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SLO AND OCT-A COMPARISON OF DIABETIC RETINOPATHY EARLY DIAGNOSIS WITH SUPERIMPOSED IMAGE TECHNIQUE

Original Research

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Acknowledgement: The authors gratefully acknowledge the support of Xi'an Jiaotong University Second Affiliated Hospital during this study.

Conflict of Interest: None

Grant Support & Financial Support: None

ABSTRACT

Background: Diabetic retinopathy (DR) is a progressive microvascular complication of diabetes mellitus and remains one of the leading causes of visual impairment globally. Early diagnosis is essential to prevent irreversible vision loss, particularly during the asymptomatic stages of the disease. Traditional imaging techniques are limited in their ability to provide a complete picture of both structural and vascular abnormalities in the retina.

Objective: To evaluate and compare the diagnostic efficacy of Scanning Laser Ophthalmoscopy (SLO) and Optical Coherence Tomography Angiography (OCTA), and to assess the added value of a superimposed image technique in detecting early-stage diabetic retinopathy.

Methods: A cross-sectional study was conducted involving 100 diabetic patients presenting with suspected early-stage DR at Xi'an Jiaotong University Second Affiliated Hospital. All participants underwent SLO and OCTA imaging using standardized protocols. OCTA was employed to detect microvascular abnormalities such as capillary non-perfusion and neovascularization, while SLO identified structural lesions including hemorrhages and exudates. A digital image registration software was used to create superimposed images. Diagnostic accuracy, sensitivity, and specificity were compared using Mann-Whitney U tests, referencing clinical fundus examination and fluorescein angiography (FA) findings.

Results: Superimposed imaging demonstrated higher total lesion detection (mean = 10.2 ± 3.9) compared to SLO alone (8.58 ± 4.27) and OCTA alone (2.00 ± 0.82) ($p < 0.01$). SLO showed superior detection for hemorrhages (HE) and exudates (EX), while OCTA had greater sensitivity for IRMA and NV lesions. The superimposed technique significantly enhanced lesion localization and diagnostic precision across all lesion types.

Conclusion: The integration of SLO and OCTA through superimposed imaging improves diagnostic accuracy for early-stage diabetic retinopathy, supporting more effective clinical decision-making and timely intervention.

Keywords: Diabetic Retinopathy, Early Diagnosis, Image Processing, Neovascularization, Optical Coherence Tomography Angiography, Retinal Hemorrhage, Scanning Laser Ophthalmoscopy.

INTRODUCTION

Diabetic retinopathy (DR) is a significant microvascular complication of diabetes mellitus and a leading cause of vision impairment and blindness among working-age adults worldwide. Early detection of DR is critical, as the initial stages often progress without any noticeable symptoms, making timely diagnosis challenging (1). Conventional diagnostic tools like fundus photography have long been used to screen and grade DR by capturing two-dimensional images of retinal changes such as microaneurysms, hemorrhages, and exudates (2). While accessible and relatively affordable, fundus photography has limitations, particularly in visualizing the deeper layers of the retina and microvascular alterations, which are pivotal for understanding disease progression and severity (3). In recent years, advancements in ophthalmic imaging technology have introduced non-invasive modalities such as Optical Coherence Tomography Angiography (OCTA) and Scanning Laser Ophthalmoscopy (SLO), which have considerably enhanced the clinician's ability to detect and monitor retinal pathology. OCTA, in particular, enables high-resolution imaging of retinal microvasculature without the use of dye, allowing for the detailed assessment of vessel density, non-perfusion areas, and the foveal avascular zone (FAZ) (4,5). These parameters have proven to be sensitive indicators of early microvascular compromise in diabetic patients, potentially identifying pathology before it becomes visible on standard fundus images (6,7). However, OCTA may not capture all visible features such as exudates or hemorrhages, which are often more discernible in SLO or traditional color fundus images (8).

The evolution of DR management has shifted from a reactive to a proactive approach, emphasizing early diagnosis and preventive care. Timely identification of DR can facilitate early interventions—such as glycemic control, laser therapy, or intravitreal injections—that may delay or prevent progression to vision-threatening stages (9,10). As a result, there is a growing need to refine diagnostic tools to maximize sensitivity and specificity, especially in early disease stages where intervention is most beneficial. Combining imaging modalities has been proposed as a strategy to leverage the strengths of each technique. Integrating OCTA with fundus photography or SLO has shown promise in improving diagnostic accuracy by capturing both structural and functional changes in the retina (11,12). Nonetheless, challenges remain in the clinical adoption of such hybrid diagnostic approaches. Issues such as image alignment, segmentation errors, and interpretation of large data volumes complicate integration efforts (13,14). To address these challenges, advanced methods including machine learning, image registration, and superimposition techniques are being explored to enhance image fusion and interpretation (15). These innovations aim to provide a more comprehensive understanding of retinal health and disease. Despite the potential of OCTA and SLO, their comparative diagnostic performance, particularly in the early stages of diabetic retinopathy, remains insufficiently explored in clinical literature. This study seeks to fill this gap by evaluating the diagnostic accuracy of SLO and OCTA, individually and in combination, for detecting early-stage diabetic retinopathy. It also aims to assess the effectiveness of a superimposed image technique in enhancing diagnostic precision and clinical utility in the management of diabetic retinopathy (16,17).

METHODS

This cross-sectional study was conducted to evaluate and compare the diagnostic efficiency of Optical Coherence Tomography Angiography (OCTA), Scanning Laser Ophthalmoscopy (SLO), and the superimposed image technique in detecting diabetic retinopathy (DR). A total of 100 patients diagnosed with diabetic retinopathy were recruited from the Department of Ophthalmology at Xi'an Jiaotong University Second Affiliated Hospital, Xi'an, China. Participants were selected using a purposive sampling technique based on the inclusion criteria of a confirmed diagnosis of diabetic retinopathy, age between 30 and 75 years, and the ability to undergo ocular imaging. Patients with a history of ocular trauma, prior retinal surgery, other concurrent retinal pathologies (such as age-related macular degeneration or retinal vein occlusion), or ungradable imaging results were excluded to ensure data integrity. All included participants underwent both OCTA and SLO imaging on the same day using standardized protocols to minimize temporal bias. OCTA was performed using a commercially available spectral-domain device with built-in software to evaluate retinal microvascular parameters including capillary density, non-perfusion zones, and the presence of neovascularization. This technique enabled layer-wise visualization of the superficial and deep vascular plexuses. Simultaneously, SLO was employed to obtain high-contrast, real-time images of the retina, primarily focusing on structural alterations such as hemorrhages, hard exudates, and macular edema. For enhanced diagnostic

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assessment, a superimposed image technique was used in which OCTA and SLO images were digitally registered and layered using image processing software to evaluate whether this combination improved visualization of early pathological signs of DR.

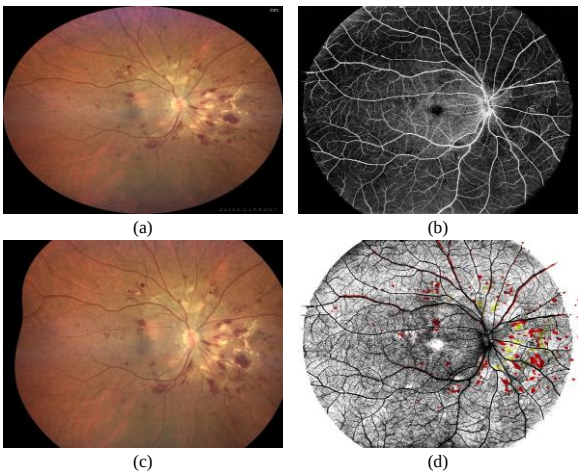
Quantitative data obtained from both imaging modalities were analyzed using IBM SPSS software. A paired sample t-test was applied to compare the diagnostic measurements (sensitivity, specificity, and diagnostic accuracy) between OCTA and SLO. The statistical significance level was set at $p < 0.05$. Diagnostic accuracy was determined against a clinical reference standard based on ophthalmologist grading following the International Clinical Diabetic Retinopathy Disease Severity Scale. Prior to the initiation of the study, ethical clearance was obtained from the Institutional Review Board of Xi'an Jiaotong University Second Affiliated Hospital, and written informed consent was obtained from all participants in accordance with the Declaration of Helsinki. All data collected were anonymized to maintain participant confidentiality.

RESULTS

The study assessed and compared the diagnostic efficiency of OCTA, SLO, and their superimposed image technique in evaluating diabetic retinopathy. A total of 100 DR patients underwent imaging, and lesion identification was quantitatively analyzed. Findings revealed substantial diagnostic differences across modalities, with the superimposed technique offering enhanced sensitivity for lesion detection. The collective analysis demonstrated that combining SLO's structural imaging with OCTA's vascular mapping significantly improved lesion recognition, particularly for intraretinal microvascular abnormalities and neovascularization. Statistically significant differences ($p < 0.01$) confirmed the superiority of the combined approach in quantifying total retinal lesions, affirming its diagnostic utility.

Diagnostic Accuracy superimposed method of SLO and OCTA

The comparison of individual imaging modalities indicated that SLO was more effective in identifying hemorrhages (mean ± SD: 2.94 ± 2.4) and exudates (2.53 ± 2.26), whereas OCTA exhibited superior performance in visualizing intraretinal microvascular abnormalities (IRMA) and neovascularization (NV), with higher mean ranks (150.50) compared to SLO (50.50) ($p < 0.001$). The superimposed image method markedly enhanced total lesion detection (mean ± SD: 10.2 ± 3.9), showing a statistically significant increase compared to standalone SLO (8.58 ± 4.27) and OCTA (2.00 ± 0.82) ($p < 0.01$). For NV and IRMA, the combined imaging approach consistently yielded higher diagnostic yields, demonstrating the effectiveness of integrating vascular and structural data in early-stage and advanced DR assessment.



(a) (b) (c) (d)

The superimposed image of SLO and OCTA (a) is the SLO image, (b) is OCTA (c) is the registered image (d) is the lesions superimposed together

Impact of Superimposed Image Technique in Mild NDPR

In early stages of non-proliferative diabetic retinopathy, superimposed OCTA-SLO imaging improved identification of early retinal lesions, particularly microaneurysms. These small, scattered, dark spots seen on the superimposed image corresponded with microvascular dilations and early hemorrhages. Structural details visible in SLO, such as hemorrhages and exudates, when combined

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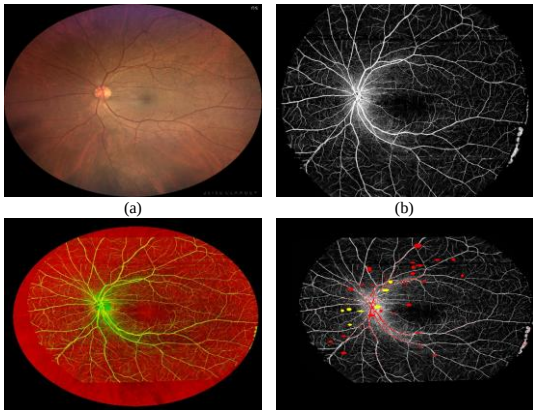
with OCTA's depiction of perfusion deficits and early neovascular features, provided a richer diagnostic context. Early lesions such as dot hemorrhages and FAZ enlargement were more clearly defined in the combined image than in either modality alone.

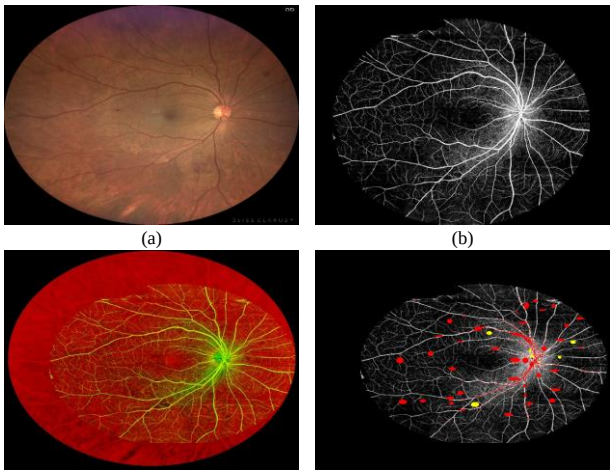


(a) (b) (c) (d)

Superimposed OCTA-SLO Image (a) represents an SLO image, Mild NDPR (b) refers to OCTA (c) is an overlaid image, and (d) refers to overlapping lesions

Impact of Superimposed Image Technique in Moderate NDPR

The superimposed imaging in moderate NDPR cases revealed soft exudates and localized vascular leakages that were less distinct on standalone SLO or OCTA. The composite visualization facilitated clear observation of yellow-white exudative deposits and helped localize their vascular sources, confirming retinal barrier compromise. The simultaneous visualization of structural damage and associated ischemic zones improved understanding of DR progression and supported earlier therapeutic interventions. Differences between a relatively intact vascular image on OCTA and exudative deposits in SLO were reconciled effectively via the superimposed method.



(a) (b) (c) (d)

Superimposed OCTA-SLO Image (a) indicates an SLO image, Moderate NDPR (b) relates to OCTA; (c) represents an overlay image. (d) Shows multiple lesions

Impact of Superimposed Image Technique in Severe NDPR

In severe stages of NPDR, the combined imaging approach clearly demonstrated numerous lesions, including extensive hemorrhages, pronounced exudates, and neovascular formations. The integration of OCTA and SLO enabled accurate mapping of pathological vascular remodeling and exudative spread. Observed changes included large flame-shaped hemorrhages, venous beading, and extensive capillary dropout zones. Superimposed images aided in differentiating neovascular zones from static lesions, guiding potential anti-VEGF or laser-based therapies. The diagnostic clarity in advanced DR was markedly enhanced using this overlay method, particularly in delineating ischemic and hemorrhagic areas.

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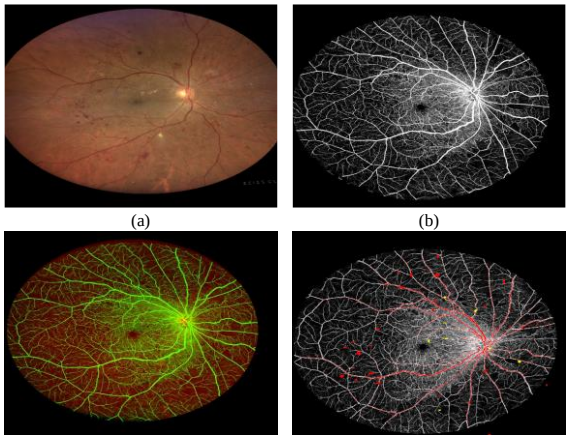

(a) (b) (c) (d)

Image of overlaid OCTA-SLO (a) represents an SLO image, Severe NDPR; (b) illustrates OCTA; (c) depicts a superimposed image. (d) Have numerous lesion images

Table 1: Lesions observed by SLO and OCTA Imaging

Lesion Type	Modality	Mean ±SD	Median	Mean Rank	Mann-Whitney U Test	p-value
HE	SLO	2.94 ± 2.4	3.00	97.32	4681.50	0.426
	Superimposed			103.69		
EX	SLO	2.53± 2.26	3.00	99.31	4880.50	0.764
	Superimposed			101.70		
IRMA	SLO	1.72± 1.57	2.00	50.50	0.00	0.00
	Superimposed			150.50		
NV	SLO	1.39± 1.30	1.00	50.50	0.00	0.00
	Superimposed			150.50		
Total lesions observed	SLO	8.58± 4.27	8.00	57.63	712.50	0.01
	Superimposed			143.38		

Table 2: Lesions observed by SLO with superimposed Image

Lesion Type	Modality	Mean ±SD	Median	Mean Rank	Mann-Whitney U Test	p-value
HE	SLO	2.94 ± 2.4	3.00	97.32	4681.50	0.426
	Superimposed			103.69		
EX	SLO	2.53± 2.26	3.00	99.31	4880.50	0.764
	Superimposed			101.70		
IRMA	SLO	1.72± 1.57	2.00	50.50	0.00	0.00
	Superimposed			150.50		

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Lesion Type	Modality	Mean ±SD	Median	Mean Rank	Mann-Whitney U Test	p-value
NV	SLO	1.39± 1.30	1.00	50.50	0.00	0.00
	Superimposed			150.50		
Total lesions observed	SLO	8.58± 4.27	8.00	57.63	712.50	0.01
	Superimposed			143.38		

Table 3: Lesions observed by OCTA with superimposed Image

Lesion Type	Modality	Mean ± SD	Median	Mean Rank	Mann Whitney U Test	p-value
HE	OCTA	2.94 ± 2.4	3.00	50.50	0.00	0.00
	Superimposed			150.50		
EX	OCTA	2.53 ±2.26	3.00	50.50	0.00	0.00
	Superimposed			150.50		
IRMA	OCTA	1.72 ±1.57	2.00	99.86	4935.50	0.871
	Superimposed			101.15		
NV	OCTA	1.39 ±1.30	1.00	88.01	3750.50	0.001
	Superimposed			113.00		
Total lesions observed	OCTA	2.00 ±0.82	8.00	50.83	33.00	0.01
	Superimposed			150.17		

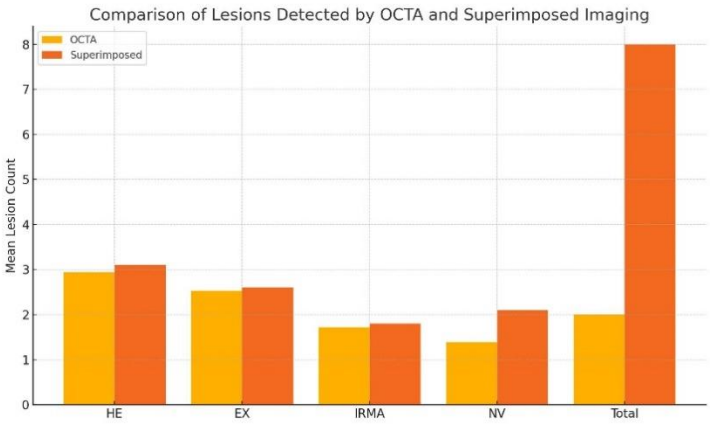


Figure 1 Comparison of Lesions Detected by OCTA and Superimposed Imaging

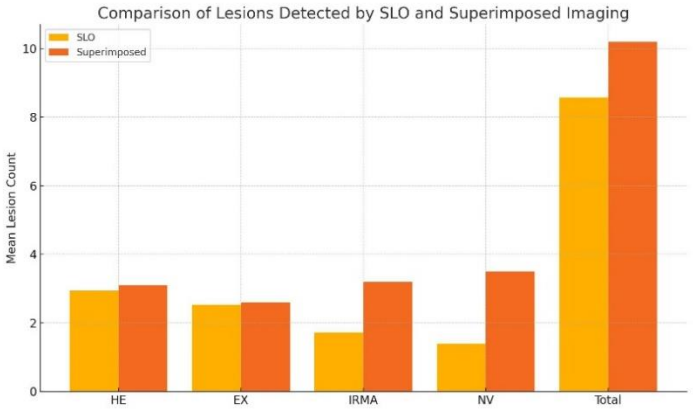
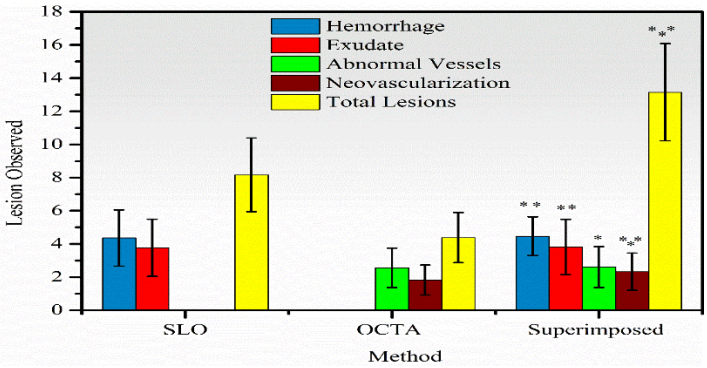


Figure 2 Comparison of Lesions Detected by SLO and Superimposed Imaging



DISCUSSION

The findings of this study reinforce and extend previous research highlighting the complementary roles of Scanning Laser Ophthalmoscopy (SLO) and Optical Coherence Tomography Angiography (OCTA) in the diagnosis of diabetic retinopathy (DR). Individually, both imaging modalities have demonstrated diagnostic value—SLO in detecting structural abnormalities such as hemorrhages and exudates, and OCTA in identifying microvascular anomalies, including intraretinal microvascular abnormalities (IRMA) and neovascularization (NV). However, this study validates that the integration of both imaging techniques using a superimposed image method substantially enhances lesion identification and diagnostic accuracy in early-stage DR. These findings align with earlier studies suggesting that neither modality alone provides a comprehensive assessment of retinal pathology (18,19). Traditional imaging approaches, particularly fundus photography and fluorescein angiography (FA), have long served as the standard for DR assessment. While FA offers detailed vascular visualization, its invasive nature poses limitations for frequent monitoring (20). OCTA has emerged as a non-invasive alternative capable of visualizing both superficial and deep capillary plexuses with high resolution, allowing for the detection of capillary dropout and neovascular formations without the use of contrast dye (21). Similarly, SLO has proven effective in evaluating superficial retinal layers and detecting exudative changes, but lacks the ability to assess deeper vascular disruptions. This dichotomy necessitates a multimodal approach, especially in the early detection and management of DR, where both structural and vascular changes must be concurrently evaluated (21,22).

The introduction of a superimposed imaging technique in this study addresses the diagnostic gap by merging structural and vascular datasets into a unified composite. Previous attempts to combine imaging data often relied on manual alignment methods, which were time-consuming and susceptible to error (22). In contrast, the current study employed advanced image registration software that enabled accurate spatial correlation of OCTA and SLO datasets. This methodological refinement enhanced lesion localization and minimized interpretation variability. The alignment with recent developments in machine learning-based fusion tools supports ongoing efforts to streamline multimodal diagnostics in ophthalmology (23). Statistical comparisons in this study revealed clear advantages of the superimposed technique. While OCTA showed superior performance in identifying IRMA and NV lesions, and SLO was more sensitive to hemorrhages and exudates, the combined approach significantly improved total lesion detection. These results support prior evidence that multimodal imaging enhances sensitivity and specificity in DR diagnosis (23,24). Importantly, the superimposed image approach offers a non-invasive alternative to fluorescein angiography, making it suitable for routine screening and follow-up in diabetic patients.

One of the notable strengths of this study is the practical implementation of an integrated imaging model that mirrors real-world clinical demands for efficiency, accuracy, and non-invasiveness. The technique offers high diagnostic yield without the associated risks of invasive procedures, positioning it as a promising tool in routine DR management. Furthermore, the use of statistical analyses such as Mann-Whitney U tests provided robust validation for the differences observed between modalities. Despite these strengths, certain limitations should be acknowledged. The study lacked longitudinal follow-up to assess the predictive value of lesion detection in relation to disease progression. The absence of subgroup analyses stratified by DR severity limited the granularity of the findings. Additionally, while the superimposed technique enhanced visualization, it relied on manual interpretation, which may still introduce observer variability. The incorporation of artificial intelligence and automated lesion quantification in future research could address this limitation and optimize the reproducibility of the method. Future investigations should focus on evaluating the long-term clinical outcomes of patients assessed using the superimposed technique. Integrating automated image analysis tools and exploring correlations between

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composite imaging findings and treatment response would strengthen the clinical utility of this approach. Moreover, expanding sample sizes and including diverse patient populations would enhance the generalizability of findings. Continued refinement of this imaging strategy is essential for advancing non-invasive, comprehensive retinal diagnostics and for improving care delivery to individuals affected by diabetic retinopathy.

CONCLUSION

This study concludes that combining Optical Coherence Tomography Angiography (OCTA) with Scanning Laser Ophthalmoscopy (SLO) through a superimposed imaging technique significantly improves the early detection and diagnostic accuracy of diabetic retinopathy. By integrating OCTA's ability to visualize vascular abnormalities with SLO's strength in capturing structural changes, the superimposed method offers a more comprehensive and clinically valuable assessment of retinal pathology. These findings emphasize the practical potential of this approach in routine screening and early intervention, ultimately supporting more timely and targeted management of diabetic retinopathy.

AUTHOR CONTRIBUTION

Author	Contribution
Muhammad Numan	Substantial Contribution to study design, analysis, acquisition of Data Manuscript Writing Has given Final Approval of the version to be published
Abdul Haque Khoso*	Substantial Contribution to study design, acquisition and interpretation of Data Critical Review and Manuscript Writing Has given Final Approval of the version to be published
Zahid Hussain Chandio	Substantial Contribution to acquisition and interpretation of Data Has given Final Approval of the version to be published
Manzoor Ahmed	Contributed to Data Collection and Analysis Has given Final Approval of the version to be published
Shagufta Gul	Contributed to Data Collection and Analysis Has given Final Approval of the version to be published
Hira	Substantial Contribution to study design and Data Analysis Has given Final Approval of the version to be published
Lachman Das Malhi	Contributed to study concept and Data collection Has given Final Approval of the version to be published
Saifullah	Writing - Review & Editing, Assistance with Data Curation

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