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Original Article

Accuracy of Implant Placement Using a Fully Guided Surgical Guide Designed Using Blenderfordental Verses Exoplan Softwares: An In Vitro Study

John Elia Farag Allah[1], Nadia Ahmed Abbas[1], Mohamed Amr ElKhashab[1]

[1] Department of Prosthodontics, Faculty of Dentistry, Cairo University, Cairo, Egypt

Email: john.elia@dentistry.cu.edu.eg

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Abstract

Aim: To compare the accuracy of implant placement when using tooth supported surgical guide using a fully guided surgical guide design performed on different software of them are non-dental software (Blenderfordental) verses a dental software (Exoplan).

Subjects and methods: Twenty study models, simulating patients with a missing upper left first molar, were divided into: Group I (Exoplan) and Group II (Blender). Each group underwent digital implant planning and surgical guide fabrication using their respective software. A virtual model, derived from a physical typodont, served as the basis for implant planning. DICOM data of a physical model were integrated into the planning software. Surgical guides were designed and fabricated using the software's features. After implant placement, postoperative scans of scanbodies attached to the implants was done. By superimposing the preoperative and postoperative scans, deviations in implant position were measured along the buccolingual, mesiodistal, and apico-coronal axes.

Results: No statistically significant differences were observed between the two groups for buccolingual ($p=0.83$), mesiodistal ($p=0.41$), and depth ($p=0.75$) dimensions.

Conclusion: Open-source software designed for non-dental applications like Blenderfordental can be utilized to create dental implant surgical guides with accuracy that is not significantly different from commercially available dental implant treatment planning software like Exoplan.

Keywords: Accuracy, guided implant surgery, Surgical guides, dental implant

I. INTRODUCTION

Accurate three-dimensional (3D) implant placement is essential for the long-term success of implant treatment. Proper implant positioning facilitates the design of functional, aesthetically pleasing, and occlusally compatible prostheses. Additionally, correct implant insertion is necessary for long-term maintenance and accessibility for proper oral hygiene. **(Li *et al,* 2023)**

Long-term implant success relies on meticulous planning of the optimal implant position and the precise translation of this plan to the surgical site. (**Nulty 2024**) Conventional planning methods, employing radiographic stents with radiopaque markers fabricated from duplicated wax-ups of ideal prostheses on study models, have yielded successful outcomes. However, a limitation of this technique lies in the surgeon's intraoperative determination of the final implant position, angulation, and depth. **(Kulkarni *et al,* 2019)**

Advanced digital technology, such as static computer-assisted implant surgery (CAIS), enables simultaneous visualization of 3D bone morphology, soft tissue, and teeth. This technology facilitates pre-surgical virtual implant planning by evaluating bone quality and quantity, anatomical structures, soft tissues, and prosthetic demands. During surgery, a 3D-printed surgical guide transfers the planned implant position to the surgical site. Guided surgical drills within the metal sleeve of the guide control implant osteotomy angulation and depth. This technique can potentially minimize the risk of complications like injury of mandibular nerve, sinus perforations, dehiscence, fenestrations, and damage to adjacent tooth roots. (**Whitley III *et al,* 2017; Bencharit *et al,* 2018)**

Most of the CAD/CAM systems are delivered with pre-installed software which are often costly, it provides limited workflow and limited pre-programmed situations to deal with. New non-dental softwares were introduced to solve the aforementioned problems and provide various solutions with less cost and more innovative approaches. Thanks to the open source softwares which provide no limits for editing and customization which act as an open gate for innovation and shortcuts of many dental procedure as well as a gate for unexpected errors that may happen during designing. **(Anand *et al,* 2018)**

Open-source segmentation software, such as 3D modeling Blenderfordental (B4D), is a widely used open-source computer-aided design (CAD) tools for manipulating mesh files in preparation for 3D printing. While these software programs offer exceptional flexibility for modeling various 3D structures, their full potential remains largely unrealized in dentistry. Their application has been predominantly limited to the fabrication of digital dental models or diagnostic wax-ups for 3D printing. Despite their immense potential, open-source software for implant treatment planning and surgical guide fabrication is often overlooked and underutilized. There is a lack of instruction and interest in these tools, which could be valuable resources in the field. **(Anand *et al,* 2018; Muta *et al,* 2020)**

Despite careful planning, deviations from the intended implant position can still occur due to various factors, including inaccuracies in image acquisition or processing, surgical guide fabrication, guide fit, intraoperative movement, or human error. **(Ahmed, AbdelHamid and AlAbbasy 2019)**

Given the potential of open-source software like Blenderfordental to generate precise implant surgical guides, can this approach serve as a viable complement to enhance the functionality of existing commercially available implant planning software? Therefore, this study aimed to evaluate the accuracy of the non-dental non-commercial software that have been developed by unprofessional organizations and to test the accuracy of the included libraries and its precision and the ability of its tools to algin the data properly to be friendly in dental use using a fully guided tooth supported surgical guides.

II. SUBJECTS AND METHODS

The findings of **Talmazov *et al,* 2020** study was used to calculate the sample size. Using an alpha level of 0.05 and a beta level of 0.10 (power=90%), a minimum sample size of 10 subjects per group, totalling 20 subjects, was determined to be adequate for the study.

Models preparation

The typodont cast (Nissin Dental Product Inc., Kyoto, Japan) was scanned using an extraoral scanner (DOF; FREEDOM HD, Seoul, Korea) to generate a virtual scan. The scanned data was processed, trimmed to design a sectional model having only one quadrant, then a virtual extraction of the upper left first molar was performed to create a study model segment STL file. Twenty study models were digitally duplicated and printed by

LCD 3D printer (Phrozen Sonic Mini 4k 3d printer, Phrozen Technology, Hsinchu, Taiwan) using grey resin (Water-Washable 3D Printing Resin, Phrozen Dental, Taiwan). The printed models were scanned again using the same extra-oral scanner to be used during the planning step on the softwares.

DICOM files were generated from CBCT scans (PLANMECA PROMAX 3D mid, Helsinki, Finland) of a study model mounted on a radiolucent plate.

Exocad group

I. Data acquisition:

A total of twenty study models were assigned to two equal groups. Group I imported STL files into Exoplan implant planning software (Exocad GmbH, Darmstadt, Germany), while Group II imported STL files into B4D implant module (Blender for dental 3.3.1, New York, USA). Both groups utilized standardized guide design and production variables to fabricate ten surgical guides using the respective software's workflow.

II. Implant planning:

A top-down approach was adopted, prioritizing the design of the future prosthesis. A virtual maxillary first molar was incorporated into the dental arch to simulate the edentulous space. A 3.7×10 mm implant (JD dental Implant, JDENTALCARE S.R.L, Italy) was selected and virtually positioned at the bone crest level, aligned with the virtual tooth.

III. Surgical guide fabrication:

Sleeve placement was facilitated by selecting the corresponding J-dental guide sleeve from the library. The sleeve was configured with a minimum base thickness of 2.5 mm with a 0.5 mm rounded edge, a height of 5 mm, a clearance height of 20 mm, and a radial offset of zero.

IV. Design of the surgical guide:

Surgical guide design in Exocad commenced with the identification and blocking of undercuts from the insertion and removal pathways. An offset of 0.03 mm was applied, allowing for undercuts up to 0.1 mm, with a smoothing bottom property of 38%.

V. Add scanbody to the assembly:

To establish a common reference point between the virtually planned implant position and the actual drilled implant position in the sample models, a scan body (JD dental Implant, JDENTALCARE S.R.L, Italy) was incorporated into the model. This scan body was accurately positioned according to the software's library, representing the physical scan body that would be placed over the drilled implant. Then, by aligning the virtual and physical scan bodies, the two datasets were able to be compared and any discrepancies between the planned and actual implant positions were identified.

Blender for dental Group

I. DICOM Import & Segmentation Model:

The STL model was imported into B4D software. Subsequently, the DICOM files were opened using the dedicated slicer software, which incorporates a B4D add on.

To integrate DICOM files with the STL model in Slicer and B4D, DICOM files were first imported into Slicer using the designated import button. A server connection was then established between the two software programs to enable live viewing of the STL model.

II. Implant Planning:

The J-dental implant library within the B4D software was selected. A J-dental implant with dimensions of 3.7×10 mm was chosen for placement in the missing tooth area.

III. Guide Sleeves Part Metal Sleeve inserts:

To incorporate J-dental implants into the B4D workflow, the existing sleeve library was utilized. A sleeve cutter was virtually inserted into the blue sleeve accompanying the implant, creating a negative space that would accurately accommodate the metal sleeve insert after guide printing.

IV. Creating the Passive Model:

A passive model/offset model was created by eliminating undercuts in the path of insertion and removal and offsetting the model by 0.03 mm, allowing for undercuts up to 0.1 mm.

V. Design implant Guide:

To replicate the external shape of the Exoplan guide, the STL file containing the model and guide's external geometry was exported from Exoplan and imported into B4D. The model was aligned within B4D software to facilitate the design of the B4d guide skeleton.

VI. Add scanbody to the assembly:

To accurately represent the physical scanbody, the digital scanbody was positioned within the software's library in accordance with its intended location on the implant. This allowed for a direct comparison between the virtual and physical scanbodies, enabling the identification of any discrepancies between the two datasets.

Guides printing

The STL file of the surgical guides was exported to 3D printing software (CHITUBOX, Shenzhen, China) to add the supporting structure. The completed guide designs were then exported to the printer (PHROZEN MINI 4K printer, Phrozen Dental, Taiwan) for fabrication. Then, the printed guides were cleaned with 95% alcohol for 15 minutes, followed by curing for an additional 15 minutes in UV light curing chamber 405 n (PHROZEN WASH and CURE, Phrozen Dental, Taiwan).

Implant placement procedures

Osteotomy preparation was carried out by employing the surgical drill sequence recommended by the manufacturer, using a fully guided surgical kit. This process was designed to accommodate a 3.7×10 mm bone-level implant, aligning with the digital design previously created for each group. The implants were placed by 45 Ncm insertion torque.

Following implant placement, compatible scanbodies were attached to each implant and scanned with extra-oral scanner.

Accuracy analysis

To assess the accuracy of implant placement, postoperative optical scans were acquired and superimposed onto the corresponding preoperative virtual plans within Exocad software. A specialized alignment tool was used to align the scanned models with their respective virtual counterparts, ensuring accurate comparison. **(Figure 1)** The distance between the planned and actual implant positions was measured along the buccolingual, mesiodistal, and apico-coronal axes using the cross-section measurement tool in Exocad. (**Ahmed, AbdelHamid and AlAbbasy, 2019; Revilla-León *et al,* 2021)**

Buccolingual Deviation (x): the assessment was conducted by measuring the distance between the virtual and actual implant positions along the buccolingual axis. This measurement was obtained using the Distance Measure tool in the software. A horizontal line was drawn between the external borders of the virtual and actual abutments to quantify this deviation **(Figure 2)**. (**Hamdi, El Khadem and Amer, 2023**)

Mesiodistal deviation (y): was quantified using the "Distance Measure" tool within the software. This involved measuring the horizontal distance, in millimeters, between the external borders of the virtual and actual implant scanbodies. **(Hamdi, El Khadem and Amer, 2023)**

Apico-coronal deviation (z): was assessed by measuring the vertical distance between the planned and actual implant positions along the z-axis. This was determined by drawing a vertical line from the superior border of the virtual scanbody to the superior border of the corresponding postoperative scanbody.**(Hamdi, El Khadem and Amer, 2023)**

Statistical analysis

Data analysis was conducted using SPSS version 20, GraphPad Prism, and Microsoft Excel 2016. Normality of the quantitative data was evaluated using the Shapiro-Wilk and Kolmogorov-Smirnov tests. The results were expressed as mean ± standard deviation (SD), median, minimum, and maximum values. Comparisons between the two groups were performed using paired t-tests

III. RESULTS

Both the Shapiro-Wilk test and the Kolmogorov-Smirnov test were used to evaluate the normality of the quantitative data.

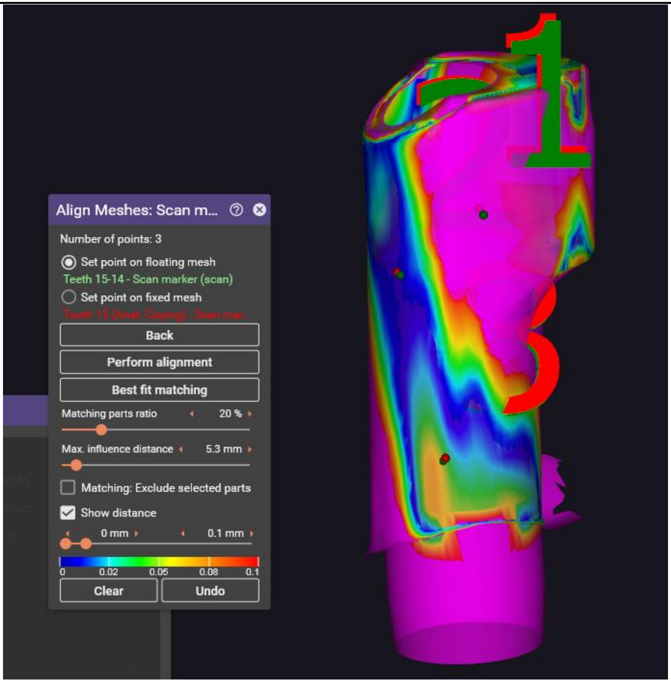

Figure 1: Alignment of each scanned model to the original design data of each group

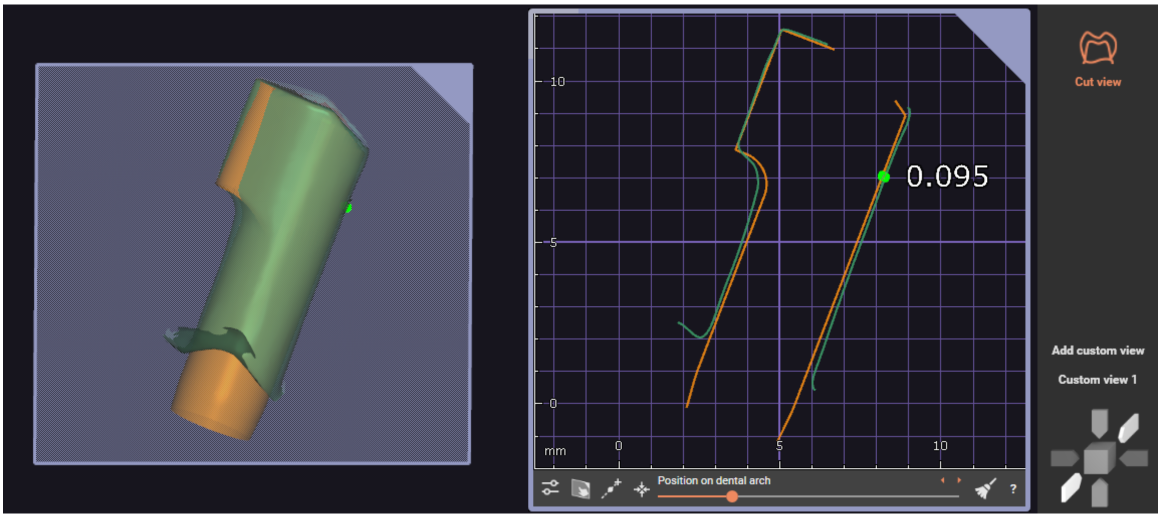

Figure 2: Buccolingual deviation estimated by measuring BL distance between the preoperative virtual implant planning's scanbody of each group and the postoperative scanned one in mm

I. Buccolingual (BL) distance:

A paired t-test was employed to compare the two groups, revealing no statistically significant difference (p=0.83) between the mean buccolingual distances of Group I (0.084±0.015 mm) and Group II (0.086±0.002 mm), with a difference of 0.002±0.009 mm (**Table 1**).

II. Mesiodistal (MD) distance:

A paired t-test demonstrated no significant difference between the two groups (p = 0.41). Group I had a mean mesiodistal distance of 0.09±0.019 mm, while Group II had a mean of 0.097±0.021 mm, with a difference of 0.007±0.009 mm between the groups (**Table 2**).

III. Depth: No statistically significant difference in depth was observed between the two groups (Exoplan and Blender) as determined by a paired t-test (p=0.75). The mean depth was 0.061±0.007 mm for Group I and 0.061±0.005 mm for Group II, with a negligible difference of 0.001±0.003 mm (**Table 3**).

Table (1): Minimum (Min.), maximum (Max.), median, mean, mean difference (MD), standard deviation (±SD) and 95% Confidence Interval of the Difference (95% CI) of Buccolingual distance in both groups.

BL direction	Descriptive results					MD	SD Diff.	95% CI		P value
	Min	Max	Median	Mean	±SD			Lower	Upper	
Group I	0.060	0.110	0.085	0.084	0.015	0.002	0.009	-0.020	0.016	0.835
Group II	0.060	0.120	0.084	0.086	0.022					

Table (2): Minimum (Min.), maximum (Max.), median, mean, mean difference (MD), standard deviation (±SD) and 95% Confidence Interval of the Difference (95% CI)) of Mesiodistal distance in both groups.

MD direction	Descriptive results					MD	SD Diff.	95% CI		P value
	Min.	Max.	Median	Mean	±SD			Lower	Upper	
Group I	0.060	0.120	0.093	0.090	0.019	0.007	0.009	-0.026	0.011	0.417
Group II	0.060	0.120	0.105	0.097	0.021					

Table (3): Minimum (Min.), maximum (Max.), median, mean, mean difference (MD), standard deviation (±SD) and 95% Confidence Interval of the Difference (95% CI) of depth in both groups.

Depth	Descriptive results					MD	SD Diff.	95% CI		P value
	Min.	Max.	Median	Mean	±SD			Lower	Upper	
Group I	0.051	0.073	0.059	0.061	0.007	0.001	0.003	-0.007	0.005	0.749
Group II	0.054	0.069	0.063	0.061	0.005					

IV. DISCUSSION:

The present study aimed to compare the accuracy of implant placement when using tooth supported surgical guide using a fully guided surgical guide design performed on different software.

Implants placed using surgical guides supported by two teeth showed significantly greater deviation compared to those supported by four or more teeth. **(El Kholy *et al,* 2019)** To ensure adequate stability and accuracy, this study utilized a minimum of four supporting teeth for the surgical guides.

Guided implant placement was performed following osteotomy site preparation using a surgical guide. The full-guided approach, encompassing both site preparation and implant placement through the surgical guide, enhanced accuracy. The implants were initially inserted by hand and then secured with a ratchet wrench. **(Turbush and Turkyilmaz, 2012; Geng *et al,* 2015)**

In this study, multiple surgical guides with varying sleeve diameters were used to precisely control the direction and depth of the drill during osteotomy preparation. **(Azevedo, Correia and Faria Almeida, 2024)**

Fully guided surgical kits were utilized in this study to standardize the process and ensure compatibility between drill diameters. **(López *et al,* 2019)**

Optical impressions were employed to determine implant positions, a technique demonstrated to be more accurate than CBCT scans. **(Brandt *et al,* 2018; Wismeijer *et al,* 2018; Komuro *et al,* 2021)**

In this study, the reference point and comparative data for implant placement were derived from the digital scan data. STL files may be more advantageous for superimposition due to their narrower field of view, which results in more clearly defined boundaries compared to CT scans with a wider range of coverage. (**Pyo *et al,* 2019)** Therefore, the accuracy of implant placement was assessed by superimposing STL files in this study.

Despite the expectation that guided surgery would enhance accuracy and precision compared to freehand techniques, deviations from the planned implant position can still occur. Template-guided surgery involves multiple steps that can contribute to deviations between planned and actual implant positions. **(Ahmed, AbdelHamid and AlAbbasy, 2019; Pyo *et al,* 2019)**

Although, it may be challenging to identify specific deviations that may occur at each stage of the process, understanding the discrepancies between virtually planned and clinically placed implant positions is crucial for avoiding anatomical risks and ensuring successful prosthetic reconstruction. **(Ahmed, AbdelHamid and AlAbbasy, 2019)**

While precision is crucial in dental implant procedures, this study evaluated the accuracy of implant placement in terms of trueness of different implant planning softwares. Trueness refers to the closeness of a measurement to the true value. By comparing the digital scans to a reference scan, we aimed to assess the deviation of the digital models from the actual physical anatomy. This approach allowed us to evaluate the overall reliability and clinical applicability of open-source software in implant planning in comparison to the Exoplan software.

The null hypothesis was accepted, indicating that there was no statistically significant difference in implant placement accuracy between the guide fabricated using a B4D software and Exoplan software.

Various methods have been employed to assess the trueness of guided implant placement, including the evaluation of entry and apical points, as well as three-dimensional (x, y, and z) coordinate deviations between the planned and actual implant positions. To accurately assess surgical guide precision, three-dimensional coordinates were measured in this study. **(Tahmaseb *et al*, 2014)**

Verhamme *et al,* 2015, proposed that analyzing three-dimensional implant placement data in both BL and MD directions offers more clinically significant results. Their study revealed statistically significant deviations in the medial-lateral translation of the surgical guide at the implant tip and shoulder in the buccolingual direction and at the implant tip in the mesiodistal direction. Thus, BL, MD, and depth measurements were done in the present study.

The Depth measurement has the highest trueness, about 0.061 ± 0.007 mm in Exoplan group and 0.061 ± 0.005 mm in Blender group. The Mesio-distal measurement has the lowest trueness, about 0.09 ± 0.019 mm in Exoplan group and 0.097 ± 0.021 mm in Blender group. The observed displacement values were comparable to those reported in previous studies **Pozzi, Polizzi and Moy, 2016; Bencharit *et al,* 2018** and are considered clinically insignificant.

The results of this study align with previous research, which has reported mean deviations of approximately 1 mm in apical-coronal distance. (**Deeb *et al,* 2017; Bell *et al,* 2018; Skjerven *et al,* 2019**) Minor deviations between the planned and actual implant positions were observed, which is anticipated in a fully guided surgical approach. **(Bell *et al,* 2018)**

In contrast to previous studies by **Bell *et al.* 2018; Skjerven *et al,* 2019; Semary *et al,* 2023**, this study found that horizontal deviations were more pronounced than vertical deviations in implant placement. The accurate placement of implants, considering factors such as length, angle, and position, is crucial for successful outcomes. This study demonstrated that the maximum deviation in the apico-coronal direction between planned and actual implant positions was minimal, measuring 0.073 mm and 0.069 mm for groups I and II, respectively. These deviations were significantly less than the commonly accepted 2 mm safety zone for vital structures.

The deviations observed in this study resulted from the total errors that emerged during the computer-assisted implant placement procedure. These errors encompassed various stages, including CBCT imaging, software planning, guide manufacturing. **(A Bilal *et al*, 2018)**

The variations in implant placement accuracy observed in this study may be influenced by several operator-dependent factors. Some deviations from the planned implant position may be attributed to the instability of the surgical guide during implant placement, particularly when addressing undercuts to ensure complete seating of the implant. Because this study was conducted in vitro, it is possible that the stability of the hand holding the printed cast and surgical guide during the procedure could have an impact on the deviations. During simulated osteotomy preparation, it can be difficult to hold the cast and the surgical guide simultaneously, which can lead to variability. Additionally, the resin used to create the 3D-printed cast has a high degree of accuracy that is well within the range of clinically relevant accuracy. **(Scherer, 2017)**

Discrepancies may arise during the merging of implant and scan body data with reference or sample models, potentially leading to minor deviations in the final outcome. The present study was limited by the use of resin models, which exhibit distinct characteristics compared to actual bone tissue. The sensation of implant placement into acrylic models differs from that experienced during implantation in real bone.

Future research should explore the use of alternative surgical guide designs, such as sleeveless open frames or selective open structures. Additionally, the potential long-term impact of resin material distortion on surgical guide accuracy should be investigated, particularly in extended procedures. Further clinical studies are required to validate the clinical accuracy and precision of Blender-designed implant surgical guides.

V. CONCLUSION:

Based on the limitations of this in-vitro study, the following conclusions can be made:

• Open-source software designed for non-dental applications, such as Blenderfordental, can be utilized to create accurate dental implant surgical guides that is not significantly different from commercially available dental implant treatment planning software like Exoplan.

• Both Exoplan and Blender groups demonstrated statistically insignificant deviations from the ideal implant position along all three axes.

Conflict of Interest:

The authors declare that there are no conflicts of interest related to this study.

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Ethics:

This study protocol was approved by the ethical committee of the faculty of dentistry- Cairo university on: 22\2\2022, approval number: 2222022

Data Availability:

Data will be available upon request

CRediT statement:

Author 1: Data curation, Writing - review & editing, Writing - original draft, Methodology, Conceptualization, Resources.
Author 2: Data curation, Conceptualization, Project administration, Supervision, Methodology, Writing - review & editing, Writing - original draft.
Author 3: Methodology, Writing - original draft, Writing - review & editing, Investigation, Formal analysis, Supervision, Data curation.

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