Surgical and Radiologic Anatomy (2019) 41:681–687
https://doi.org/10.1007/s00276-019-02213-y

ORIGINAL ARTICLE

A computed tomography study of the fibula: morphology, morphometry, intramedullary anatomy, application prospects on intramedullary nailing

I. Bazin[1] · M. Armendariz[1] · P. S. Marcheix[1] · M. Pichon[1] · F. Fredon[1] · C. Mabit[1] · P. A. Mathieu[1]

Received: 13 June 2018 / Accepted: 5 March 2019 / Published online: 11 April 2019

Abstract

Purpose The intramedullary percutaneous pinning in fractures of the lateral malleolus is a technique of osteosynthesis that can reduce complications of ORIF. Our study describes the morphology and the morphometry of the fibula, in particular intramedullary, so as to specify the best fibular nail features.

Methods We conducted a retrospective study on CT acquisitions of fibulae in vivo. We studied total length, and the distal malleolar angle. Regarding intramedullary morphology, six axial study levels were defined. Each level was assigned a morphometric classification (oval, triangular, quadrangular or irregular), and a measure of the diameter of the cavity. The distance between the smaller diameter and the malleolar tip was investigated.

Results We included 50 patients for 97 fibulae. The average age was 66.5 years. The irregular morphology type was the most frequently found. The average length was 370.5 mm (SD = 18.1; CI 95% [366.9; 374.1]), the average distal malleolar angle was 163.5° (SD = 3.7; CI 95% [162.7; 164.2]). The average minimal intramedullary diameter at malleolus level was 3.2 mm (SD = 1.2; CI 95% [3.0; 3.5]), with a minimum size reaching 95.8 mm (SD = 13.8; CI 95% [93.0; 98.5]) of the malleolar tip.

Conclusions The analysis of morphological parameters of the fibula, in particular the lateral malleolus and intramedullary morphology is necessary for the design of a morpho-adapted nail. Interpersonal variability must be taken into account by the implant industry to offer nails of suited lengths and diameters.

Keywords Fibula · Intramedullary · Morphology · Morphometry · Nailing · Anatomy

Introduction

Malleolar fractures occupy the third rank of traumatic injuries of the musculoskeletal system, behind the lower end of the radius and the upper extremity of the femur. In France, the incidence of malleolar fractures varies from 100 to 200 fractures for 100,000 people-years [1, 7, 13]. These lesions preferentially affect young men under 40 and women after 50 years old [6].

The fibula is a thin bone. The distal end, which participates in the ankle–joint complex, must be rebuilt as anatomically as possible. Lateral malleolus fixation is perilous, because of its environmental characteristics. It is immediately below the skin and the area is poorly vascularized.

Open reduction internal fixation (ORIF) has become the reference treatment [16, 22]. However, the risk of complications (sepsis, scarring disorders, difficult disassembly) remains significant [3, 14, 23], especially in the presence of significant co-morbidities (cardiovascular disease, diabetes, neuropathy, etc.) in an old population.

Lateral malleolar nailing is an interesting surgical alternative for fracture treatment. It might be associated with less post-operative complications [3]. The key features of the malleolar nail are: diameter, length, and angulation.

The purpose of this study was to assess the main morphometric measurements of the fibula regarding the gender, the side, the morphology and the intramedullary anatomy, to propose specifications for a morpho-adapted fibular nail.

✉ I. Bazin
isaline.bazin@hotmail.com

[1] Centre Hospitalier Universitaire de Limoges Dupuytren, 2 Avenue Martin Luther King, 87000 Limoges, France

Materials and methods

Our monocentric retrospective study was intended to describe the morphometric characteristics of the fibula on in vivo CT scans.

Patients who had received a computed angiotomography of the lower limb between July 2013 and April 2014 were included. We excluded all the fibulae with traumatic sequelae and those that were not analyzed in their full length.

We used General Electric devices (Optima CT 66 and LightSpeed VCT). Parameters of CT reconstruction were cutting thickness of 1.25 mm, and an increment of 0.6 mm. All measures were conducted on a workstation type GE Advantage Windows 4.6.

All measurements described were made by a single operator, to avoid inter-operator bias.

Morphological study

At different anatomical levels (proximal metaphysis, diaphysis, and distal metaphysis), we determined a geometric shape of the cortical bone structure, according to four pre-set morphotypes: triangular, quadrilateral, ovoid, and irregular.

Morphometric study

We measured the average fibular length, the average distal malleolar angle (Fig. 1), the L_{mini} height, corresponding to the distance between malleolar apex and intramedullary isthmus, the average malleolar medullary diameters, and the intramedullary limiting diameters at five fixed levels (9%, 18%, 50%, 75% and 95% from the distal end, until the proximal end) and L_{mini} (Fig. 2).

Fibular length and the average malleolar angle were analyzed by gender, and by laterality of the fibula (left vs. right).

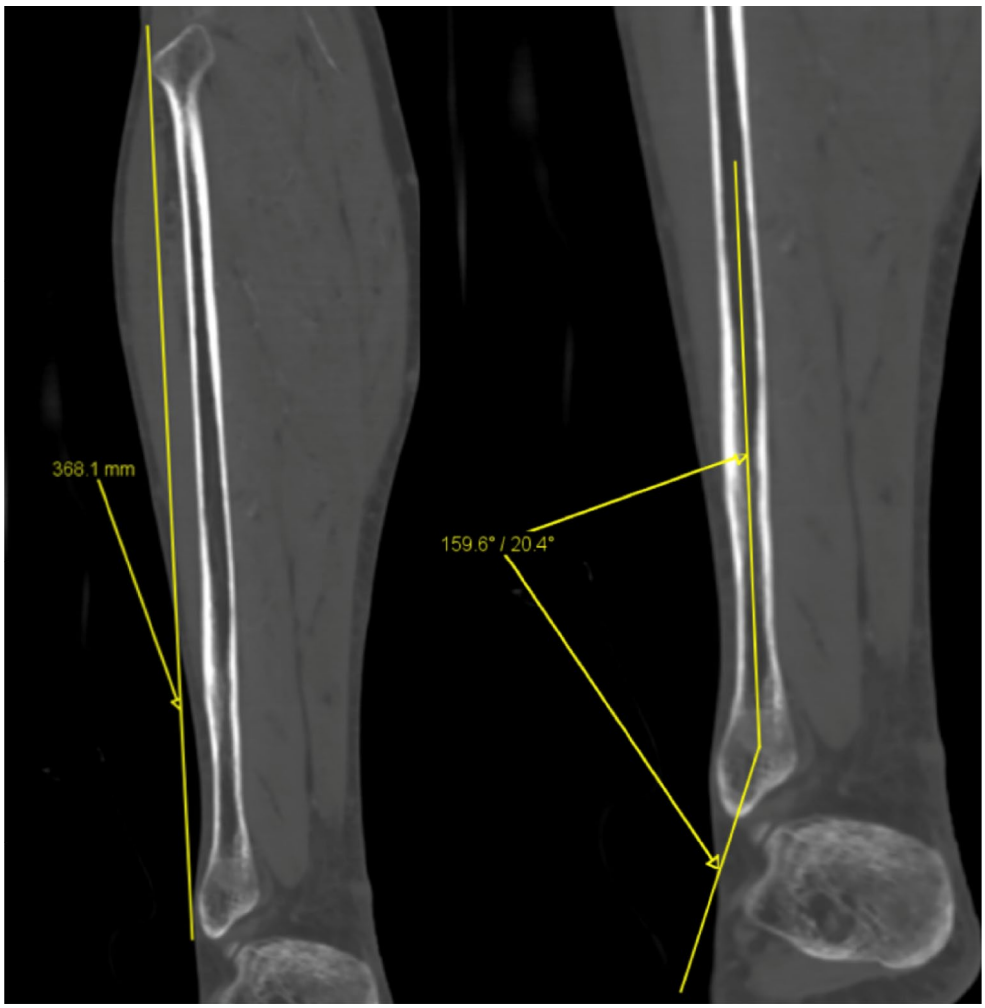

Fig. 1 Measurement of total length and distal malleolar angle of the fibula

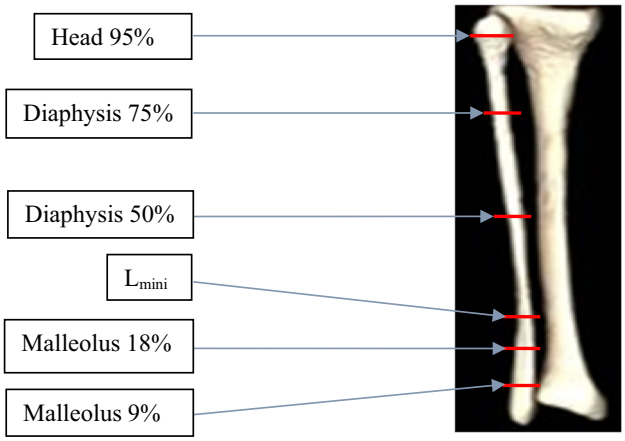

Fig. 2 Different levels of section defined during the study

Statistical analyses

The minimal fibulae sample estimated was of 30. First of all, we did a descriptive statistical analysis. Numbers and their corresponding percentages, as well as confidence intervals 95% (CI 95%) were shown for qualitative variables (morphotype and sex). Regarding continuous variables (fibulae characteristics, age), a Shapiro–Wilk test was done to verify the first hypothesis of normality. After this verification had been made, the distribution was presented as a mean (standard deviation); confidence interval of 95% (CI 95%). Otherwise, the median and the scope (range [minimum; maximum]) were added to characterize adequately, sample distribution, and an adjustment to a normal law was made, by a Kolmogorov–Smirnov test. Comparative Analyses were conducted using a two-tailed Mann–Whitney nonparametric test. We employed XLSTAT software for all analyses, and a p value < 0.05 was considered to be significant.

Results

97 fibulae in 50 patients have been analyzed (47 right, 50 left, 41 men, 9 women). The average age was 66.5 years (SD = 13.5; CI 95% = [62.8; 70.3]). Physical parameters of the patients were unknown.

The morphological study showed a predominance of the "irregular" morphotype: 68% of the fibulae studied at its proximal metaphyseal level (CI 95% = [58.8; 77.3]), 53, 6% at the diaphyseal level and at the distal metaphyseal level (CI 95% = [43.7; 63.5]) (Figs. 3, 4).

In the morphometric study, the average length was 370, 5 mm (SD = 18.1; CI 95% = [366, 9; 374, 1]). The average lateral malleolar distal angle was 163.5° (SD = 3.7; CI 95% = [162, 7; 164, 2]). The average L_{mini} length was 95.8 mm (SD = 13.8; CI 95% = [93.0; 98.5]). Malleolar medullary diameter was 3.2 mm (SD = 1.2; CI 95% = [3, 5, 0; 3, 5]). Intramedullary limiting diameters at different levels of section are summarized in Fig. 5.

The comparative men vs. women analysis revealed a difference concerning the total length of 374.mm (SD = 20; CI 95% = [335, 2, 8; 404, 8]) vs. 354.6 mm (SD = 11.4; CI 95% = [334.6; 368.1]) (p 0.0001) as well as for the lateral malleolar distal angle of 163.0° (SD = 5.2; CI 95% = [153.1; 170.1]) vs. 165.4° [SD = 4.1; (CI 95% = [159.4; 168]), ($p = 0.009$)] (Fig. 6).

There was no proof of a statistical difference ($p > 0.05$) when comparing right and left fibulae.

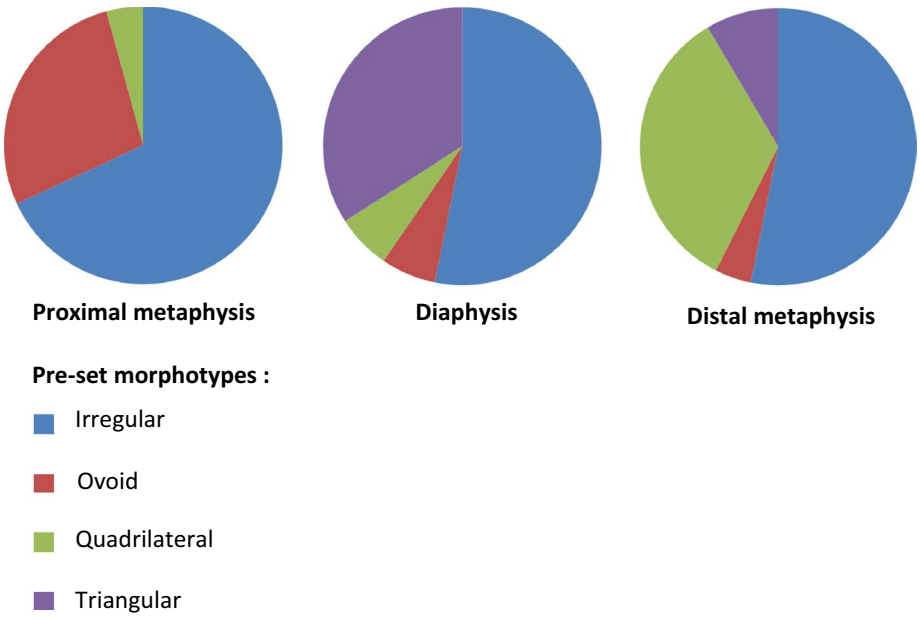

Fig. 3 Descriptive morphological analysis in cross-section. Visualization of dominant morphotype depending on level of cross section from angiotomography in lower limbs (97 fibulae, 50 patients), on three levels of cross-section, with four pre-set morphotypes

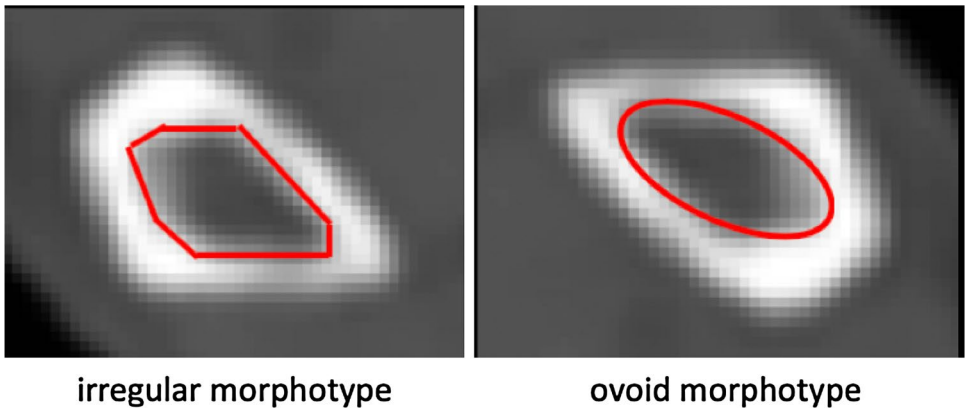

Fig. 4 Examples of morphotype

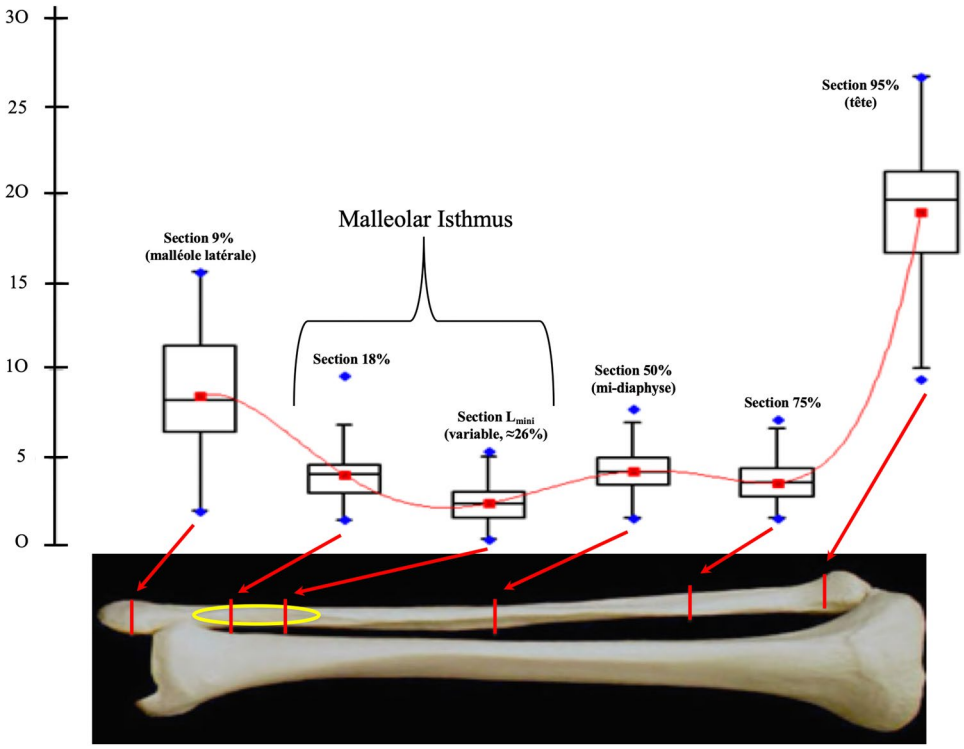

Fig. 5 Evolution-limiting intramedullary diameters, on six successive levels of cross section. Red Square markers represent the average values of each distribution, they are connected by a curve of trend polynomial to facilitate the visualization of the evolution. The blue losangiques markers represent extreme values (minimum and maximum) of each distribution. Box plots follow a model of classical representation: median, first and third quartiles, deciles one and nine. (Color figure online)

Discussion

Most of the anatomical studies about the fibula deal with its vascularization in the interest of fibular vascularized flap [2, 5, 10, 18, 25, 27–29]. Its complex morphometry is less studied, and our work is a first approach to its intramedullary morphology.

The inclusion of a large number of intact fibulae, studied in vivo, with CT acquisitions on infra-millimetric image resolution, gives a high accuracy of measurement and provides satisfactory descriptive analysis data.

In 1996, Mabit et al. [15] presented a detailed study of morphological variations of the lateral malleolar groove and their involvement in fibular tendon dislocations.

Our morphological study showed the geometric complexity of the fibula and its interpersonal variability, with a majority of an "irregular" morphotype. In 2013, Ide et al. [11] found the same morphotype predominance, in a study measuring the extra-medullary diameters of the fibula.

Limiting diameters measured for each intramedullary variable followed a similar evolution and showed an initial decrease along the malleolus sections, reaching a minimum value at the level of the section L_{mini}. The intramedullary canal never disappeared. Then, the canal's diameter size increased progressively throughout the diaphyseal sections, before reaching its maximum with an increase in the dimensions of the proximal epiphysis.

The men/women comparison showed a highly statistical significant difference concerning the total length, but this

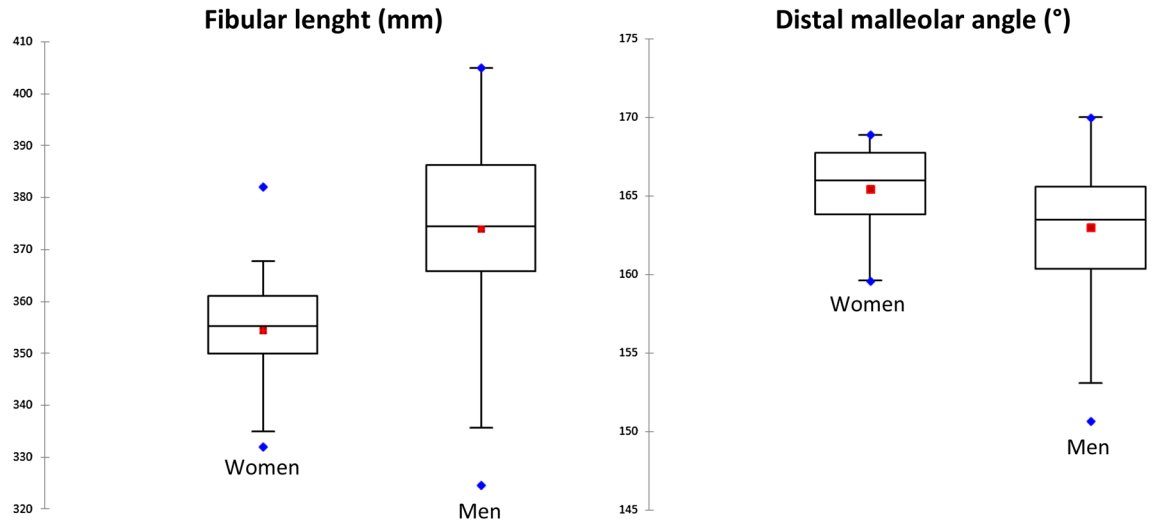

Fig. 6 Gender-based analysis. Only gender-based analysis with statistically significant difference was illustrated. The Red Square markers represent the average values of each distribution. The blue losangiques markers represent extreme values (minimum and maximum) of each distribution. Box plots follow a model of classical representation: median, first and third quartiles, deciles 1 and 9th. (Color figure online)

finding remains intuitive and gives few information due to the lack of patient physical parameters. In 2013, Ide et al. [11] also found a significant size difference in a comparative analysis based on sex.

The lack of difference when comparing right and left fibulae refers to bilateral symmetry. In 2014, Mathieu et al. [17], in a morphometric clavicle study, showed a significant difference between right and left clavicles. This difference is due to the existence of a dominant upper limb and would be less described on lower limbs.

Our work shows the narrowness of the medullar canal in its distal portion, and confirms the importance of intramedullary reaming during nailing. It also highlights the variability of some parameters. L_{mini} length, and especially average intramedullary limiting diameter, have variation coefficients of more than 10% (respectively, 14% and 38%), with widely dispersed variables inducing a loss of reliability in estimating mean corresponding values [20]. On the contrary, lateral malleolar distal angle and length have a coefficient of variation inferior to 5%, making the estimation of mean associated values more reliable. These observations suggest that it seems better to design an intramedullary fibular nail (defined mainly by its length, diameter and its eventual angle) with a range of different lengths and diameters so as to allow it to adapt to the anatomical studied variables. Even though, offering several distal angles seems irrelevant because of the low variability observed. Besides, to facilitate intramedullary implantation of the nail with less reaming, an open angle close to the 180° seems good solution, and is not far from anatomical reality.

The average age of the included patients could be considered as representative of the population targeted by the substantive issue, the incidence of fibular fractures increasing appreciably after 50 years [6]. However the sex ratio of fibular fractures is largely in favour of women after 50 years [6]. This was not the case in our study.

This study concerns a adult population. The age impact in morphometry and shape was not studied.

The use of intramedullary nails has gradually developed. Walton et al. [26] in 2016, emphasized on the mini-invasive and percutaneous features, allowing shortening of operating time, maintaining of the fracture hematoma, and a lower rate of complications. In 2017, Challagundla et al. [4] in a retrospective study of 15 patients, found no postoperative complications. In all his cases, he reported a return to weight bearing between 2 and 6 weeks. Forch et al. [9] allowed the full weight bearing on a walking boot, immediately after the fixation of the nail, in 34 patients. He found no complications. Rajeev et al. [19] in 2011 showed good functional and radiological results, thanks to the immediate mobilization authorized by the stability of the nail. According to Bugler et al. [3], these results would be only achieved by a correct locking.

Several authors compared intramedullary and extra-medullary treatments. Asloum et al. [1] in 2014 described better results of bone healing and of cutaneous and infectious complications in the early post-operative follow-ups with nailing, compared to screw plating. However, Jain et al. [12] in a literature review, with 1008 patients, found no convincing improving results regarding complications with nailing compared to ORIF. Rehman et al. [21] in 2015 did the same

comparison in a cohort of 375 patients, but without enough statistical power to conclude.

Switaj et al. [24] compared in 2016, the biomechanical resistances of lateral malleolar plates and nails. They found no significant differences between both groups, except in torsion forces, where plates had better resistance. Dehghan et al. [8] also highlighted in 2017 in his study about unusual nailing (clavicle, forearm, and fibula) lack of torsional stability and risk of shortening. These problems would be diminished by locking the nail, but still not reaching the same stability as of a plate.

Conclusion

Our study is the first to be interested in the intramedullary anatomy of the fibula. It showed the geometric complexity of the fibula and its interpersonal variability. We have described a supramalleolar isthmus. The intramedullary canal is open all along the fibula length. Our results provide actionable data to develop morpho-adapted fibula nails and develop the technique of intramedullary nailing. The complexity and interpersonal variability described must be taken into account by the industry to offer suited nail lengths and diameters. A larger cohort of elderly patients, with a female-positive sex ratio would be more representative of the population concerned by this pathology. A new comparative prospective randomized, non-inferiority, large-scale study could be done to validate the surgical indication and highlight the expected benefits of this surgical technique in management of fractures of the distal third of the fibula.

Author contributions IB, manuscript writing/editing. MA, other rereading. PSM, other rereading. MP, data collection or management. FF, other rereading. CM, protocol/project development. PAM, protocol/project development.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. For this type of study formal consent is not required.

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