Preliminary exploration of a quantitative assessment index for the matching performance of anatomical bone plates using computer

Xuhua Wu1†, Qingquan Xia2†, Ke Rong2, Minfeng Gan1, Gen Wen1, Xiaofan Yin2 and Huilin Yang1*

Abstract

Background: To explore a new quantitative index to assess the matching performance of anatomical bone plates using digital technology.

Methods: CT data of normal tibias of 40 adults were collected. Two brands of medial distal tibia plates were digitized. Two trained orthopedists simulated the surgical operation in Rhino 5.1 software by placing the plate curve on the medial distal tibia surface. The volume of the interstice between the plate curve and the bone surface was measured. The inverse value of this average interstice distance was used as the matching performance index (MPI). A wall thickness analysis tool was used to mark various interstice distances with varied colors.

Results: The Kangli medial distal tibia plate had a MPI of 0.55 ± 0.08 by operator A and 0.55 ± 0.06 by operator B. The general care medial distal tibia plate had a MPI of 0.32 ± 0.06 by operator A and 0.31 ± 0.05 by operator B. There were significant variations in the MPI between the two types of plates by both operators (p < 0.001). And significant variations were observed in the MPI of general care medial distal tibia plates among various operator groups (p = 0.028).

Conclusion: This quantitative index of matching performance is straightforward and intuitive. However, we still need a method to improve the experimental repeatability, especially when it comes to a plate with poor matching performance.

Keywords: Anatomical bone plate, Matching performance, Quantitative index

Introduction

Numerous designs of anatomical bone plates are available for limb fractures, particularly, periartricular fractures, for matching the fracture form of the patient. For a specified thickness of the bone plate, an increase in the number of anatomical bone plates (used for fracture fixation) matching the patient’s bone, reduces the likelihood of discomfort caused by the plate. The matching performance of the bone plate can directly affect the somatosensory system and limb activity of the patient, particularly when periartricular fractures are involved. However, a bone plate is not capable of adequately matching the bone surface of all the patients due to the variations of bone structure among individuals and among the various human races. Therefore, mass-produced anatomical bone plates are not likely to be suitable for all patients. Currently, no quantifiable generic index is available for assessing the matching performance of mass-produced anatomical bone plates; moreover, detection and supervision in this regard is inadequate. Clinical use of mass-produced anatomical bone plates involves potential risks. In this study, a new quantitative assessment method and index is used to compare the matching performance of two types of anatomical bone plates; moreover, a preliminary discussion is…

* Correspondence: suzhoupine@outlook.com
† Xuhua Wu and Qingquan Xia are co-first authors.
1 Department of orthopedics, The First Affiliated Hospital of Soochow University, No.899, Pinghai Road, Soochow 215006, China
Full list of author information is available at the end of the article
undertaken on the feasibility of this quantitative assessment index.

Materials and methods

Patients
Thin-slice CT scanning data (Siemens 64-slice spiral CT, Dicom format) of normal tibias of 40 adults (20 male and 20 female cases, who suffered contralateral lower limb fracture that need to perform CT scan) were extracted from CT images obtained between April 2015 and Mar 2018. The slice thickness was 0.6 mm. The average age of the patients was 36.4 years (ranging from 25 to 52 years), tibia fractures were absent, and cases involving lower limb deformity, osteoarthritis, and tumor were excluded.

Experimental design
The 40 cases of tibia CT data were imported into an interactive medical image control system 18.0 (MIMICS 18.0 by Materialise, Belgium). The threshold was set to 180–3071 HU, and the bone tissues were separated using the thresholding tool. The tibia was reconstructed in 3D using the Calculate 3D tool (Fig. 1). The morphology operation tool was used to fill the small voids on the surface and smoothen the surface of the bone structure. The tibia model (Fig. 2) was then exported in STL format, and the length of the tibia was measured.

Two commercial bone plates were used for the purposes of this study. Rhino 5.1 (Robert McNeel, USA) was used to perform a proportional 3D digital modeling of the general care distal medial tibia 8-hole anatomical bone plate (general care International, Lyon, France) and the Kangli distal medial tibia 8-hole anatomical bone plate (Suzhou Kangli Orthopaedics Instrument Co., Ltd., China). The bone-facing curves were extracted and the screw holes were filled (Fig. 3). Two trained orthopedists simulated the surgical operation by placing the plate curve on the medial distal tibia surface and adjusted the position until the optimal attachment state was attained (Fig. 4). In order to make the placement of the plate as standardized as possible, three criteria must be followed as explained below:

1. The axis of the plate should be parallel to the axis of the tibia at the sagittal plane.
2. The plate should be placed as close as possible to the bone surface, and it should be made sure that there is at least one point that sticks to the bone surface.
3. The distance between the distal end of the plate and the bone surface should be no greater than 2 mm.

The surface extrusion tool in solid tools was used to extrude the longitudinal axle and generate a solid vertical to the tibia to facilitate the overlapping of the solid and the bone (Fig. 5). It is feasible to determine the form of the interstice between the bone curve and the anatomical plate surface using a Boolean calculation (Fig. 6). The volume of the interstice was calculated by the solid analysis tool, and the average interstice distance was obtained by dividing the interstice volume by the surface area of the bone plate. The average interstice distance is inversely proportional to the matching performance of the bone plate. The smaller the interstice between the bone plate and the bone, the higher is the matching performance, and vice versa. Therefore, this study used the reciprocal of the average interstice distance as a
The quantitative matching performance index (MPI) in order to assess an anatomical bone plate. A higher value of this index represents higher matching performance.

The matching performance formula is as follows:

\[
\text{Matching performance index (MPI)} = \frac{1}{\text{Average interstice distance}} = \frac{\text{Surface area of bone-facing plate}}{\text{Interstice volume}}
\]  

(1)

The interstice model was exported in STL format and then imported into 3-matic Research 9.0. The wall thickness analysis tool in analysis was opened, and the parameter was set to 3 mm. With this value as the threshold, interstice distances larger than this value were marked by the color red, and those smaller than this value were marked by the color green. Thus, the various thicknesses in the interstice model were marked with varied colors.

Statistical analysis

The statistical analysis was performed using the SPSS 18.0 statistical software (PASW Statistics, IBM, USA). Normally distributed data were expressed as mean ± standard deviation (x ± s), and the data analysis program included two independent samples: a t-test (e.g., gender impact) and Pearson correlation analysis (plate type impact). A value of \( p < 0.05 \) indicates statistical significance.

Results

For the Kangli 8-hole medial distal tibia plate, the surface area of the bone-facing curve was 2388 mm², the interstice volume was 4417.8 ± 620.9 mm³ by operator A and 4393.9 ± 477.6 mm³ by operator B, the MPI was 0.55 ± 0.08 by operator A and 0.55 ± 0.06 by operator B. For the general care 8-hole medial distal tibia plate, the surface area of the bone-facing curve was 2505 mm², the interstice volume was 8041.1 ± 1553.1 mm³ by operator A and 8241.5 ± 1252.5 mm³ by operator B, and the MPI was 0.32 ± 0.06 by operator A and 0.31 ± 0.05 by operator B (Table 1). In this study, there were significant variations in the MPI between the two types of plates by both operators (by operator A, \( p < 0.001 \); by operator B, \( p < 0.001 \)). No significant variation was observed in the MPI of Kangli medial distal plate among various operator groups (for Kangli, \( p = 0.664 \)). However, significant variations were observed in the MPI of general care medial distal tibia plates among various operator groups (for general care, \( p = 0.028 \)) (Table 2). When using the quantitative index to compare the two types of plates, it was discovered that the Kangli medial distal tibia plate exhibited higher matching performance while a large red
area with a relatively fixed position was observed for the general care medial distal tibia plate (Fig. 7). A significant further enhancement is feasible.

**Discussion**

Varying degrees of racial, gender, and individual variations exist in the skeletal morphology of the human body [1–9]; however, clinical customized 3D printed plates are not currently popular due to time and production costs. Currently, the most common anatomical bone plate for clinical use exhibits a high price–performance ratio. Moreover, a variety of anatomical bone plates are available for clinical use [10–14] and the products are becoming increasingly mature; numerous companies have claimed superiority of the matching performance of
their respective anatomical bone plates. Nonetheless, a few studies on the matching performance of anatomical bone plates indicate that mismatch problems continue to exist in certain commonly used clinical anatomical bone plates [15, 16].

A standardized matching performance test, which is essential before putting mass-produced anatomical bone plates into clinical use, is unavailable. Moreover, it is challenging for the clinicians to provide a personalized evaluation of the plate matching performance for the patient before the operation. This poses a potential risk in its clinical use [17, 18]. According to existing literature, a majority of studies on the matching performance of anatomical bone plates started by measuring the bones of corpses [15, 16] or the CT images of living individuals [19]. When the measurement is conducted based on certain local surface characteristics of particular bone plates and bones, it is not feasible to quantitatively assess the

| Sample | Gender | Tibia length (mm) | Kangli (MPI) Operator A | Kangli (MPI) Operator B | General care (MPI) Operator A | General care (MPI) Operator B |
|--------|--------|-------------------|--------------------------|-------------------------|-------------------------------|-------------------------------|
| 1      | Male   | 353.00            | 0.53                     | 0.56                    | 0.29                          | 0.31                          |
| 2      | Male   | 355.00            | 0.63                     | 0.59                    | 0.21                          | 0.22                          |
| 3      | Male   | 357.00            | 0.50                     | 0.53                    | 0.34                          | 0.30                          |
| 4      | Male   | 358.00            | 0.77                     | 0.67                    | 0.50                          | 0.45                          |
| 5      | Male   | 361.00            | 0.63                     | 0.59                    | 0.43                          | 0.42                          |
| 6      | Male   | 361.00            | 0.59                     | 0.67                    | 0.40                          | 0.37                          |
| 7      | Male   | 363.00            | 0.56                     | 0.63                    | 0.37                          | 0.33                          |
| 8      | Male   | 365.00            | 0.48                     | 0.50                    | 0.33                          | 0.29                          |
| 9      | Male   | 356.00            | 0.71                     | 0.67                    | 0.28                          | 0.25                          |
| 10     | Male   | 368.00            | 0.67                     | 0.59                    | 0.34                          | 0.31                          |
| 11     | Male   | 366.00            | 0.56                     | 0.56                    | 0.33                          | 0.37                          |
| 12     | Male   | 359.00            | 0.47                     | 0.50                    | 0.37                          | 0.34                          |
| 13     | Male   | 371.00            | 0.63                     | 0.63                    | 0.34                          | 0.31                          |
| 14     | Male   | 370.00            | 0.67                     | 0.63                    | 0.30                          | 0.29                          |
| 15     | Male   | 360.00            | 0.59                     | 0.59                    | 0.26                          | 0.27                          |
| 16     | Male   | 357.00            | 0.53                     | 0.50                    | 0.30                          | 0.29                          |
| 17     | Male   | 362.00            | 0.48                     | 0.50                    | 0.24                          | 0.26                          |
| 18     | Male   | 366.00            | 0.50                     | 0.53                    | 0.26                          | 0.28                          |
| 19     | Male   | 358.00            | 0.56                     | 0.56                    | 0.21                          | 0.24                          |
| 20     | Male   | 355.00            | 0.45                     | 0.48                    | 0.32                          | 0.29                          |
| 21     | Female | 337.00            | 0.59                     | 0.56                    | 0.36                          | 0.32                          |
| 22     | Female | 338.00            | 0.42                     | 0.45                    | 0.30                          | 0.29                          |
| 23     | Female | 338.00            | 0.43                     | 0.45                    | 0.29                          | 0.31                          |
| 24     | Female | 339.00            | 0.53                     | 0.50                    | 0.34                          | 0.30                          |
| 25     | Female | 339.00            | 0.50                     | 0.50                    | 0.30                          | 0.33                          |
| 26     | Female | 340.00            | 0.48                     | 0.48                    | 0.31                          | 0.32                          |
| 27     | Female | 340.00            | 0.53                     | 0.56                    | 0.38                          | 0.36                          |
| 28     | Female | 341.00            | 0.45                     | 0.48                    | 0.34                          | 0.31                          |
| 29     | Female | 341.00            | 0.67                     | 0.63                    | 0.32                          | 0.34                          |
| 30     | Female | 342.00            | 0.59                     | 0.59                    | 0.37                          | 0.31                          |
| 31     | Female | 345.00            | 0.56                     | 0.56                    | 0.30                          | 0.32                          |
| 32     | Female | 350.00            | 0.53                     | 0.56                    | 0.29                          | 0.29                          |
| 33     | Female | 333.00            | 0.59                     | 0.56                    | 0.30                          | 0.29                          |
| 34     | Female | 332.00            | 0.48                     | 0.50                    | 0.24                          | 0.26                          |
| 35     | Female | 346.00            | 0.50                     | 0.50                    | 0.36                          | 0.29                          |
| 36     | Female | 352.00            | 0.53                     | 0.56                    | 0.26                          | 0.23                          |
| 37     | Female | 337.00            | 0.59                     | 0.56                    | 0.24                          | 0.26                          |
| 38     | Female | 344.00            | 0.45                     | 0.48                    | 0.45                          | 0.42                          |
| 39     | Female | 350.00            | 0.71                     | 0.63                    | 0.34                          | 0.31                          |
| 40     | Female | 343.00            | 0.56                     | 0.50                    | 0.32                          | 0.36                          |
| Average value | 351.2 ± 11.25 | 0.55 ± 0.08 | 0.55 ± 0.06 | 0.32 ± 0.06 | 0.31 ± 0.05 |
comprehensive matching performance of the anatomical bone plate from a global perspective. Furthermore, because there is no generic quantitative index, it is not feasible to quantitatively compare the matching performances of various types of anatomical bone plates.

With the development of the digital orthopedic platform, the quantitative assessment of the matching performance of anatomical bone plates using the computer has been made feasible [20–22]. In this study, a 3D reconstruction of the bones of a normal population was performed by CT while the surgical operation was

Table 2 Significant difference observed in the tibia matching performance between different bone plates in an identical operator group

| Group       | Kangli  | General care | T value | p value |
|-------------|---------|--------------|---------|---------|
| Operator A  | 0.55 ± 0.08 | 0.32 ± 0.06 | 15.863  | < 0.001 |
| Operator B  | 0.55 ± 0.06 | 0.31 ± 0.05 | 20.906  | < 0.001 |

Table 2: Significant difference observed in the tibia matching performance between different bone plates in an identical operator group.

Wu et al. Journal of Orthopaedic Surgery and Research (2019) 14:202

Fig. 7 Matching performance of nephogram for anatomical bone plates. Using the wall thickness analysis tool in 3-matic Research 9.0 to mark parts with various thicknesses in the interstice model with varied colors—the smaller the interstice, the greener the color; the larger the interstice, the redder the color.
simulated to calculate the interstice volume between the plate and the bone. The reciprocal of the average distance between the bone-facing plate curve and the corresponding bone surface is used as a quantitative index of the matching performance. It is considered that the average interstice distance is inversely proportional to the matching performance; a higher index value represents higher matching performance. However, this index is not affected by the surface area of the bone plate; therefore, various anatomical bone plates can be compared in parallel. With the wall thickness analysis tool of the 3-magic Research kit in Mimics 18.0, areas with large interstice distance can be visually identified. For areas with high matching requirements, such as periarticular parts, special attention must be accorded. The process of placing the plate in the software requires the services of an orthopedist, while the plate is to be constantly adjusted until the optimal position is attained. Owing to the reliance on the experience of an orthopedist for the placement of the bone plate, the placement is significantly affected by subjective judgment and operation. With the future development of computer technology, this operation could be simulated by computer artificial intelligence: by calculating the curve of the anatomical bone plate, the plate will be automatically placed at the position most suitable for the target bone surface. The MPI of the bone plate and the bone surface will be calculated; thus, the subjective factors of the operator will be eliminated in order to achieve higher repeatability.

The method and index used in this study are straightforward and intuitive and are highly suitable for the quantitative assessment of matching the performance of anatomical bone plates. It is also suitable for use in the selection and comparison of anatomical plates before the clinical operation. The proper use of the computer in a virtual environment or that of a computer control mechanism in an actual environment to place the anatomical plate accurately in the optimum position remains a technical challenge that urgently requires a solution. We still need a method to improve the experimental repeatability, especially when it comes to a plate with poor matching performance.

**References**

1. Auerbach B, Ruff C. Limb bone bilateral asymmetry: variability and commonality among modern humans. J Hum Evol. 2006;50:203–18.
2. Gauldi-Russo E. Study on long bones: variation in angular traits with sex, age, and laterality. Anthropol Anthropol. 1998;56:289–99.
3. Holliday T, Ruff C. Relative variation in human proximal and distal limb segment lengths. Am J Phys Anthropol. 2001;116:26–33.
4. Kiriç Y, Ozan H. Determination of sex from the tibia of adult Turkish cadavers. Kaibogakuzashii. 1999;74:537–43.
5. Ruff C, Jones H. Bilateral asymmetry in cortical bone of the humerus and tibia-sex and age factors. Hum Biol. 1981;53:69–86.
6. Daruwalla Z, Courts P, Fitzpatrick C, Fitzpatrick D, Mullett H. Anatomic variation of the clavicle: a novel three-dimensional study. Clin Anat. 2010;23:199–209.
7. Cummings S, Cauley J, Palermo L, Study of Osteoporotic Fractures Research Group, et al. Racial differences in hip axis lengths might explain racial differences in rates of hip fracture. Osteoporos Int. 1994;4:226–9.  
8. Handa V, Lockhart M, Fielding J, et al. Racial differences in pelvic anatomy by magnetic resonance imaging. Obstet Gynecol. 2008;111:914–20.
9. Warden S, Hill K, Ferra A, et al. Racial differences in cortical bone and their relationship to biochemical variables in Black and White children in the early stages of puberty. Osteoporos Int. 2013;24(6):1869–79.
10. Jain D, Goyal G S, Garg R, et al. Outcome of anatomic locking plate in extraarticular distal humeral shaft fractures[J]. Indian journal of orthopedics. 2017;51(1):86–92.
11. Črnić M, Zyskowski M, Beirer M, et al. Using an anatomically pre-shaped low-profile locking plate system leads to reliable results in comminuted radial head fractures. Arch Orthop Traum Surg. 2017;137(6):789–95.
12. Jose A, Suranigi S, Deniese P, Babu A, Rengasamy K, Najimudeen S. Unstable distal radius fractures treated by volar locking anatomical plates. J Clin Diagn Res. 2017;11(1):OC04–8.
13. Goyal K, Skalak A, Marcus R, Valler H, Cooperman D. Analysis of anatomic percutaneous tibial plate fit on normal adults. Clin Orthop Relat Res. 2007;461:245–57.
14. van Olden G. VA-LCP anterior clavicle plate: the anatomically precontoured fixation system with angular stability for clavicle shaft. Musculoskelet Surg. 2014;98:217–23.
15. Zhou Z, Tang Z, Zhao X, et al. Mismatch of AO anatomically shaped distal humeral plate with humeral shaft forward flexion angulation in adult Chinese population. Eur J Orthop Surg Traumatol. 2014;24(7):1145–50.
16. Hwang J, Oh J, Oh C, Yoon Y, Choi H. Mismatch of anatomically pre-shaped locking plate on Asian femurs could lead to malalignment in the minimally invasive plating of distal femoral fractures: a cadaveric study. Arch Orthop Traum Surg. 2012;132(5):16.

**Funding**

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

**Availability of data and materials**

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

**Ethics approval and consent to participate**

The Ethics Committee of The First Affiliated Hospital of Soochow University approved this study.

**Consent for publication**

Not applicable

**Competition of interests**

The authors declare that they have no competing interests.

**Author details**

1 Department of orthopedics, The First Affiliated Hospital of Soochow University, No.899, Pinghai Road, Soochow 215006, China. 2Department of orthopedics, Minhang Hospital, Fudan University, No.170, Xinsong Road, Shanghai 211199, China.

Received: 9 January 2019 Accepted: 5 June 2019

Published online: 04 July 2019

**Abbreviations**

CT: Computed tomography; MPI: Matching performance index

**Acknowledgements**

We would like to thank the Central Laboratory of First Affiliated Hospital of Soochow University for technical guidance.

**Authors’ contributions**

XW conceived the study. XW and QX participated in its design and coordination. KR and XY performed the operations. XW and GW analyzed the data and drafted the manuscript. All authors interpreted the data and participated in drafting the text and tables. All authors read and approved the final manuscript.
17. Ahmad M, Nanda R, Bajwa A, Candal-Couto J, Green S, Hui A. Biomechanical testing of the locking compression plate: when does the distance between bone and implant significantly reduce construct stability? Injury. 2007;38:358–64.

18. Lau TW, Leung F, Chan CF, Chow SP. Wound complication of minimally invasive plate osteosynthesis in distal tibia fractures. Int Orthop. 2008;32:697–703.

19. Puchwein P, Schildhauer T, Schöffmann S, Heidari N, Windisch G, Pichler W. Three-dimensional morphometry of the proximal ulna: a comparison to currently used anatomically preshaped ulna plates. J Shoulder Elb Surg. 2012;21:1018–23.

20. Harith H, Schmutz B, Malekani J, Schuetz M, Yarlagadda P. Can we safely deform a plate to fit every bone? Population-based fit assessment and finite element deformation of a distal tibial plate. Med Eng Phys. 2016;38:280–5.

21. Schmutz B, Wullschleger M, Kim H, Noser H, Schütz M. Fit assessment of anatomic plates for the distal medial tibia. J Orthop Trauma. 2008;22:258–63.

22. Schmutz B, Wullschleger M, Noser H, Barry M, Meek J, Schütz M. Fit optimisation of a distal medial tibia plate. Comput Methods Biomech Biomed Engin. 2011;14:359–64.

Publisher's Note
Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.