Original Article

Comparison of Angle Kappa and Visual Outcomes in Pseudophakic Patients with Monofocal and Multifocal Intraocular Lenses

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ABSTRACT

Aim: To compare angle kappa and visual outcomes in pseudophakic patients implanted with monofocal versus multifocal intraocular lenses (IOLs) and to evaluate postoperative changes in angle kappa.

Study Design: Pre- and post-interventional study.

Duration and Settings of the Study: Conducted over 9 months, starting from September 2023 to May 2024, at Frontier Institute of Ophthalmology, Peshawar.

Methods: Patients undergoing uneventful phacoemulsification included through purposive sampling were randomly divided into two groups. One group (23 participants) received monofocal IOLs (Alcon AcrySof SA60 AT) and the second group (23 participants) received multifocal IOLs (Alcon AcrySof ReSTOR SN6AD1). Best-corrected distance visual acuity was measured using the LogMAR chart at baseline, one week, and one month. Angle kappa was assessed using Oculus Pentacam AXL. Data were analyzed in SPSS v25. Normality was tested using Shapiro-Wilk. Intra-group comparisons used the Friedman test (BCDVA) and repeated measures ANOVA (angle kappa); between-group comparisons used the MannWhitney U and independent t-tests (angle kappa).

Results: A total of 46 patients were included. The mean age of the monofocal group was 55.96 ± 9.52 years, and of the multifocal group, it was 48.95 ± 6.39 years. Both groups showed significant improvement in BCDVA ($p < 0.001$). At one month, the multifocal group achieved better BCDVA ($p < 0.05$). Angle kappa significantly decreased in both groups postoperatively ($p < 0.05$). No significant intergroup difference existed at baseline and one week, but the multifocal group had a higher residual angle kappa at one month ($p < 0.05$).

Conclusion: Both IOLs improved vision and reduced angle kappa postoperatively. Multifocal IOLs provided superior acuity but retained higher angle kappa, potentially increasing dysphotopsia risk. Preoperative angle kappa evaluation may help guide IOL selection.

Keywords: Intraocular lenses; Angle kappa; Pseudophakia; Visual acuity; Cataract surgery; Phacoemulsification.

INTRODUCTION

A cataract is characterized by a cloudy or opaque appearance of the natural crystalline lens, which can often interfere with routine activities like reading, writing, and mobility, ultimately diminishing individual's overall quality of life.[1,2] Cataract remains the primary cause of preventable blindness worldwide.[3,4] Despite ongoing advancements in potential pharmacological therapies, surgical intervention continues to be the most reliable and effective method for restoring vision.[5,6] The three primary surgical techniques for cataract removal include phacoemulsification (Phaco), Extracapsular Cataract Extraction (ECCE), and Manual Small-Incision Cataract Surgery (MSICS), with phacoemulsification being the most widely practiced approach.[7,8]

Cataract surgery ranks among the most frequently performed surgical interventions globally, with more than 25 million procedures carried out annually.[9] The primary goal after cataract removal is to implant an IntraOcular Lens (IOL) to replace the opacified natural lens, thereby restoring vision across various distances without the need for

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glasses or contact lenses.[10]

There are two common types of IOLs: monofocal and multifocal. Monofocal IOLs offer good distance vision with minimal disturbances and are more affordable but typically require glasses for intermediate and near tasks. Multifocal IOLs, which are designed with multiple refractive zones, offer improved vision for both near and distant objects. The increase in digital device use has made intermediate vision, crucial for activities like using smartphones and computers, more important. This increasing demand has heightened the significance of multifocal IOLs, which are designed to offer clear vision across various distances, particularly addressing the need for enhanced intermediate visual performance.[11,12] However, multifocal IOLs have been associated with some undesirable visual side effects after surgery, impacting patient satisfaction and visual quality.[9]

One parameter that may be affected by multifocal IOL implantation is angle kappa, defined as the angular difference between the pupillary and visual axis.[10] Changes in angle kappa could influence visual function after multifocal IOL placement.[13] The theory suggests that in eyes with significant angle kappa deviation, decentration is more likely, causing incoming light to pass through the peripheral multifocal rings instead of the central optic zone, potentially leading to visual disturbances such as glare and halos.[12] Understanding the impacts of multifocal IOLs on visual parameters like angle kappa can provide guidance on proper patient selection and management to optimize outcomes.[14]

A pronounced angle kappa has been associated with a higher incidence of postoperative visual disturbances, such as glare and halos, following multifocal IOL implantation.[15] It is also linked to poorer visual outcomes, including a reduced Modulation Transfer Function (MTF) cutoff, particularly after the implantation of trifocal diffractive intraocular lenses.[16] Research indicates that a larger angle kappa may compromise visual quality, as reflected by a lower Strehl ratio and increased internal Higher-Order Aberrations (HOAs).[17] Additionally, a larger horizontal angle kappa has been correlated with increased horizontal IOL decentration, whereas greater anterior chamber depth and a larger vertical angle kappa are associated with more pronounced vertical decentration.[18]

Several commercially available instruments can be used to estimate angle kappa. Precise measurement of angle kappa is often performed using instruments such as a synoptophore or a major amblyoscope. With advancements in biometer precision, newer devices capable of measuring angle kappa are increasingly being adopted in clinical practice. Pentacam has become increasingly popular for measuring angle kappa in recent years. Furthermore, Lenstar, iTrace, and ORBscan are often used to determine angle kappa.[19]

Although both monofocal and multifocal IOLs are widely used in cataract surgery, limited local data exists on their comparative impact on angle kappa and postoperative visual outcomes. Most studies focus primarily on visual acuity improvements, with insufficient attention to angle kappa variations and their potential influence on visual quality, especially with multifocal IOLs. Furthermore, no study from our region has systematically evaluated the postoperative angle kappa or its possible correlation with visual outcomes. This study was therefore undertaken to compare the changes in angle kappa and visual acuity after implantation of monofocal versus multifocal IOLs and to determine whether these parameters are interrelated in pseudophakic patients. The study aimed to offer surgeons valuable insights to support more accurate IOL selection, focusing on how changes in angle kappa relate to visual disturbances.

METHODS

This study employed a pre- and post-interventional design which was conducted at the Frontier Institute of Ophthalmology, Peshawar, from September 2023 to May 2024. Ethical approval was obtained from the institutional review board, and all procedures followed the ethical standards outlined in the Declaration of Helsinki. Written informed consent was obtained from all participants prior to enrollment.

A total of 46 patients were enrolled using a non-probability purposive sampling method, based on predefined inclusion criteria relevant to the study objectives. Participants were divided into two equal groups of 23 eyes each: one group received multifocal IOLs and the other received monofocal IOLs. All IOLs were from the same manufacturer: the monofocal group received the Alcon AcrySof SA60AT, and the multifocal group received the Alcon AcrySof ReSTOR SN6AD1. Study participants included individuals aged 40 to 75 years of either gender, presenting with visually significant cataracts graded as nuclear opalescence =4 based on the Lens Opacities Classification System III (LOCS III). Additional criteria included refractive errors ranging between > ±0.5 diopters and < ±6 diopters, and scheduled for unilateral phacoemulsification.

Exclusion criteria included prior ocular surgery, ocular comorbidities, cognitive or physical impairments, retinopathy of prematurity, axial myopia >26 mm, axial hyperopia <20 mm, or preoperative Best-Corrected Visual Acuity (BCVA) worse than 0.6 Log MAR.

A thorough preoperative evaluation was conducted for all patients, including BCVA (logMAR chart), slit-lamp examination, refraction, keratometry, anterior chamber depth, and axial length measured by Oculus Pentacam AXL. Postoperative assessments were conducted at 1 week and 1 month, including repeat BCVA, slit-lamp examination, refraction, and angle kappa measurement.

Angle kappa was derived indirectly using Pentacam AXL data by calculating the distance (in millimeters) between the corneal light reflex (Purkinje image) and the center of the pupil on the topographic map, then converting this linear displacement to angular units (degrees) using the formula: è = arctan (d/r)

where *d* is the measured chord length and *r* is the radius of the corneal curvature (approximated by mean keratometry). This method estimates the angle between the visual axis and pupillary axis based on corneal topography and pupil center displacement. Each measurement was repeated three times for each eye, and the average value was used for analysis. All measurements were taken by a single trained technician to maintain consistency. All surgeries were carried out by a single experienced surgeon using the standard phacoemulsification technique, with IOL implantation in the capsular bag. Postoperative medication regimens were standardized across participants. The primary outcome was the change in angle kappa postoperatively. Secondary outcomes comprised postoperative BCVA and refractive error. In addition, intermediate and near visual acuity were evaluated in the multifocal IOL group using Jaeger charts at testing distances of 60 cm and 40 cm, respectively. Data were collected using a structured proforma and analyzed using IBM SPSS Statistics version 25. Descriptive statistics, including means, standard deviations, and frequency distributions, were calculated for variables such as age, gender, Best-Corrected Distance Visual Acuity (BCDVA), and angle kappa. The Shapiro-Wilk test was used to assess normality for continuous variables. For within-group (intra-group) comparisons over time, The **Friedman test**, a non-parametric alternative, was used to evaluate changes in BCDVA over time within each group, as

BCDVA data were not normally distributed. Repeated Measures ANOVA was used to analyze changes in angle kappa within each group across the three time points (preoperative, 1 week, and 1 month), assuming normality and sphericity. For between-group comparisons, The MannWhitney U test was applied for non-normally distributed variables (e.g., BCDVA at each time point) between the two groups. The independent samples t-test was used to compare normally distributed continuous variables (e.g., angle kappa at each time point) between the monofocal and multifocal IOL groups. A p-value < 0.05 was considered statistically significant.

RESULTS

Participants were categorized into two groups based on the type of IOL implanted: monofocal and multifocal IOLs. In the monofocal group, the mean age was 55.96 years (SD ± 9.52), ranging from 41 to 70 years. The multifocal group had a younger mean age of 48.95 years (SD ± 6.39), with ages ranging from 40 to 61 years. Gender distribution in the monofocal group included 11 males (47.8%) and 12 females (52.2%), reflecting a slight female predominance. Conversely, the multifocal group comprised 14 males (60.9%) and 9 females (39.1%), indicating a higher proportion of male participants, as detailed in Table 1.

Table 1: Showing the demographic data of participants of both groups

Variables		Monofocal Group	Multifocal Group
Age (Mean (SD*)		55.96 (9.52)	48.95 (6.39)
Gender {n† (%‡}	Male	11 (47.8%)	14 (60.9%)
	Female	12 (52.2%)	9 (39.1%)

*SD = Standard Deviation, † n = Frequency, ‡ % = Percentage .

The observed differences in age and gender distribution between the two groups may reflect broader demographic trends or patient-specific factors influencing IOL selection. These variations could be attributed to gender-related differences in visual demands, occupational or lifestyle needs, and referral patterns influencing lens choice.

Visual Acuity Comparison:

Visual acuity assessments in both the monofocal and multifocal IOL groups demonstrated significant improvement over time, as analyzed using the Friedman test. In the Monofocal IOL (n = 23) group, the baseline mean BCDVA was 0.56 ± 0.09 logMAR, which improved to 0.26 ± 0.09 logMAR at the first follow-up (1 week post-op), and further to 0.12 ± 0.11 logMAR at the second follow-up (1 month post-op). The Friedman test indicated a statistically significant difference in visual acuity across the three time points. The test yielded a statistically significant result (÷² = 44.652, df = 2, p < 0.001), indicating a significant change in visual acuity over time. The mean ranks were 3.00 for baseline, 1.93 for the first follow-up, and 1.07 for the second follow-up, suggesting a consistent improvement.

Table 2. Changes in Best-Corrected Distance Visual Acuity (BCDVA) Group Over Time in Monofocal IOL Group (n = 23)

Time	Monofocal Group Mean (SD*)	Mean Ranks	P-value
Baseline (Pre-surgery)	0.55 (0.08)	3.00	
First follow-up (Post-surgery at 1 week)	0.26 (0.08)	1.93	0.000
Second follow-up (Post-surgery at 1 month)	0.12 (0.11)	1.07	

Friedman Test: ÷² = 44.652, df = 2, p < 0.001
*SD = Standard Deviation

Similarly, In the Multifocal IOL group (n = 23), there was a significant improvement in BCDVA over time. The mean (±SD) BCDVA improved from 0.52 ± 0.09 logMAR at baseline to 0.18 ± 0.07 at first follow-up (1 week post-op), and further to 0.05 ± 0.09 at the second follow-up (1 month post-op). The Friedman test revealed a statistically significant difference in visual acuity across the three time points (÷² = 43.143, df = 2, p < 0.001). The mean ranks also showed a progressive improvement from baseline (Mean Rank = 3.00) to second follow-up (Mean Rank = 1.17), indicating a consistent improvement in visual acuity over time following multifocal IOL implantation (Table 3).

Table 3: Changes in Best-Corrected Distance Visual Acuity (BCDVA) Over Time in Multifocal IOL Group (n = 23)

Time	Monofocal Group Mean (SD*)	Mean Ranks	P-value
Baseline (Pre-surgery)	0.52 (0.08)	3.00	
First follow-up (Post-surgery at 1 week)	0.17 (0.07)	1.83	0.000
Second follow-up (Post-surgery at 1 month)	0.05 (0.08)	1.17	

Friedman Test: $\div^2 = 43.143$, df = 2, $p < 0.001$
*SD = Standard Deviation

These results from the Friedman test demonstrate that both types of IOLs lead to substantial visual improvements post-implantation, with statistical confirmation of the observed changes.

A Shapiro-Wilk test was performed to assess the normality of the visual acuity data, which confirmed that the data did not follow a normal distribution. The Mann-Whitney U test was used to compare visual acuity between patients with monofocal and multifocal IOLs, as the visual acuity data did not follow a normal distribution. The analysis revealed that the multifocal group had a lower mean rank (19.61) compared to the monofocal group (27.39), suggesting a greater improvement in visual acuity for patients with multifocal IOLs (Figure 1)

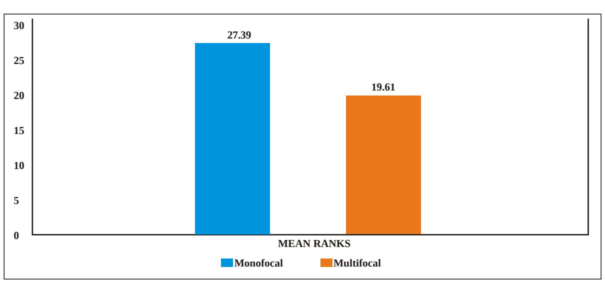

Figure1: Comparison of mean visual acuity improvements over time between the Monofocal and Multifocal groups.

This is because visual acuity measured using the LogMAR scale is inversely related to performance, where lower LogMAR values represent better visual acuity. Consequently, a lower mean rank reflects a trend toward better visual acuity outcomes in the multifocal group. The Mann-Whitney U statistic was 175.000, with a Z-value of -2.261 and a *p*-value of 0.024. This indicates a statistically significant difference in visual acuity between the two groups at the 0.05 level. Patients with multifocal IOLs demonstrated significantly greater improvements in visual acuity compared to those with monofocal IOLs.

Angle Kappa Comparison:

The assessment of Angle Kappa in both Monofocal and Multifocal groups, using Repeated Measures ANOVA, reveals significant decreases over time in both groups. In the Monofocal group, Angle Kappa decreased as Mean (SD) from 0.54 (0.16) at baseline to 0.30 (0.13) at the first follow-up and further to 0.23 (0.11) at the second follow-up ($p < 0.05$). Similarly, in the Multifocal group, Angle Kappa decreased as Mean (SD) from 0.59 (0.12) at baseline to 0.36 (0.11) at the first follow-up and 0.31 (0.09) at the second follow-up ($p < 0.05$) (Table 4 & Fig. 2).

Table 4: Mean score of Angle Kappa in both groups

Time	Monofocal Group	Multifocal Group	P-value
	Mean (SD*) in degree		
Baseline (Pre-surgery)	0.54 (0.16)	0.59 (0.12)	
First follow-up (Post-surgery at 1 week)	0.30 (0.13)	0.36 (0.11)	<0.05
Second follow-up (Post-surgery at 1 month)	0.23 (0.11)	0.31 (0.09)	

*SD = Standard Deviation

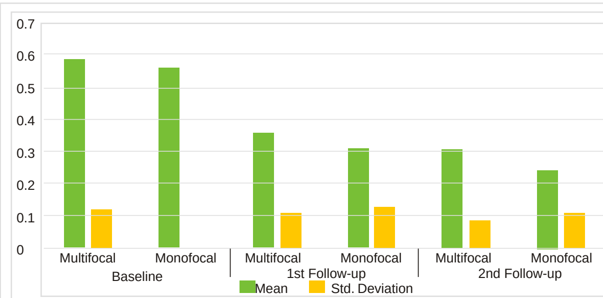

Figure 2: Comparison of angle kappa measurements of both group at different points

Mauchly's Test of Sphericity revealed that the sphericity assumption was violated in both groups, leading to the use of Greenhouse-Geisser corrections. The tests of within-subjects effects showed highly significant F-values for both groups. Pairwise comparisons confirmed significant differences between all time points in both groups, highlighting the substantial impact of IOL implantation on reducing Angle Kappa post-surgery.

The comparison of angle kappa between Monofocal and Multifocal groups was analyzed using an independent samples t-test. Before conducting the t-test, the Shapiro-Wilk test was employed to assess the normality of the data, determining whether the sample distribution deviated significantly from a normal distribution. The results supported the normality assumption, allowing for the use of the t-test.

The Multifocal group had consistently higher mean angle kappa values compared to the Monofocal group. Levene's Test for Equality of Variances was conducted to assess the homogeneity of variances between the two groups. For baseline and 1st follow-up angle Kappa, Levene's test yielded non-significant results ($p > 0.05$), which indicate similar variances between the groups, and the t-tests were conducted assuming equal variances. However, for the 2nd follow-up Angle Kappa, Levene's test indicated unequal variances ($p < 0.05$), necessitating the use of Welch's t-test, which revealed a significant difference in mean Angle Kappa between the groups ($p = 0.027$). These results suggest that while angle kappa was generally larger in the multifocal group, the difference only became statistically significant over time, specifically at the 2nd follow-up. (Table 5)

Table 5. Showing Test statistics for independent samples t-test comparing angle kappa at different time points

	Levene's Test for Equality of Variances		t-test for Equality of Means						
	F	Sig.	t	df	Sig. (2tailed)	Difference of mean	Std. Error Difference	95% Confidence Interval Lower	95% Confidence Interval Upper
Baseline Angle Kappa (Pre-surgery)	.132	.71	-.959	43	.343	-0.38	.03	-.11	.04
1st follow-up (Post-surgery at 1 week)	.366	.54	-1.45	43	.154	-.54	.03	-.13	.02
2nd follow-up (Post-surgery at 1 month)	.320	.57	-2.298	43	.26	-.07	.03	-.13	-.00

DISCUSSION

Our study found that both monofocal and multifocal IOLs resulted in significant improvements in visual acuity, with multifocal IOLs showing slightly better outcomes ($p < 0.05$). Notably, angle kappa improved significantly in both groups after surgery, and the multifocal group not only achieved greater visual acuity but also had a higher mean angle kappa, underscoring the importance of angle kappa in selecting the appropriate IOL type.

When comparing our findings with previous studies, it becomes evident that our results align with and expand upon existing research. For instance, Cervantes-Coste, et al focused on the effects of optical parameters, specifically angle kappa and angle alpha on visual outcomes in patients implanted with trifocal IOLs. The study reported a significant postoperative reduction in angle kappa ($p = 0.0007$), whereas angle alpha remained relatively unchanged ($p = 0.5158$) and showed an association with increased higher-order aberrations, which tended to adversely affect near vision ($p = 0.0543$).[13] Our study, however, demonstrated that angle kappa also decreases significantly postoperatively in both monofocal and multifocal groups, and the improvement in visual acuity was more pronounced in the multifocal group. This suggests that angle kappa is a critical factor in determining the success of IOL implantation, particularly in multifocal lenses.

In contrast to our findings, another study involving 548 eyes examined the impact of angle kappa on visual outcomes after multifocal IOL implantation and subsequent LASIK (Bioptics). Although a significant reduction in angle kappa was observed following surgery, no substantial correlation was identified between angle kappa and corrected distance visual acuity (CDVA) or the safety index (SI).[20] This inconsistency with our findings may be attributed to variations in surgical techniques and differences in patient demographics. These discrepancies underscore the importance of further research to better understand the role of angle kappa in predicting visual outcomes across diverse clinical contexts.

Multifocal IOLs are specifically designed to provide clear vision at various distances that is near, intermediate, and far, through the incorporation of multiple optical zones within a single lens. This approach offers an effective correction for presbyopia, often reducing dependence on corrective eyewear and resulting in improved overall visual acuity compared to monofocal IOLs. Patients selected for multifocal IOL implantation generally present with favorable ocular conditions, which may further contribute to the enhanced visual outcomes observed in this group. Notably, significant postoperative changes in angle kappa particularly among recipients of multifocal lenses, appear to play a key role in visual performance. Angle kappa, defined as the angular distance between the visual axis and the pupillary axis, has been shown to influence IOL centration and, by extension, the quality of vision. The findings from this study underscore the importance of achieving optimal lens alignment with the visual axis, whether through natural postoperative adjustments or refined surgical techniques. These observations reinforce the value of preoperative angle kappa assessment as a critical component of surgical planning, aimed at enhancing lens positioning and minimizing the likelihood of postoperative visual disturbances.

Furthermore, a related study also examined preoperative angle measurements in patients who tested positive for Multifocal Contact Lenses test (MCLT) prior to multifocal refractive lens surgery. The results revealed that 17% of MCLT-positive eyes had both angle kappa values greater than or equal to 0.5 mm, and these eyes demonstrated significant improvements in visual acuity at the 1-year follow-up.[20] Our findings align with these results, showing that both the monofocal and multifocal groups experienced substantial visual acuity improvements, with the multifocal group showing a more pronounced gain. Additionally, the decrease in postoperative angle kappa was more pronounced in the multifocal group compared to the monofocal group, further emphasizing the critical role of angle kappa in optimizing visual outcomes, particularly with multifocal IOLs.

This study is subject to several limitations that may influence the interpretation of its findings. It focuses exclusively on the comparison between monofocal and multifocal IOLs, excluding other lens types such as toric or extended depth of focus (EDOF) lenses, which limits the generalizability of the results to a broader patient population. Furthermore, the study primarily evaluates visual acuity, without considering functional vision outcomes such as contrast sensitivity or glare, both of which are essential for a comprehensive understanding of the IOLs' impact on patients' overall quality of life. Additionally, the measurement of visual acuity can be subjective, potentially introducing bias into the findings. The study also does not examine the underlying causes of changes in angle kappa following surgery, which could be influenced by factors like surgical technique or individual anatomical differences. Moreover, the relatively small sample size (46 participants) may not provide sufficient statistical power to detect subtle differences or allow for broad generalizations. Future research should incorporate a wider range of IOL types, larger sample sizes, and assessments of functional vision outcomes. Investigating the factors influencing angle kappa changes could also provide valuable insights into further optimizing visual outcomes.

The findings of this study carry significant implications for clinical practice. The crucial role of angle kappa in visual outcomes, particularly in patients receiving multifocal IOLs, underscores the importance of thorough preoperative evaluation and careful IOL selection to enhance patient satisfaction. Clinicians should consider incorporating angle kappa measurements into routine preoperative assessments to ensure optimal IOL choice, especially for patients with a favorable visual prognosis. Future research should aim to investigate the impact of angle kappa across various IOL types, explore the underlying factors influencing its postoperative changes, and assess functional vision outcomes. Such research would provide a more comprehensive understanding of IOL performance. Ultimately, these efforts will lead to more personalized and effective cataract surgery outcomes, thereby improving the overall quality of patient care.

This study highlights the critical role of angle kappa assessment in cataract surgery with IOL implantation. Postoperative improvements in visual acuity and reductions in angle kappa were observed for both monofocal and multifocal IOLs. While both IOL types contributed to enhanced visual outcomes, multifocal IOLs demonstrated slightly superior visual acuity, though they were associated with a higher mean angle kappa compared to monofocal IOLs. These findings emphasize the importance of a thorough preoperative evaluation of angle kappa to ensure optimal outcomes, particularly with multifocal IOLs, which necessitate precise alignment to maximize postoperative performance.

CONCLUSION

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Conflicts of Interest

The authors declare that there are no conflicts of interest, financial or otherwise, that could have influenced the conduct or outcomes of this study.

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AI Declaration

No artificial intelligence tools were used in the preparation of this manuscript.

Patient Consent: Informed consent was obtained from all patients involved in this study.

Ethical Approval: Ethical approval for this study was granted by The University of Faisalabad under Ref # TUF/IRB/386/24.

Author(s) Contributions

AS: Conceptualization and design of the study, drafting, review and final approval of the final manuscript and agrees to be accountable for all aspects of the work.

AU: Data analysis, review and final approval of the final manuscript and agrees to be accountable for all aspects of the work.

SA: Data analysis, review and final approval of the final manuscript and agrees to be accountable for all aspects of the work.

SSQ: Data analysis, review and final approval of the final manuscript and agrees to be accountable for all aspects of the work.

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AA: Data analysis, review and final approval of the final manuscript and agrees to be accountable for all aspects of the work.

FN: Data analysis, review and final approval of the final manuscript and agrees to be accountable for all aspects of the work.

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