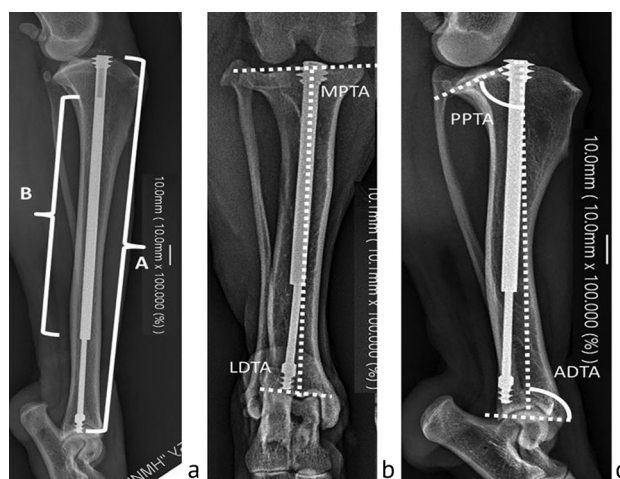


Fig. 1 Diagrams of measurements: a tibia length and superposition of rod parts: A total tibia length, rod length; B superposition value (SP), $B \times 100 \% / A = SP \%$; b joint angles in the AP radiograph; c joint angles in the lateral view

The secondary calculated parameter was the amount of spontaneous growth loss of the experimental limb in comparison with the contralateral control limb.

The obtained quantitative data were subjected to statistical analysis using the AtteStat add-in version 13.1 for Excel spreadsheets (2016, 16.0.5278.1000). The sample size was not previously calculated. Descriptive statistics methods were used: mean values (M) and standard deviation (SD). Comparative studies were performed using the Wilcoxon test for independent samples. The difference in measurement values between researchers was assessed using the coefficient of variation. Differences in indicators were considered significant at $p \leq 0.05$.

During the experiments, the principles of humane treatment of animals were observed in accordance with the requirements of the European Convention for the Protection of Vertebrate Animals used for Experiments

and other Scientific Purposes, and Directive 2010/63/EU of the European Parliament and the Council of the European Union of September 22, 2010 on the protection of animals used for scientific purposes. A positive decision was received from the local ethics

committee to conduct experiments to study the effect of intramedullary sliding structures on the growth of limb bones (minutes No. 2 (57) of the meeting of the Committee on Ethics of the Ilizarov center dated May 17, 2018).

RESULTS

No infectious or neurological complications were observed in any animal. No blocking of the rods was recorded; telescoping of the inner part relative to the outer one was observed in all cases. Also, there was no migration of the rod parts (protrusion into the knee or ankle joints or lateral migration), as well as no loss of fixation of the threaded sections of the rods in the epiphyses.

The location of the proximal threaded part was in the middle third both in the AP radiographs and in the lateral ones in all cases. However, the distal threaded part in all the cases was located in the posterior part (posterior third) of the distal tibial epiphysis, which is due to the natural anatomical recurvatum curve in the middle third of the canine tibial shaft.

The radiographic studies showed that the difference in the measurements of the studied parameters between the data of different researchers did not exceed 2.4 %, which indicates the accuracy and reproducibility of quantitative measurements of the studied parameters.

Table 1 presents the parameters of the length of the tibia and the measurement of the superposition of the parts of the rods. Analysis of the results showed that with a significant increase in the longitudinal growth of the experimental and control limbs, there was no significant difference in length between them at the end of the experiment. Moreover, only in one case, the lower leg with the installed rod was shorter by 8 mm. In other cases, the difference in the length of the tibia between the right and left pelvic limbs did not exceed 1 mm, which is within the limits of the measurement error. That is, we did not get a significant impact of the telescopic rod on the tibia growth.

Table 1
Mean parameters of the length of the tibia in the experiment, telescoping of intramedullary rods

Tibia length, mm	right	D ₀	119 ± 26.2	
	left		119.3 ± 27.5	
	right	D ₂₁₀	133 ± 24.02*	
	left		135.7 ± 28.7*	
Rod parts superposition, mm (%)			D ₁	84.7 ± 11.5 (77.3 ± 8.7)
			D ₂₁₀	73.4 ± 8.1 (60.3 ± 3.7)
Growth loss, mm (%)				2.7 ± 4.8 (1.6 ± 2.9)

* Significant differences in tibia length at the start and end of the experiment ($p < 0.05$)

Table 2 presents the average values of the radiographic angles of joint surface orientation of the limbs in the experimental animals.

Table 2
Mean values of MPTA, LDTA, PPTA, ADTA in the course of the experiment (°)

Angle	D ₀		D ₂₁₀	
	Right limb	Left limb	Right limb	Left limb
MPTA	90 ± 0.0	90.3 ± 0.58	94.3 ± 1.5	93.7 ± 2.5
LDTA	85.7 ± 2.08	85.7 ± 2.08	84.3 ± 0.6	80.7 ± 1.2*
PPTA	68.0 ± 2.0	68.7 ± 0.58	70.7 ± 1.2	69.3 ± 2.1
ADTA	84.3 ± 1.5	84.7 ± 1.2	85.7 ± 6.5	74.4 ± 1.2*

* Significant difference between right and left limb upon completion of the experiment ($p < 0.05$)

The data presented in Table 2 clearly show that the displacement of the threaded part of the inner rod posteriorly from the center of the distal growth zone had an impact on the orientation of the articular surface of the experimental segment, which had a significant influence on the ADTA and LDTA values in comparison with the control limb (Fig. 2).

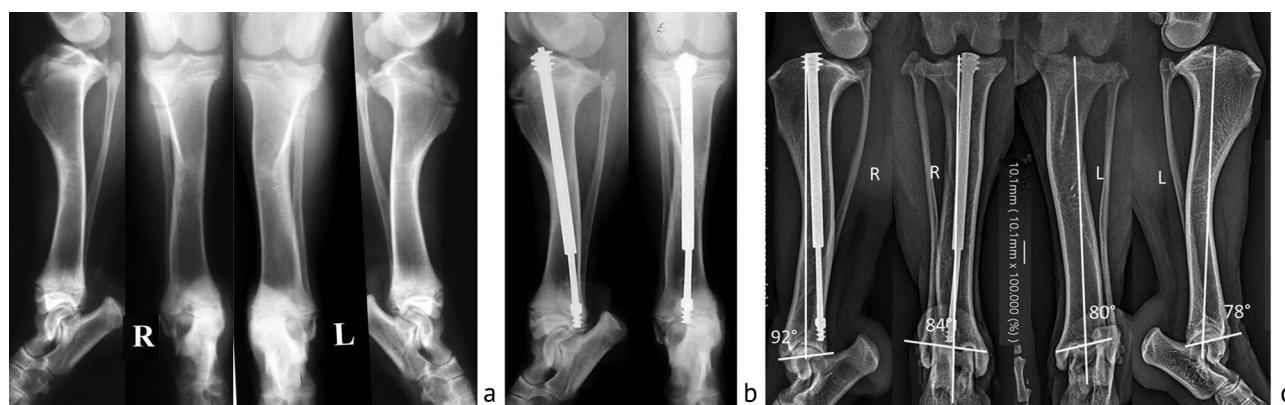


Fig. 2 Radiographs of the right and left lower legs during the experiment: a before surgery; b on the day of intervention; c 7 months after surgery

Intramedullary osteosynthesis of an intact canine tibia with a Russian telescopic rod did not cause a pathological slowdown in the longitudinal bone growth. The location of the threaded part of the rod in the center of the growth

zone of the proximal epiphysis did not affect the formation of the angle of inclination of the articular surface. By eccentric placement of the threaded part of the rod in the distal epiphysis, an angular deformity was formed.

DISCUSSION

Telescopic reinforcement is a key element in osteogenesis imperfecta surgery in children [1, 6, 10]. The success of using sliding structures depends on many factors: design of the products themselves and the material from which they are made, the features of surgical techniques for their installation, the severity of clinical manifestations of the disease, the morphofunctional state of the bone tissue, and even the physical activity of the patients themselves [14-17]. Among other aspects of reconstructive orthopedics, attention is also paid to the issue of the influence of transphyseal pinning on the process of residual growth of the reinforced segment [18].

In clinical practice, there are conflicting reports on the effect of transphyseal intramedullary pinning on the function of the growth plate cartilage. Horn J. et al. in their work observed partial epiphyseodesis and, as a result, the development of angular deformity in the treatment of fractures in children with similar methods [19]. In turn, Langenhan R and Yung PS et al. argue that transphyseal placement of straight Kirschner wires does not affect the growth of the operated limb [20, 21].

In a previous experimental study of transphyseal elastic reinforcement of intact long bones, we did not reveal a significant effect of such osteosynthesis on longitudinal bone growth. The loss of residual growth did not exceed 2.5 % [9]. At the same time, a change in the angle of inclination of the distal articular surface of the tibia was noted. The eccentric insertion of intramedullary elements through the medial malleolus caused varization of the ankle joint. The results of the present study are absolutely concordant with the previous one in that the transphyseal telescopic pinning did not cause premature closure of the growth zones and did not significantly affect the slowdown in longitudinal growth in the absence of additional bone trauma (imitation of a fracture by osteotomy).

An important issue is the topography of pinning through the growth zone. Seil R et al. in an experiment

on 18 lambs did not observe angular deviation in a centrally located canal pinning during the subsequent growth of the segment [22]. In our study, the central location of the rod in the proximal epiphysis did not change the formation of the proximal articular end of the tibia compared to the uninvolved one. However, eccentric pinning in the distal epiphysis resulted in significant differences in orientation parameters of the distal joint end of the tibia compared to the intact bone by the end of spontaneous growth.

Holmes et al. also indicated the importance of the central positioning of the corresponding threaded sections of the rods [23]. However, that work dealt with the relationship of the central location of the rods and their greater survival in the long-term period with a smaller number of migrations of parts of the telescopic rod, failure to telescope and other complications. However, our study is concordant with the above in terms of the need for precise central placement of the rods in the epiphyses.

Despite the fact that the central position of the ends of the intramedullary telescopic rods in the center of the epiphyses is obviously important for achieving correct telescoping, it is difficult to ensure this condition in some cases. The reasons may be deformities, poor quality of the bone, previous canal reaming, and other circumstances.

In our study, the eccentric location of the rod in the distal epiphysis, achieved during the surgery, is explained by the natural S-curve of the dog's tibia. At the same time, it should be noted that we did not observe violations of the divergence of the rod parts during the growth process. These data demonstrate that there are no problems with a telescopic Russian-made rod from a titanium alloy.

It was stated that the most common concomitant complication is the proximal migration of the rod in different periods after its installation [16, 24]. In the experimental study conducted, no cases of longitudinal migration of implant parts were detected.

CONCLUSION

The impact of telescopic titanium rodding on longitudinal growth is insignificant in isolated

intramedullary osteosynthesis for preventive reinforcement. Titanium telescopic rods did not show a

tendency to block during limb growth or lose position of their threaded parts in the epiphyses. The eccentric passage of the rods through the growth plate of the epiphyses is the cause of angular deformities in the course of subsequent physiological growth of the segment.

Further research in this direction should be carried out in relation to changing the surface of the threaded parts of the implants. The impact of the rod on the limb growth under the conditions of an experimental fracture (osteotomy) needs to be studied.

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