Use of the Bone Ninja Mobile Application as a Pre-operative Assessment and Simulation Tool in Patients Undergoing High Tibial Osteotomy*

Uso do aplicativo móvel Bone Ninja como ferramenta de avaliação e simulação pré-operatória em pacientes submetidos a osteotomia tibial alta

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Abstract

Objective Our purpose was to facilitate the simulation of preoperative correction to enable shared doctor-patient decision-making in individuals undergoing high tibial osteotomy (HTO).

Methods A total of 22 patients underwent high tibial osteotomy using internal or external fixation devices for medial compartment osteoarthritis of the knee. Preoperatively, assessment of deformity parameters and simulation of the corrective osteotomy was done in the presence of the patient, using Bone Ninja. Postoperatively, the patient's satisfaction level with the quality of explanation provided by the use of this software was assessed using the Patient Satisfaction Questionnaire-short (PSQ-18). A comparison of the correction obtained using paper cuttings and the simulation software was performed.

Results All patients were satisfied with their role in the decision-making process. They showed a good understanding and comprehension of the proposed surgery. There was no statistically significant difference between simulated preoperative Medial Proximal Tibial Angle (MPTA) obtained by paper cuttings and software-assisted correction. The PSQ-18 mean score for communication was 4.24 (0.88), for technical quality it was 4.11 (0.59) and for general satisfaction it was 3.11 (0.68).

Conclusion Bone Ninja is an effective, convenient, user-friendly and cost-effective deformity planning tool that supersedes the arduous traditional method of paper tracings and scissors.

Keywords
- osteotomy
- osteoarthritis, knee
- surveys and questionnaires
- patient satisfaction
- radiology information systems

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Resumo

Objetivo Nosso objetivo foi facilitar a simulação da correção no pré-operatório para permitir a tomada de decisão médico-paciente compartilhada em indivíduos submetidos a osteotomia tibial alta (OTA).

Método 22 pacientes foram submetidos a osteotomia tibial alta usando dispositivos de fixação internos ou externos para osteoartrite do compartimento medial do joelho. No pré-operatório, a avaliação dos parâmetros de deformidade e a simulação da osteotomia corretiva foram realizadas na presença do paciente, utilizando Bone Ninja. No pós-operatório, o nível de satisfação do paciente com a qualidade da explicação fornecida pelo uso deste software foi avaliado usando o Questionário de Satisfação do Paciente (Patient Satisfaction Questionnaire-short, PSQ-18, na sigla em inglês). Foi realizada uma comparação da correção obtida com recortes de papel e com o software de simulação.

Resultados Todos os pacientes ficaram satisfeitos com seu papel no processo de tomada de decisão. Eles mostraram uma boa compreensão e entendimento da cirurgia proposta. Não houve diferença estatisticamente significativamente entre o ângulo tibial proximal medial (ATPM) pré-operatório simulado obtido por recortes de papel e correção assistida por software. O escore médio do PSQ-18 para comunicação foi de 4,24 (0,88), para a qualidade técnica foi de 4,11 (0,59) e para a satisfação geral foi de 3,11 (0,68).

Conclusão Bone Ninja é uma ferramenta de planejamento de deformidade eficaz, conveniente, fácil de usar e econômica que substitui o método tradicional árduo de traçar no papel e com tesoura.

Palavras-chave

- ► osteotomia
- ► osteoartrite do joelho
- ► inquéritos e questionários
- ► satisfação do paciente
- ► sistemas de informação em radiologia

Introduction

Deformity correction and limb reconstruction is rapidly emerging as a promising and upcoming subspecialty of orthopedics across the globe. To correct any deformity, a surgeon must first characterize the deformity and then appropriately plan a corrective strategy. The role of meticulous preoperative planning and measurement of a deformity is critical in the management of growth disturbances, malalignment, malunions and unicompartmental osteoarthritis. This is typically done with various Picture Archiving and Communication Systems (PACS) and software programs such as TraumaCad (Brainlab, Munich, Germany) and PeekMed (PeekMed, Peek Health SA, Braga, Portugal).[1] Some of these are fairly expensive and may not be readily accessible to all. Bone Ninja, a mobile application, was developed for the integrated doctor and patient education and is available on the iPad platform (iOS).[2] This application enables surgeons to measure, plan and simulate deformity correction without the need for scissors, paper tracings, goniometers or expensive software programs.

The aim of the present study was to facilitate simulation of correction preoperatively to enable shared doctor-patient decision making in individuals undergoing high tibial osteotomy (HTO). The objectives were to compare the correction achieved using paper cuttings with the simulation software and to assess the level of patient satisfaction and understanding of the surgical procedure using the Patient Satisfaction Questionnaire-short (PSQ-18).

Patients and Methods

This was a prospective study conducted at a tertiary care orthopedic center from December 2016 to June 2019 after clearance from the institutional ethical committee. A total of 22 patients with symptomatic medial compartment osteoarthritis (MCOA) of the knee, who were worked up for corrective surgery (HTO), were included in the study. We excluded those who did not undergo surgery (HTO), or who had an incomplete database.

All patients underwent a preoperative assessment, which included clinical examination for ligamentous laxity and measurement of joint range of motion and limb shortening. Full length, long-leg radiographs were obtained, which were imported from the radiology department in a DICOM file format, or else, using the iPad camera, a picture of the radiograph was taken and uploaded on the Bone Ninja software. Besides this, clinical photographs of both lower limbs in standing position were obtained and stored in a computerized patient database. The sequence of planning was abbreviated by the acronym 'MAP the ABC',[2] where M stands for Measure (measuring the mechanical axis deviation or MAD and the limb length discrepancy), A stands for Analyze (the joint angles/bone lengths) and P stands for Pick (the bone to treat). The first step was to calibrate the magnification marker using a magnification ball which measured one inch (2.54 cm). The surgeon could also choose the desired magnification as per his requirements. Next, using the 'draw lines' tool, the anatomical and mechanical axes were drawn and the mechanical axis

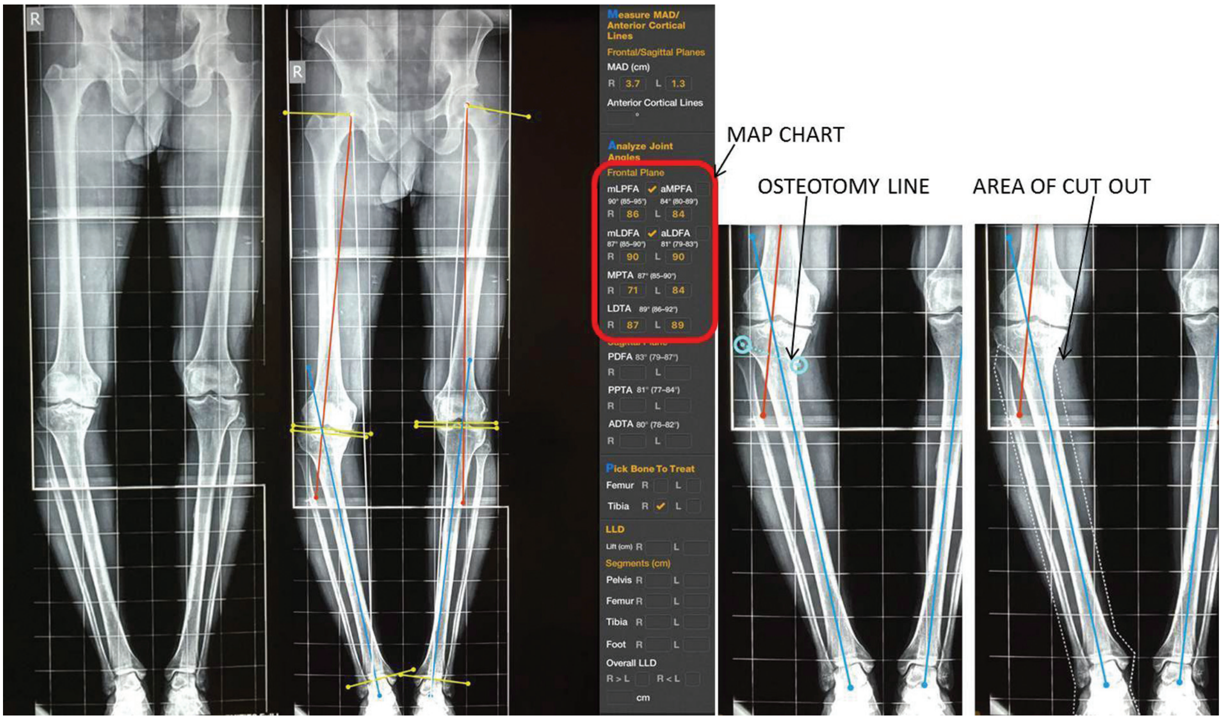

Fig. 1 Marking joint orientation lines and angles.

deviation was calculated using the 'ruler' tool. The overall malalignment and leg length discrepancy were recorded. The amount of varus deformity was calculated using the 'protractor' tool. The next step was to mark the important joint orientation lines and angles such as the mechanical lateral proximal femoral angle (mLPFA), the lateral distal femoral angle (LDFA), the medial proximal tibial angle (MPTA) and the lateral distal tibial angle (LDTA).[3] These were recorded in the MAP chart provided. (►**Fig. 1**) For convenience, the standard reference lines and angles could be assessed at any point of time using the 'resource' tool.

Once the initial measurements and analyses were completed, we then proceeded to perform the 'ABC', where A implies determining the Apex of deformity, B implies choosing a Bone cut level and C stands for choosing a correction level and type. The affected bone was the tibia and the apex of the deformity was located at the level of the proximal tibial metaphysis. After marking the line of osteotomy and selecting the cut-out area, we then used the 'thumb-tack' tool to perform a rotational movement of the cut-out area about a specific point (►**Fig. 1**). The 'thumb-tack' was placed at the level of the tip of the fibular head to create a medial opening wedge osteotomy and, along with it, the mechanical axis of the distal segment was realigned to coincide with the proximal mechanical axis. (►**Fig. 2**) We mostly performed an over-correction, up to the Fujisawa point.[4] A quantification of the amount of correction (base of the wedge in millimeters) was then done using the 'ruler'. Similarly, a simulation of the corrective osteotomy was performed using the clinical photographs, in the presence of the patient, which enabled both surgeon and patient to see the postoperative radiographic and clinical appearance of the limb (►**Fig. 3**).

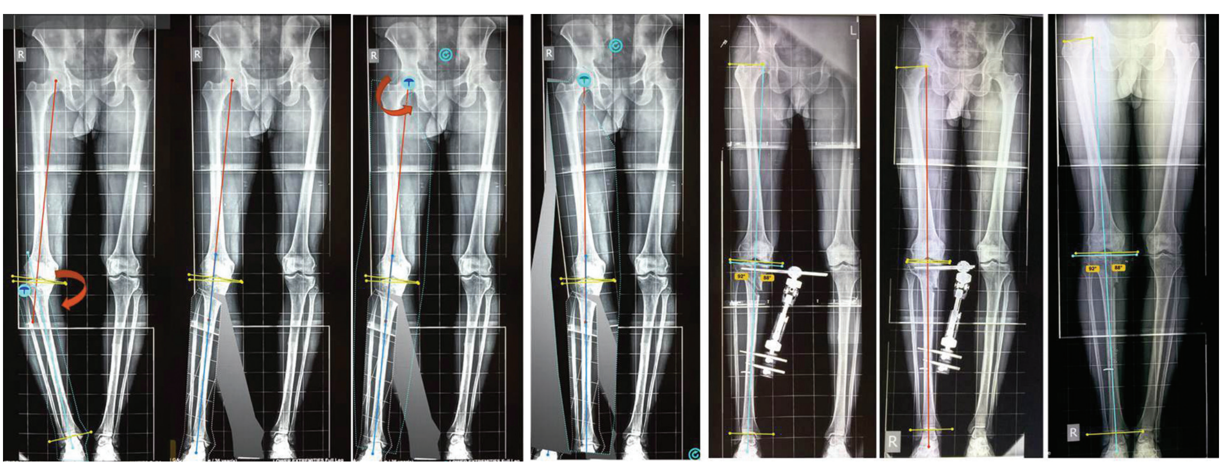

Fig. 2 Simulation of correction using Bone Ninja.

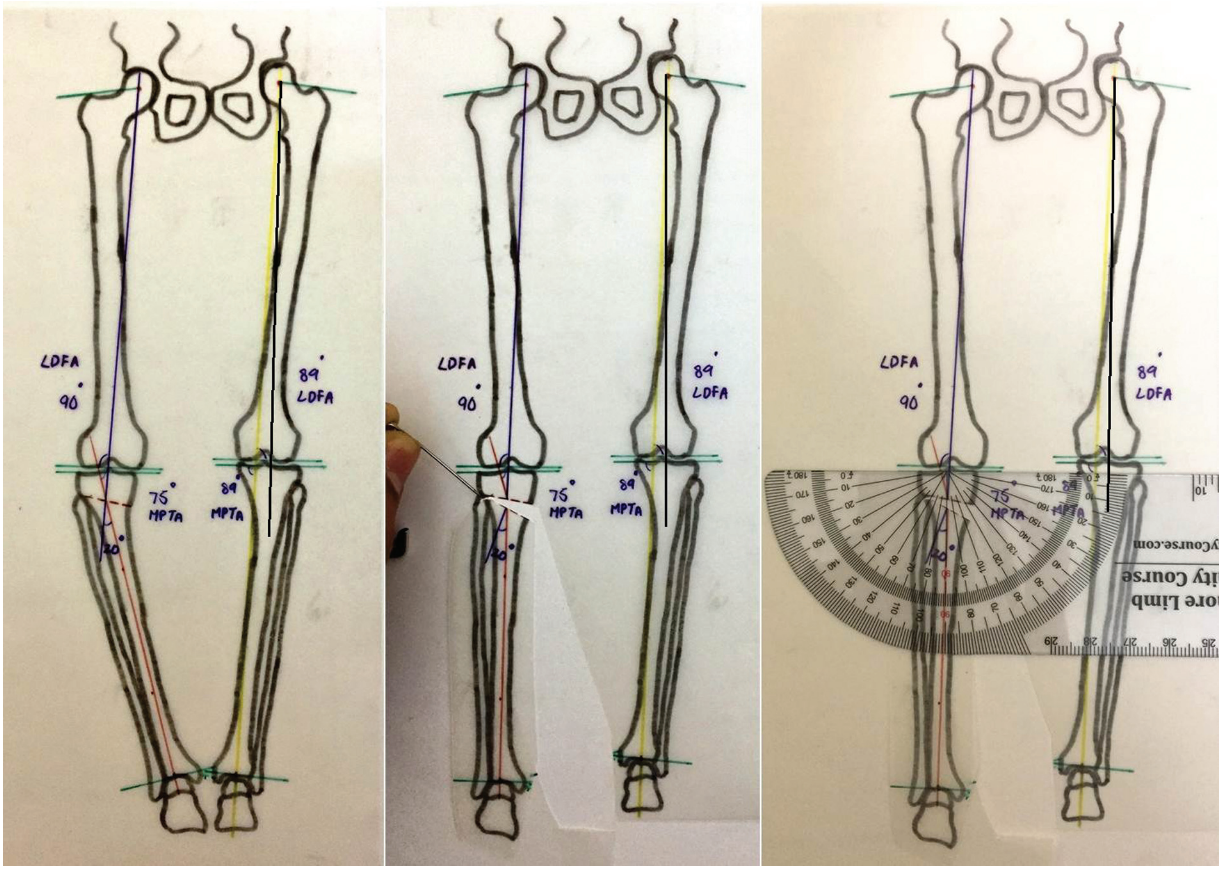

Fig. 3 Simulation of correction using paper tracings.

For the sake of comparison, a paper tracing of the radiograph was drawn and all reference lines and angles were marked, as descried above (►**Fig. 4**). After drawing the osteotomy line, the cut was made with scissors and the distal fragment was rotated by placing a pin or thumb-tack at the level of the fibular head. After correction, the pieces of paper were taped together and the axes and angles were measured again. The angle of correction obtained, which equals to the amount of correction required (assuming that $1° = 1$ mm), was recorded.

The surgical intervention performed was a medial opening wedge HTO using either a modular, monolateral, polyaxial external fixator (Pitkar Orthotools, Pune, India) or a locking plate (Tomofix, Synthes, West Chester, PA, USA). As per protocol, the fixation device was retained for twice the period of distraction to facilitate consolidation of the osteotomy. Fixator removal was done after complete consolidation of the regenerate, following which a final radiographic analysis was done using the application. The joint orientation angles were again recorded in the database. Statistical analysis for comparison of the preoperative MPTA obtained after paper correction and that obtained by the simulation software was done using Microsoft Excel 2019 (Microsoft Corporation, Redmond, WA, USA) and the test used was the Student *t*-test.

The present work was approved by the institutional ethics committee and informed consent was obtained from all individual participants included in the study.

Fig. 4 Simulation of correction on patient's clinical photograph.

Results

A total of 22 patients, including 14 males and 8 females, undergoing HTO, were included in the study. The mean patient age was 42.45 (4.84) years. All patients demonstrated good understanding and comprehension of the proposed surgery. They were all overwhelmed at the initial visit and appreciated seeing the simulated postcorrection results. The surgeons were satisfied with the ease of assessment and recording of pre- and postoperative radiographic parameters using this tool. The average preoperative MPTA was 74.18° (2.26), the average MPTA obtained by paper cutting was 87.63 ° (0.78), the average MPTA obtained by software simulation was 87.86° (0.94) and the average MPTA following surgical correction was 87.95° (0.72).The mean MPTA obtained with paper tracings was compared with the MPTA obtained from software-assisted correction and the difference between the two groups was not statistically significant ($p = 0.29$) (►**Table 2**).

At the time of discharge, all patients were asked to fill up the short version of the Patient Satisfaction Questionnaire (PSQ-18), which gave us a feedback about their satisfaction level[5] (►**Table 1**). The mean score for general satisfaction was 3.11 (0.68), the mean for technical quality was 4.11(0.59), the mean score for interpersonal matter was 3.97(0.69), the mean score for communication was 4.24(0.88), the mean score for financial aspects was 3.93(0.75), the mean score for time spent with the doctor was 3.45(0.79), and the mean score for accessibility and convenience was 3.84 (0.84). Most importantly, all patients were very satisfied with their role in the decision-making process.

Table 1 Statistics for Patient Satisfaction Questionnaire-18 subscales and constituent items

PSQ-18 Subcategories	Mean score	SD
General satisfaction	**3.11**	**(0.68)**
The medical care that I have been receiving is just about perfect	3.27	0.63
I am dissatisfied with some things about the medical care I receive	2.95	0.72
Technical quality	**4.11**	(0.59)
I think my doctor's office has everything needed to provide complete medical care	4.04	0.57
Sometimes doctors make me wonder if their diagnosis is correct	4.23	0.52
When I go for medical care they are careful to check everything when treating and examining me	4.45	0.59
I have some doubts about the ability of the doctors who treat me	4.54	0.59
Interpersonal matter	**3.97**	(0.69)
Doctors act too impersonal and business-like toward me	3.95	0.65
My doctors treat me in a friendly and courteous manner	4	0.75
Communication	**4.24**	(0.88)
Doctors are good at explaining the reason for medical tests	4.45	0.67
Doctors sometimes ignore what I tell them	3.22	0.61
Financial aspects	**3.93**	(0.75)
I feel confident that I can get the medical care I need without being set back financially	4.05	0.77
I have to pay for more of my medical care than I can afford	3.81	0.79
Time spent with doctor	**3.45**	(0.79)
Those who provide my medical care sometimes hurry too much when they treat me	3.04	0.72
Doctors usually spend plenty of time with me	3.86	0.63
Accessibility and convenience	**3.84**	(0.84)
I have easy access to the medical specialists I need	4.22	0.61
Where I get medical care people have to wait too long for emergency treatment	2.86	0.71
I find it hard to get an appointment for medical care right away	4.13	0.56
I am able to get medical care whenever I need it	4.13	0.63

Abbreviation: SD, standard deviation.

Discussion

Traditionally, deformity planning has been performed by paper tracing and cutting along with rotation about a pin or thumbtack. This cumbersome process began with preparing a sketch or trace of the affected bones followed by measurements using rulers, protractors and goniometers.[6,7] These tools worked well with hard copy X-rays. In the current digital era, most radiographs are now images on a computer screen. Pencils and goniometers do not translate well to the new digital medium. This had resulted in the evolution of various Picture Archiving and Communication System (PACS) tools for deformity planning.[8] With PACS, there are lesser chances of an image being lost, stolen or mislabeled. Commonly used digital tools include TraumaCad (Brainlab, Munich, Germany), Adobe Photoshop (Adobe inc., California, USA), and PeekMed (Peek Health SA, Braga, Portugal).[11] The goal of this innovation is to perform preoperative planning and simulation of the expected results prior to surgery.

TraumaCad, introduced in 2005, allows surgeons to evaluate and manipulate digital images while performing preoperative surgical planning for corrective osteotomies and limb lengthening.[9] The mobile version of the software was launched in 2015. It also has integrated features such a growth calculator, a pediatric hip deformity analysis module and a specialized Taylor spatial frame module. It has been used for the assessment of cup orientation in hip resurfacing by Westacott et al.[12] and has been found to correlate well with CT scanning. Stefanou et al.[13] used TraumaCad in their study on radiographic assessment of lower limb lengthening in achondroplastic patients using the Ilizarov Frame. Segev et al.[14] reported good reliability of this tool in terms of intra- and interobserver variability, and suggested its use in

Table 2 Comparative assessment of outcomes

	Preoperative MPTA	MPTA (paper cutting)*	MPTA (Bone Ninja)*	Postoperative MPTA
Mean	74.18	87.63	87.86	87.95
Standard deviation	2.26	0.78	0.94	0.72
Confidence Level (95.0%)	1.03	0.34	0.44	0.31
Upper limit	75.21	87.97	88.30	88.26
Lower limit	73.15	87.29	87.42	87.64

Abbreviation: MPTA, medial proximal tibial angle.
*p value on comparison between MPTA (paper cutting) and MPTA (Bone ninja) is calculated using the Student *t*-test as being 0.29, which implies there is no statistically proven difference between the two groups.

deformity planning in pediatric orthopedics. Preoperative planning for joint replacement, fracture management and lower limb pediatric deformities using digitalized software systems such as TraumaCad has also been recommended by Steinberg et al.[15] Despite its several advantages, we believe that the high cost and intricacy of the software has been a deterrent to its use globally.

The Bone Ninja mobile application is a teaching tool developed by Standard and Herzenberg at the International Centre for Limb Lengthening at the Sinai Hospital of Baltimore in 2012.[16] It was designed to help surgeons learn to analyze long bone deformities and simulate osteotomies by drawing lines, measuring angles, measuring lengths, and manipulating bone fragments. For beginners, several lessons on normal frontal and sagittal plane alignment, deformities in the frontal and sagittal plane, oblique plane deformities, double level deformities, foot and ankle deformities, limb length discrepancy and some special chapters on novel deformity planning methods are available. The application also gives a recommended solution to each lesson so that the surgeon can receive feedback, and also enables current lessons to be downloaded from the web. Additional features include the option of adding virtual hardware such as monolateral fixators, plates, screws and six-axis fixators to the image to help decide the level of placement of transosseous elements. Hambardzumyan et al.[17] have suggested that it is a useful educational tool resulting in better understanding and lesser decisional conflicts and unrealistic expectations on the part of the patients. Whitaker et al. compared PACS and Bone Ninja for the assessment of lower extremity limb length discrepancy and alignment and reported no statistical difference between the two modalities.[18]

In the present study, the Bone Ninja application has been extremely beneficial in terms of patient education and surgeon preparation. This was assessed by the shorter, English and Hindi versions of the Patient Satisfaction Questionnaire (PSQ-18), which is an 18 item questionnaire encasing each of the 7 aspects of satisfaction with medical care.[19,20] Results indicated that satisfaction levels were highest for communication, implying that the patients perceived that the procedure was well explained to them, which might have affected their decision-making to some extent. Short learning curves, user-friendly features, accurate prediction of correction coupled with low costs made this application our preferred preoperative planning and assessment tool.

A possible limitation of the present study was the sample size, which may warrant the need for further studies that are based on patient satisfaction levels.

Conclusion

The current literature supports the use of digital software programs for radiographic analysis of orthopedic deformities. Bone Ninja is an effective, convenient and cost-effective planning and educational software that supersedes the laborious method of paper tracings and scissors. However, until now, there is very little published data to validate Bone Ninja as a planning tool for deformity correction.

Informed Consent

Informed consent was obtained from all individual participants included in the study.
The authors are in no way associated with the makers of the software (Sinai Hospital, Baltimore).

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Conflict of Interests

The authors have no conflict of interests to declare.

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