ORIGINAL ARTICLE

Prediction Accuracy of IOL Calculation Formulas in Combined Cataract Surgery and Trabeculectomy

Precisão das Fórmulas de Cálculo de LIO na Cirurgia Combinada de Catarata e Trabeculectomia

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ABSTRACT

INTRODUCTION: Information regarding the predictability of modern intraocular lens (IOL) calculation formulas in combined cataract surgery and trabeculectomy is lacking. This study aimed to evaluate the prediction error of the IOL calculation formulas incorporated in the European Society of Cataract & Refractive Surgeons (ESCRS) IOL calculator, as well as the Sanders Retzlaff Kraff/Theoretical (SRK/T) formula.

METHODS: Retrospective study included consecutive patients who underwent uneventful combined cataract surgery and trabeculectomy with monofocal IOL implantation. The following IOL calculation formulas were applied to predict the target spherical equivalent (SE) for the implanted IOL in each subject: Barrett Universal II, Cooke K6, EVO, Hill-RBF, Hoffer QST, Kane, PEARL DGS and SRK/T. Biometry was obtained using a swept-source optical biometer (IOL Master 700; Carl Zeiss). Prediction errors (PE), defined as the difference between postoperative and formula-predicted SE based on the IOL power implanted, were calculated at 3-6 months follow-up. Mean absolute error (MeanAE), median absolute error (MedAE) and the percentage of eyes within ±0.25 diopters (D), ±0.50D and ±1.00D of PE were determined.

RESULTS: A total of 41 eyes from 41 patients with a mean axial length (AL) of 23.39±0.82 mm were included. The mean postoperative SE was -0.55±0.71D. The formula presenting the lowest MedAE was EVO (0.29D), followed by SRK/T (0.30D), Cooke K6 (0.32D), Kane (0.34D), Hoffer QST (0.35D), Hill-RBF (0.35D), PEARL GDS (0.38D), and finally Barrett Universal II (0.43D). The percentage of eyes within ±0.50D of PE was superior for Hill-RBF (65.9%), followed by Cooke K6 (64.1). For eyes within ±1.00D of PE, the formula showing a higher proportion was Hoffer QST (92.7%), followed by Kane (90.2%). Barrett Universal II was the formula with less percentage of eyes in all groups (29.3% for ±0.25D PE, 53.7% for ±0.50D PE, and 78.0% for ±1.00D PE).

CONCLUSION: Overall, all formulas evaluated showed a robust performance. The finding that none of the modern formulas exhibited a significant advantage when compared to SRK/T suggests that eyes undergoing combined cataract surgery and trabeculectomy should be evaluated as a singular subgroup in terms of IOL power calculation.

KEYWORDS: Glaucoma; Lens Implantation, Intraocular; Phacoemulsification; Refractive Errors; Trabeculectomy.

RESUMO

INTRODUÇÃO: Informação relativa à precisão das fórmulas modernas de cálculo de lentes intraoculares (LIO) em cirurgia combinada de catarata e trabeculectomia é escassa. Este estudo teve como objetivo a avaliação do erro de previsão das fórmulas de cálculo da LIO incorporadas na calculadora da Sociedade Europeia de Cirurgiões de Catarata e Refrativa, bem como da fórmula Sanders Retzlaff Kraff/Theoretical (SRK/T).

MÉTODOS: Estudo retrospectivo que incluiu doentes consecutivos submetidos a facotrabeculectomia com implante de LIO monofocal. As seguintes fórmulas de cálculo da LIO foram aplicadas para prever o equivalente esférico alvo (EE) para a LIO implantada: Barrett Universal II, Cooke K6, EVO, Hill-RBF, Hoffer QST, Kane, PEARL DGS e SRK/T. A biometria foi obtida através do biómetro óptico IOL Master 700 (Carl Zeiss). Erros de previsão (EP), definidos como a diferença entre EE pós-operatório e o previsto pela fórmula com base na potência da LIO implantada, foram calculados aos 3-6 meses de seguimento. Foram determinados o erro absoluto médio, o erro absoluto mediano (EAMed) e a percentagem de olhos dentro de ±0,25 dioptrias (D), ±0,50D e ±1,00D de EP.

RESULTADOS: Foram incluídos 41 olhos de 41 doentes com um comprimento axial médio de 23,39±0,82 mm. O EE pós-operatório médio foi de -0,55±0,71D. A fórmula que apresentou menor EAMed foi a EVO (0,29D), seguida por SRK/T (0,30D), Cooke K6 (0,32D), Kane (0,34D), Hoffer QST (0,35D), Hill-RBF (0,35D) , PEARL GDS (0,38D) e, finalmente, Barrett Universal II (0,43D). A percentagem de olhos dentro de ±0,50D do EP foi superior para a Hill-RBF (65,9%), seguido pela Cooke K6 (64,1). Para olhos dentro de ±1,00D do EP, a fórmula que apresentou maior proporção foi a Hoffer QST (92,7%), seguida da Kane (90,2%). A Barrett Universal II foi a fórmula com menor proporção de olhos em todos os grupos (29,3% para ±0,25D EP, 53,7% para ±0,50D EP e 78,0% para ±1,00D EP).

CONCLUSÃO: Todas as fórmulas avaliadas apresentaram um bom desempenho. O facto de que as fórmulas modernas não demonstraram superioridade em relação à SRK/T sugere que os olhos submetidos a facotrabeulectomia devem ser avaliados como um subgrupo singular em termos de cálculo do poder da LIO.

PALAVRAS-CHAVE: Erros Refrativos; Facoemulsificação; Glaucoma; Implante de Lente Intraocular; Trabeculectomia.

INTRODUCTION

Combined cataract surgery and trabeculectomy, known as phacotrabeculectomy, is often considered a cost-effective approach for patients who suffer from both medically uncontrolled intraocular pressure (IOP) and lens opacification, minimizing postoperative IOP spikes, improving visual acuity, and reducing the hospital burden related with two stage operations.[1-6] As such, phacotrabeculectomy represents a viable option in cases of either open-angle glaucoma (OAG) or angle-closure glaucoma (ACG).[1]

Advancements in surgical techniques, ocular biometry devices, and intraocular lens (IOL) calculation formulas have transformed cataract surgery into a more refractive procedure, with patients presenting increasingly higher expectations for the refractive outcomes of this surgery.[7]

Nevertheless, the refractive results achieved through phacotrabeculectomy have not been as satisfactory as those observed in standard cataract surgery. Recent studies have reported a prediction error within ±0.50D for approximately 73%-88% of eyes in simple cataract surgery using modern IOL calculation formulas.[8-10] In contrast, the percentage of eyes undergoing combined cataract surgery and trabeculectomy achieving this level of accuracy was less than 70%.[11-13] This discrepancy can be attributed to the changes induced by trabeculectomy in corneal curvature and ocular biometry, particularly in terms of corneal astigmatism, AL and anterior chamber depth (ACD). These changes can compromise the accuracy of IOL calculation formulas, as these formulas rely on preoperative biometric data.[2,7] In fact, the inclusion of ACD in modern formulas is considered one of the primary contributors to their high accuracy in predicting the effective lens position in standard cataract surgery, which is different from third-generation formulas that rely solely on AL and keratometry, thus resulting in lower prediction accuracy.[14,15] However, the improved accuracy of modern formulas based on preoperative ACD measurements may not hold significant value for phacotrabeculectomy cases due to the deviated preoperative values in patients with uncontrolled IOP.[2]

Numerous studies have assessed the refractive outcomes of combined cataract surgery and trabeculectomy, but the results have been inconsistent, with most of these studies employing third-generation formulas.[2,12,13,16-21] Therefore, information regarding the prediction error of modern formulas, which are considered the most accurate in standard cataract surgery, is lacking for phacotrabeculectomy.[2,11]

Recently, the European Society of Cataract & Refractive Surgeons (ESCRS) developed a web application for IOL power calculation that simultaneously employs multiple modern formulas. This innovative tool enables ophthalmologists to obtain multiple results with just a single data entry session. The formulas integrated into the ESCRS online calculator (https://iolcalculator.escrs.org/terms) include Barrett Universal II, Cooke K6, EVO, Hill-RBF, Hoffer QST, Kane, and PEARL DGS.

Hence, the primary objective of this study was to evaluate the prediction accuracy of these modern formulas and compare them with the third-generation Sanders Retzlaff Kraff/Theoretical (SRK/T) formula in patients undergoing combined cataract surgery and trabeculectomy.

METHODS

STUDY DESIGN AND PATIENT SELECTION

This study involved a retrospective review of consecutive cases in which uneventful phacoemulsification was performed, followed by in-the-bag implantation of an AcrySof SN60AT IOL (Alcon Laboratories, Inc). This procedure was combined with standard trabeculectomy, utilizing either a superior fornix or limbal-based conjunctival flap and a partial-thickness scleral flap. The study was conducted between January 2020 and June 2023 at a tertiary care hospital.

Exclusion criteria included cases with incomplete data, a history of previous ocular surgery, ocular trauma, or other concurrent eye diseases, patients who had undergone ultrasonic biometry instead of optic biometry, history of intraoperative or postoperative complications that might influence refractive outcomes, patients who had less than 3 months of postoperative follow-up, or postoperative corrected distance visual acuity (CDVA) > 0.5 logMAR.

The study followed the ethical tenets of the Declaration of Helsinki and received approval from the local ethics committee.

DATA COLLECTION

Demographic and clinical data were retrieved from each patient file and included sex, date of birth, pre and postoperative (at 3-6 months) IOP, pre and postoperative CDVA, number of IOP-lowering medications taken pre and postoperatively (at 3-6 months), preoperative mean deviation (MD) value in standard automated perimetry (Humphrey visual field analyzer, 24-2 program; Carl Zeiss Meditec AG), as well as slit-lamp and fundoscopic examination findings. Biometry was obtained with swept-source optical coherence tomography biometer (IOLMaster 700; Carl Zeiss Meditec AG). Manifest postoperative refraction was performed by experienced ophthalmologists at 3-6 months post-operatively.

ASSESSMENT OF PREDICTION ERROR

Using the biometry data collected, the predicted SE for the IOL power implanted was back-calculated for the following IOL calculation formulas: Barrett Universal II (BUII), Cooke K6, EVO, Hill-RBF, Hoffer QST, Kane, PEARL DGS (all available at https://iolcalculator.escrs.org) and SRK/T.

The optimized A-constants proposed by the software were used for formulas available at ESCRS online calculator. For the SRK/T formula, the User Group for Laser Interference Biometry optimized constant was used.[22]

Prediction errors, defined as the difference between postoperative and formula-predicted SE, were calculated between 3 and 6 months of follow-up. Before lens factor optimization, outcomes included the mean numerical error (ME) and the proportion of eyes with a hyperopic prediction error. Then, following the principles described by Hoffer *et al*,[23] the systematic refractive error of the formulas was eliminated by zeroing out the mean numerical error. Subsequently, MeanAE, MedAE and the percentage of eyes within ±0.25, ±0.50, and ±1.00 D of PE were determined.

STATISTICAL ANALYSIS

Statistical analysis was performed using SPSS software version 23 (IBM Corporation). Descriptive analysis was carried out for all variables under investigation. To compare the mean numerical error and the MedAE, Friedman test was employed. For comparing the proportions of eyes falling within the ranges of ±0.25, ±0.50, and ±1.00 D, the Cochran's Q test was used. To account for multiple comparisons, a post-hoc Bonferroni correction was applied. Statistical significance was defined as a p-value less than 0.05.

RESULTS

DEMOGRAPHIC AND CLINICAL DATA

A total of 41 eyes from 41 patients (mean age 74.12 ± 10.63, range 29 – 92 years old; 46.3% female), 35 with OAG and 6 with ACG, were included. The pre and postoperative clinical data of the study population are summarized in Table 1. A statistically significant decrease in mean IOP was observed (26.98 ± 7.27 pre-op *vs* 13.80 ± 0.88 mmHg post-op, p<0.001), paired with a simultaneous decrease in the number of IOP-lowering medications (3.98 ± 0.88 pre-op *vs* 0.88±1.05 post-op, p<0.001),

Table 1. Pre and postoperative clinical data of the study cohort.	
Variable	**Value (mean ± SD)**
CDVA (logMAR)	
Pre-operative	0.33 ± 0.24
Post-operative	0.19 ± 0.16
IOP (mmHg)	
Pre-operative	26.98 ± 7.27
Post-operative	13.80 ± 3.64
N.º of IOP-lowering medications	
Pre-operative	3.98 ± 0.88
Post-operative	0.88 ± 1.05
Pre-operative MD	-15.60 ± -8.95
Pre operative AL (mm)	23.39 ± 0.82
Pre operative ACD (mm)	3.01 ± 0.38
Pre operative K1 (D)	43.04 ± 1.31
Pre operative K2 (D)	44.11 ± 1.35
IOL power (D)	21.70 ± 2.08
Post-operative SE (D)	-0.55 ± 0.71

SD – standard deviation; CDVA – corrected distance visual acuity; IOP – intraocular pressure; MD – median deviation; AL – axial length; D – diopters.

as well as an improve in mean CDVA (0.33 ± 0.24 pre-op *vs* 0.19 ± 0.16 logMAR post-op, *p*=0.001).

PREDICTION ERROR

Before constant optimization, all formulas showed a mean negative numerical error with the exception of Hoffer QST (0.02 D) (Table 2). Fig. 1 shows the proportion of hyperopic PE for each formula before constant optimization,

Table 2. Mean numerical error of IOL calculation formulas before constant optimization in the study cohort.	
Formula	**ME ± SD (D)**
EVO	-0.12 ± 0.69
SRK/T	-0.06 ± 0.60
Cooke K6	-0.01 ± 0.60
Kane	-0.07 ± 0.59
Hoffer QST	0.02 ± 0.62
Hill-RBF	-0.07 ± 0.58
PEARL DGS	-0.04 ± 0.59
BUII	-0.09 ± 0.62

SD – standard deviation; IOL - intraocular lens; ME - mean numerical error; D - diopters.

demonstrating that the highest percentage was observed in Cooke K6 and Hoffer QST formulas (56.4% and 53.7%, respectively), whereas EVO, Kane and SRK/T formulas yielded the lowest percentages of hyperopic error (39.0% each).

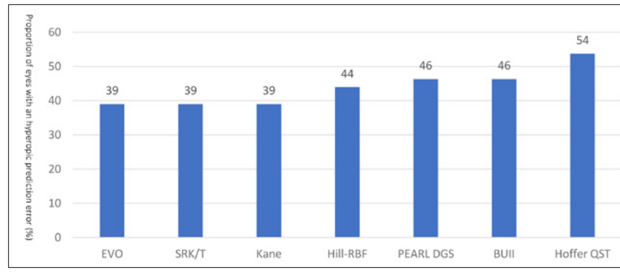

Figure 1. Graph representation of the proportion of eyes with a hyperopic prediction error by intraocular lens formula ordered from lowest to highest before constant optimization.

The overall accuracy of the IOL calculation formulas after constant optimization is presented in Table 3, and Fig. 2 shows the MedAE by IOL formula ordered from lowest to highest after constant optimization. EVO formula showed the lowest MedAE (0.29D), followed by SRK/T (0.30D), Cooke K6 (0.32D) and Kane (0.34D). Conversely, BUII yielded the highest MedAE (0.43D). However, no statistically significant differences were observed (*p*=0.44).

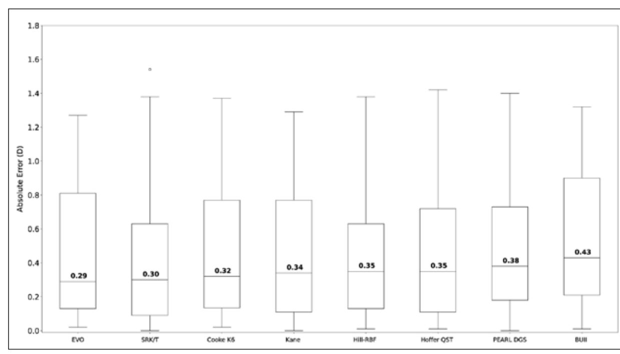

Figure 2. Graph representation of the absolute prediction error by intraocular lens formula after constant optimization. The indicated values correspond to the median absolute error for the respective formula.

Regarding the proportion of eyes with a PE within ±0.25, ±0.50 and ±1.00 D for each evaluated optimized formula (Fig. 3), Kane was among the best formulas in all three categories, with a PE of ±0.25, ±0.50, and ±1.00 D in

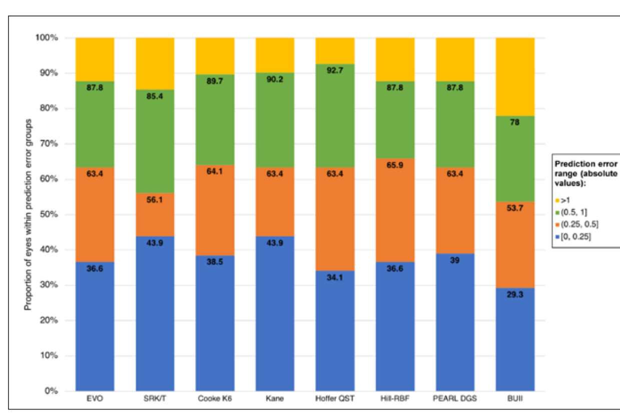

Figure 3. Graph representation of the proportion of eyes with a prediction error within ±0.25, ±0.50 and ±1.00 D for each evaluated optimized formula.

Table 3. Accuracy of calculation formulas for IOL power calculation in the study cohort.[a]

				% of eyes within PE range[b]		
Formula	**MeanAE (D)**	**MedAE (D)**	**STDEV (D)**	**±0.25**	**±0.50**	**±1.00**
EVO	0.46	0.29	0.38	36.6	63.4	87.8
SRK/T	0.45	0.30	0.42	43.9	56.1	85.4
Cooke K6	0.46	0.32	0.38	38.5	64.1	89.7
Kane	0.44	0.34	0.38	43.9	63.4	90.2
Hoffer QST	0.47	0.35	0.39	34.1	63.4	92.7
Hill-RBF	0.45	0.35	0.38	36.6	65.9	87.8
PEARL DGS	0.46	0.38	0.37	39.0	63.4	87.8
BUII	0.55	0.43	0.42	29.3	53.7	78.0

IOL - intraocular lens; MeanAE - mean absolute prediction error; MedAE - median absolute prediction error; PE = prediction error; STDEV - standard deviation of the error; D - diopters.

[a] After optimization of formula constants. Organized by ascending order of MedAE.
[b] Proportion of eyes with absolute PEs within these diopters.

43.9%, 63.4% and 90.2% of the eyes, respectively. Nevertheless, a good performance was observed overall, with >55% and >85% of the eyes within a PE of ±0.50 and ±1.00 D respectively for all formulas, with exception of BUII. This formula yielded the lowest percentage in all groups (53.7% for ±0.50D PE, and 78.0% for ±1.00D PE), even though no statistically difference has been observed (p=0.34 and p=0.19, respectively).

DISCUSSION

To the best of our knowledge, this is the first study to include a more extensive array of modern IOL calculation formulas for analyzing their predictive accuracy in combined cataract surgery and trabeculectomy. Several prior studies have focused on assessing the prediction error of third-generation formulas, such as SRK/T,[1,12,13,16,19,21] and despite the reported AL shortness after either trabeculectomy or phacotrabeculectomy,[2,16,24,25] these studies have not demonstrated a significant difference in PE between phacotrabeculectomy and isolated phacoemulsification.[1,16,19,21]

Nevertheless, in light of the excellent refractive outcomes observed with modern formulas such as BUII, Kane, EVO, Hill-RBF, and PEARL DGS in standard cataract surgery,[7,8,26] recent studies analyzing the refractive outcomes of phacotrabeculectomy have incorporated some of these newer formulas, specifically BUII, revealing less favorable outcomes compared to standard cataract surgery.[2]

This diminished performance of modern formulas in combined cataract surgery and trabeculectomy is further supported by the findings of our study. All the formulas evaluated exhibited a proportion of eyes within ±0.50 and ±1.00 D of PE of less than 66% and 95%, respectively. This is in contrast to isolated cataract surgery, where modern formulas like BUII, Kane, EVO, Hill-RBF, and PEARL DGS have consistently shown results in various studies with percentages of eyes within ±0.50 and ±1.00 D of PE exceeding 80% and 95%, respectively.[7,8,26]

Moreover, none of the modern formulas exhibited a significant advantage when compared to SRK/T, contradicting the results presented by Iijima K *et al*, who compared the refractive outcomes of BUII and SRK/T in combined cataract surgery and trabeculectomy, finding that the absolute PE using BUII was significantly smaller than that using the SRK/T formula.[11] However, when comparing the MedAE of BUII obtained in their study with our results, they were very similar: 0.46 D in Iijima K *et al versus* 0.43 D in our study, and slightly lower than the values observed in another study (0.51 D) by Shin JH *et al*,[2] which exclusively evaluated the performance of BUII in phacotrabeculectomy. In contrast, the MedAE of the SRK/T formula observed by Iijima K *et al* was considerably higher compared to our cohort (0.56 D *vs* 0.30 D in our study) and the cohort analyzed by Chung JK *et al* (0.32 D).[13]

Hence, these results seem to be controversial and show significant variability between studies. This can be attributed, on one hand, to the fact that some of these works did not incorporate constant optimization for the IOL formulas evaluated, possibly failing to exclude the presence of systematic bias.[23] On the other hand, differences in the timing between surgery and the refractive measurements might contribute to these discrepancies. For example, the interval was 3 months in the study by Iijima K *et al*,[11] 1 month in Shin JH *et al*,[2] and a mean of 14.7 months in Chung JK *et al*.[13] Prior research[25,27,28] has shown that the ACD, AL, and corneal curvature can vary within 12 months after trabeculectomy. In fact, a myopic refractive PE has been observed in most studies analyzing the PE in the first 3 months after surgery[12,17,20] with a tendency to become less negative over time.[13]

Even considering the above-mentioned divergences between studies, it is worth noting that, unlike what has been established in the literature regarding isolated phacoemulsification, where BUII has consistently been among the most accurate IOL power calculation formulas,[7,8] in our study, BUII exhibited the highest MedAE and the lowest percentage of eyes within ±0.25, ±0.50, and ±1.00 D of PE. However, this inferiority was not statistically significant when compared to the other formulas assessed, and our values closely align with those reported in other studies evaluating the PE of BUII in either isolated cataract surgery[8,28] or phacotrabeculectomy.[11]

As for the other modern formulas evaluated (Cooke K6, EVO, Hill-RBF, Hoffer QST, Kane, and PEARL GDS), to our knowledge, this is the first study to report on their prediction accuracy in combined cataract surgery and trabeculectomy. While the EVO formula exhibited the lowest MedAE, and the Kane formula displayed the best overall performance in terms of the proportion of eyes within ±0.25, ±0.50, and ±1.00 D of PE, all the formulas demonstrated good performance. Nevertheless, none of them exhibited a significant superiority over the less modern SRK/T formula. Thus, our study supports the hypothesis previously discussed in other studies, suggesting that the improved accuracy of modern formulas based on the inclusion of additional pre-operative measures might not be significantly advantageous for phacotrabeculectomy cases due to the preoperative values of these measures being altered in patients with uncontrolled intraocular pressure (IOP).[2]

It is important to acknowledge the limitations of this study. First, as mentioned earlier, refraction measurements were performed in the first 3 to 6 months after surgery, not accounting for potential changes that may occur in the refractive power of the eye beyond this period. Nonetheless, the majority of studies to date have evaluated refractive outcomes during this time frame, facilitating the comparison of our results with the literature. Second, we did not conduct a separate analysis based on the type of glaucoma, which could provide insights into the performance of IOL power calculation formulas in open-angle versus angle-closure glaucoma. Finally, phacotrabeculectomy surgeries were performed by different surgeons; however, some authors have suggested that these differences may not be significant in clinical outcomes with respect to cataract surgery.[30]

CONCLUSION

Up to the present moment, this is the first study to assess the performance of the most recent IOL calculation formulas in combined cataract surgery and trabeculectomy.

Despite the strong performance observed in all the modern formulas evaluated, the traditional SRK/T formula emerged as one of the top-performing options. This implies that when it comes to IOL power calculation, eyes undergoing phacotrabeculectomy should be regarded as a distinctive subgroup.

CONTRIBUTORSHIP STATEMENT / DECLARAÇÃO DE CONTRIBUIÇÃO

SG: Study design, data collection and analysis, drafting and revising the manuscript.

JB: Study design, data collection and analysis, revising the manuscript.

JS: Study design, data collection, revising the manuscript.

MS, MS and SS: Data collection.

TQ and PF: Data collection, revising the manuscript.

JM: Revising the manuscript.

All authors approved the final version to be published.

SG: Conceção do estudo, recolha e análise de dados, redação e revisão do manuscrito.

JB: Conceção do estudo, recolha e análise de dados, revisão do manuscrito.

JS: Conceção do estudo, recolha de dados, revisão do manuscrito.

MS, MS e SS: Recolha de dados.

TQ e PF: Recolha de dados, revisão do manuscrito.

JM: Revisão do manuscrito.

Todos os autores aprovaram a versão final a ser publicada.

RESPONSABILIDADES ÉTICAS

Conflitos de Interesse: Os autores declaram a inexistência de conflitos de interesse na realização do presente trabalho.

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Confidencialidade dos Dados: Os autores declaram ter seguido os protocolos da sua instituição acerca da publicação dos dados de doentes.

Proteção de Pessoas e Animais: Os autores declaram que os procedimentos seguidos estavam de acordo com os regulamentos estabelecidos pela Comissão de Ética responsável e de acordo com a Declaração de Helsínquia revista em 2013 e da Associação Médica Mundial.

Proveniência e Revisão por Pares: Não comissionado; revisão externa por pares.

ETHICAL DISCLOSURES

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Confidentiality of Data: The authors declare that they have followed the protocols of their work center on the publication of data from patients.

Protection of Human and Animal Subjects: The authors declare that the procedures followed were in accordance with the regulations of the relevant clinical research ethics committee and with those of the Code of Ethics of the World Medical Association (Declaration of Helsinki as revised in 2013).

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