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Observational study to analyze the role of ultrasound biomicroscopy in the detection and management of anterior segment pathologies

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Abstract
Ultrasound Biomicroscopy (UBM) is a high-frequency ultrasound imaging technique that provides detailed cross-sectional images of the anterior segment of the eye. This study aims to investigate the role of UBM in diagnosing anterior segment disorders and compares its efficacy with traditional diagnostic tools.

Materials and Methods: An observational, cross-sectional study was conducted over 15 months at a tertiary care center in South Gujarat, involving 40 patients with anterior segment disorders. Inclusion criteria encompassed adults with opaque media, ocular trauma, and suspected tumors. Exclusion criteria included uncooperative patients and active infections. Comprehensive examinations, including UBM, were performed using an Appasamy UBM machine at frequencies of 35 and 50 MHz.

Results: A total of 55 eyes were evaluated. The mean age of participants was 47 years, with angle-closure glaucoma being the most prevalent condition (41.8%). UBM revealed lens vault thickness in 69.5% of angle-closure glaucoma cases and abnormalities in corneal opacities, traumatic injuries, and iris cysts. The imaging provided critical insights into anterior segment pathologies, facilitating accurate diagnoses and guiding treatment plans.

Conclusion: UBM enhances diagnostic accuracy and management of anterior segment disorders, allowing for detailed anatomical assessments that positively impact surgical outcomes. The findings of our research suggest that UBM could be standard practice for routine and complex cases, paving the way for advancements in personalized ophthalmic care.

Keywords: Ultrasound biomicroscopy, anterior segment pathologies, glaucoma, corneal opacity, iris cysts, ophthalmology, diagnostic imaging

1. Introduction

The human eye, a marvel of biological engineering, has a complex structure that requires precise tools for diagnosis and management of various ocular pathologies. The anterior segment of the eye, including the cornea, iris, ciliary body, and anterior chamber, is prone to a myriad of conditions such as glaucoma, trauma, and corneal opacities. Traditional diagnostic methods like slit-lamp examination and gonioscopy, although effective, may be limited in certain scenarios, particularly when dealing with opaque media or posterior structures hidden from view [1].

In this context, Ultrasound Biomicroscopy (UBM) emerges as a revolutionary tool. The introduction of UBM by Pavlin *et al.* [2] significantly advanced our understanding of the pathophysiology of anterior segment disorders. UBM is a high-frequency (35 - 50 MHz) ultrasound imaging technique that provides detailed, cross-sectional images of the anterior and posterior segments of the eye, up to an approximate depth of 4 mm [1]. Unlike optical coherence tomography (OCT), which mainly offers cross-sectional views of the anterior chamber, UBM allows for a longitudinal assessment, providing valuable insights into structures like the ciliary body, angle recess, and lens position [3].

This study aims to document the role of UBM in diagnosing anterior segment disorders, comparing its advantages with conventional diagnostic tools. We hypothesize that UBM offers a significant improvement in diagnosing conditions including, but not limited to, angle-closure glaucoma, corneal opacities, and iris cysts, thus aiding in better patient management and outcomes.

2. Materials and Methods

This was an observational, cross-sectional study conducted at a tertiary care centre in South Gujarat. The study spanned 15 months, including 12 months of data collection and 3 months of data analysis. Ethical approval was obtained from the Institutional Ethics Committee before commencing the study. The study evaluated 40 patients with anterior segment disorders, accounting for 55 eyes, between April 2022 to July 2024.

2.1 Inclusion criteria

- Patients aged 18 and above, of any gender, who provide consent for the study.
- Patients with opaque anterior segments for the detection of pupillary pathologies, dislocation or subluxation of the lens, cataract or post-cataract complications, and the integrity of the posterior capsule.
- Ocular trauma patients where visibility is obscured by the presence of hyphema, for the identification of angle recession, cyclodialysis, etc.
- Patients with foreign body injuries where clear direct visualization is not possible, to locate and identify the type of foreign body based on ultrasound echoes.
- Patients with clear media but suspected iris or ciliary body tumors, to determine the size and extent of the tumor.
- Patients with suspected angle closure, to demonstrate the cause of angle closure

2.2 Exclusion criteria

- Patients who do not provide consent.
- Patients under the age of 18.
- Uncooperative patients.
- Patients with cognitive impairments.
- Patients with active corneal infections.
- Patients with recent open globe injuries.
- Patients with severe dry eye.
- Patients in the early post-operative period following intraocular surgery.

2.3 Methodology

Each patient underwent a comprehensive ophthalmic examination, including slit-lamp examination, gonioscopy, and UBM. A detailed medical history, including chief complaints and prior imaging results, was recorded.

The UBM was conducted using the Appasamy UBM machine, operating at frequencies of 35 MHz and 50 MHz, depending on the required depth of imaging. Two different-sized silicone chambers were used for paediatric and adult populations. Topical anaesthesia with 0.5% paracaine eye drops was administered, and sterile water was used as the coupling medium. UBM images were captured with patient in supine position. Clock quadrants were scanned in the primary gaze position and by giving appropriate gaze positions without the probe contacting the cornea. Each patient's data and UBM findings were meticulously recorded. All data was systematically entered into an Excel spreadsheet for subsequent analysis.

3. Results

The current study investigated the efficacy of ophthalmic ultrasound biomicroscopy (UBM) in assessing anterior segment disorders and aiding in treatment planning. A total of 40 patients underwent UBM evaluations for 55 eyes.

3.1 Patient Demographics

We evaluated 40 patients aged 18 to 67 years. The mean age of the participants of our study was 47 years with majority being in the age group of 41 to 60 years.

3.2 Distribution of Cases: Among the 40 patients, UBM was conducted on 55 eyes, and the distribution of cases is shown in Table 1. Out of the eyes evaluated, 41.8% were attributed to angle closure glaucoma, while 23.6% were related to corneal opacity.

3.3 UBM Findings in Angle Closure Glaucoma

Among the 23 eyes diagnosed with angle closure glaucoma, evaluated by UBM, the most common observation was an increase in lens vault thickness or lens intumescence, noted in 69.5% of the eyes. Other findings included seclusio pupillae (13%), plateau iris (13%), and primary angle closure (4.3%).

3.4 UBM Findings in Corneal Opacity

UBM was done for 13 eyes with corneal opacity. Notably, 53.8% of eyes displayed abnormal segment anatomy, while 15.4% showed corneal opacity affecting only the anterior half of the stroma and 30.8% had opacity involving more than half of the stroma.

3.5 UBM Findings in Blunt Ocular Trauma

We evaluated 4 eyes from patients with blunt ocular trauma using UBM. One patient showed a widened ciliary body region with a dialysis cleft, another had a large posterior capsule defect with lens matter subluxation, one exhibited a partially absorbed cataract with adherence of the anterior and posterior lens capsules, and the fourth had an intraocular foreign body lodged in the lens with a localized cataract.

3.6 UBM Findings in Iris Cysts

We evaluated 2 eyes with iris cysts using UBM. One eye exhibited a hyperechoic cyst wall with hypoechoic uniform content at the peripheral zone of the anterior iris, while the other showed similar findings at the peripheral zone of the posterior iris.

3.7 UBM Findings in Limbal Swelling

We evaluated a patient with limbal swelling using UBM. The imaging revealed a cystic swelling with thin hyperechoic walls and heterogeneous hypoechoic and hyperechoic content, confirming the presence of a benign lesion.

3.8 UBM Findings in Pseudo exfoliation Syndrome

We evaluated 5 patients with pseudo exfoliation syndrome, examining 8 eyes using UBM. Two patients had open angles with no detectable anomalies. One patient showed a decreased angle recess area and central anterior chamber depth, but no other abnormalities. In two other patients, UBM revealed open angles with a heterogeneous, speculated appearance of the zonules.

3.9 UBM Findings in Monitoring IOL Position Post-Implantation

We evaluated 2 eyes from 2 patients using UBM to assess

intraocular lens (IOL) positioning post-implantation. In one patient, UBM confirmed that the intraocular collamer lens (ICL) was properly positioned in the ciliary sulcus without the haptic touching the iris during routine follow-up after refractive surgery. In the second patient, who had undergone cataract surgery with a posterior chamber IOL (PCIOL) and developed chronic macular edema, UBM showed that the IOL was correctly placed in the posterior capsular bag, with no contact between the haptic and the iris.

3.10 UBM Findings in Anterior Segment Anomaly: We performed UBM on a patient with a prominent Schwalbe's line observed during gonioscopy. The UBM revealed a hyperechoic dot on the inner corneal surface, confirming the anterior termination of Descemet's membrane and diagnosing posterior embryotoxon.

4. Discussion

Ultrasound biomicroscopy (UBM) has emerged as an indispensable imaging modality for the evaluation of anterior segment pathologies. Its capacity to generate high-resolution, cross-sectional images of the anterior segment structures makes it a valuable tool in both clinical diagnosis and surgical planning. The diverse range of applications for UBM, as highlighted in various studies, underscores its relevance in contemporary ophthalmology.

One of the most significant uses of UBM is in the diagnosis and management of glaucoma, particularly angle-closure glaucoma. Janet L. Alexander *et al*. (2021) pointed out that glaucoma is one of the most common indications for UBM. [4] The detailed visualization provided by UBM is crucial in identifying structural changes in the anterior chamber that contribute to increased intraocular pressure [1]. Studies by Barkana *et al*. (2007) and Kumar *et al*. (2008) further demonstrated that UBM is particularly useful in assessing iridotrabecular apposition in eyes with angle-closure glaucoma. Barkana *et al*. revealed that UBM detected iridotrabecular apposition in 94% of eyes under dark conditions, emphasizing the device's ability to visualize dynamic anatomical changes that may not be apparent in a regular clinical examination [5]. Kumar *et al*.'s findings on plateau iris in 32.3% of their patients additionally suggest that UBM is instrumental in detecting underlying anatomical variants that contribute to angle closure [6].

The mean age of the patients in our study was 47 years, with a wide variety of anterior segment pathologies evaluated using ultrasound biomicroscopy (UBM). The distribution of cases varied, with angle closure glaucoma being the most common, accounting for 41.8% of the cases, followed by corneal opacity, which was observed in 23.6% of the cases.

In 23 eyes diagnosed with angle closure glaucoma, UBM provided critical insights into the underlying anatomical changes. Of these eyes, 69.5% were found to have an increased lens vault thickness or lens intumescence, suggesting that lens-related mechanisms played a major role in the angle closure in these cases. Additionally, 13% of the eyes exhibited seclusio pupillae, a condition where the pupil is blocked due to posterior synechiae. Another 13% of the cases were identified as having plateau iris, where the peripheral iris is displaced forward due to a structural anomaly, and 4.3% of the eyes showed evidence of primary angle closure without any secondary mechanisms.

Beyond angle closure, UBM's utility in the evaluation of corneal abnormalities is also noteworthy. Corneal opacity and associated anterior segment pathologies pose a significant diagnostic challenge, and UBM provides valuable insights in such cases. Studies by Chen *et al*. (2020) [7] and Yangzes S. *et al*. (2024) [8] underscored UBM's role in evaluating patients with corneal opacity, with findings ranging from iridocorneal adhesions to lens subluxations and iris abnormalities. The ability to image deeper structures that are obscured by corneal opacity is a critical advantage, as it allows for more accurate diagnosis and targeted management. For example, Yangzes S. identified congenital anomalies such as Peters anomaly and coloboma, which would have been difficult to diagnose without the detailed structural information provided by UBM [8].

In our research, among the 13 eyes with corneal opacity, UBM revealed various degrees of anterior segment abnormalities. In 53.8% of these eyes, the UBM examination showed abnormal segment anatomy, which could be contributing to the visual impairment associated with corneal opacity. Additionally, 15.4% of these eyes exhibited opacity confined to the anterior half of the corneal stroma, while 30.8% showed more extensive involvement, with opacity affecting more than half of the stroma. This detailed imaging allowed for a better understanding of the extent of corneal damage and helped guide further management.

UBM is also a valuable diagnostic tool in cases of ocular trauma. Traumatic injuries often involve complex and subtle damage to the anterior segment that may not be readily visible through standard examination techniques. UBM's ability to visualize structures such as the ciliary body, zonules, and anterior chamber angle makes it particularly useful in these cases [1]. Park and Kondo (1998) demonstrated UBM's capability in diagnosing cyclodialysis clefts post-blunt trauma. The detailed imaging provided by UBM not only confirmed the diagnosis but also allowed for ongoing monitoring of the condition. [9] Similarly, Vaidehi Bhatt *et al*. (2021) utilized UBM to assess blunt trauma cases, revealing degrees of zonular stretching and tearing, which were critical for determining the appropriate management [10].

In 4 eyes that suffered from blunt ocular trauma, UBM proved to be an invaluable tool in detecting a range of traumatic injuries. The findings included a cyclodialysis cleft, which involves the separation of the ciliary body from the sclera, a posterior capsule defect, lens matter subluxation, and in one case, the presence of an intraocular foreign body. UBM's ability to visualize such detailed structural changes, even in cases where standard clinical exams may fall short, highlights its critical role in trauma evaluation and management.

In addition to trauma, UBM has demonstrated substantial utility in evaluating cysts and tumors of the anterior segment. Helin Ceren Köse *et al*. (2020) [11] and Marigo *et al*. (1998) [12] both emphasized the effectiveness of UBM in classifying iris cysts based on their structural characteristics. UBM allowed for the differentiation of cyst types based on their echogenicity and wall thickness, aiding in the accurate diagnosis and monitoring of these lesions. In fact, Marigo's study found that over 92% of anterior segment cysts were neuroepithelial, thin-walled, and echolucent, characteristics that UBM could clearly delineate [12].

Two eyes in our study were diagnosed with iris cysts, and UBM allowed for precise classification of these lesions. One

of the cysts was found to be an anterior pigment epithelial cyst, while the other was identified as a posterior pigment epithelial cyst. UBM's high-resolution imaging helped distinguish between different types of cysts, which is crucial for determining the appropriate course of treatment and follow-up. In a separate case involving a patient with limbal swelling, UBM revealed a cyst containing both hyperechoic and hypoechoic components, suggesting a mixed composition. This imaging finding led to a probable diagnosis of a benign lesion, which might have been difficult to confirm through external examination alone.

Pseudoexfoliation syndrome (XFS) is another condition where UBM has proven to be invaluable, especially in identifying early zonular changes. Inazumi *et al*. (2002) [13] and Ritch *et al*. (2007) [14] reported that UBM could detect granular zonules and speculated appearances in patients with XFS, which are not typically seen during slit-lamp examination. These findings are particularly important in understanding the progression of XFS and in making decisions regarding surgical interventions, as zonular instability increases the risk of complications during cataract surgery.

Among the 8 eyes diagnosed with pseudoexfoliation syndrome (XFS), UBM was instrumental in assessing the anterior chamber angles and zonular apparatus. In 5 of these cases, the UBM examination showed open angles, indicating that angle closure was not a concern in these patients. However, in 3 of the cases, decreased angle recess was observed, along with abnormalities in the zonules, suggesting the potential for zonular instability, a known complication of XFS, particularly during cataract surgery [15].

For pseudophakic patients, UBM is useful in evaluating the position and stability of intraocular lenses (IOLs). Sewelam *et al*. (2001) provided an extensive analysis of haptic positioning in pseudophakic eyes, where UBM was able to detect malpositioned IOLs, helping guide surgical revisions. [16] This is particularly critical in patients with post-operative complications, as accurate assessment of IOL position can impact visual outcomes [17].

In our study as well, UBM was performed to monitor intraocular lens (IOL) positioning in 2 patients. The detailed imaging allowed for precise visualization of the IOL haptics and their placement within the capsular bag, ensuring proper positioning and aiding in the assessment of any post-surgical complications.

Lastly, UBM's role in evaluating congenital anterior segment dysgenesis is well established. Quingdan Xu *et al*. (2023) demonstrated UBM's ability to visualize hyperechoic foci on the posterior corneal surface, confirming the diagnosis of posterior embryotoxon in patients with anterior segment anomalies [18]. The ability to diagnose such congenital conditions early can guide appropriate management and follow-up to prevent vision loss. In our study, UBM was utilized in a case involving posterior embryotoxon, a congenital anomaly characterized by an abnormal prominence of the Schwalbe's line on gonioscopy. UBM confirmed the diagnosis by revealing a hyperechoic dot corresponding to the abnormality observed during slit-lamp examination, providing further validation of the clinical findings.

While our study showcases UBM's effectiveness across a broad spectrum of anterior segment disorders, it is limited by a small sample size and a non-uniform distribution of cases, which may hinder the generalizability of our findings. Furthermore, the absence of quantitative data complicates the ability to assess prevalence or statistical significance, making broader conclusions challenging.

UBM is a versatile and powerful tool for diagnosing a wide range of anterior segment disorders, from glaucoma to congenital anomalies. Its high-resolution imaging capabilities allow for the detailed visualization of structures that are often inaccessible through other diagnostic methods. In our study, UBM proved to be an essential diagnostic tool, offering detailed anatomical insights across a wide range of anterior segment disorders.

Fig 1: A wide ciliary body band in traumatic angle recession.

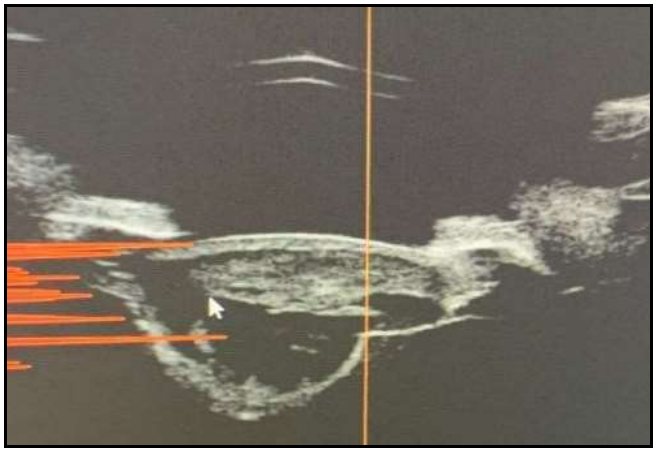

Fig 2: A large posterior capsular defect with prolapse of lens matter posteriorly.

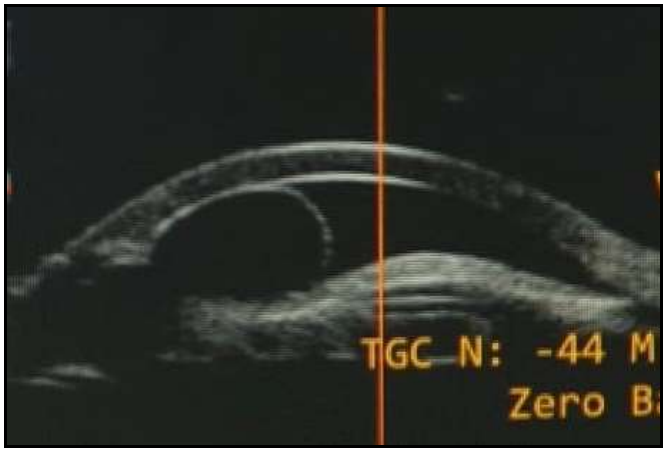

Fig 3: Anterior pigment epithelial cyst.

Fig 4: Posterior pigment epithelial cyst.

Fig 5: Limbal swelling (probably benign).

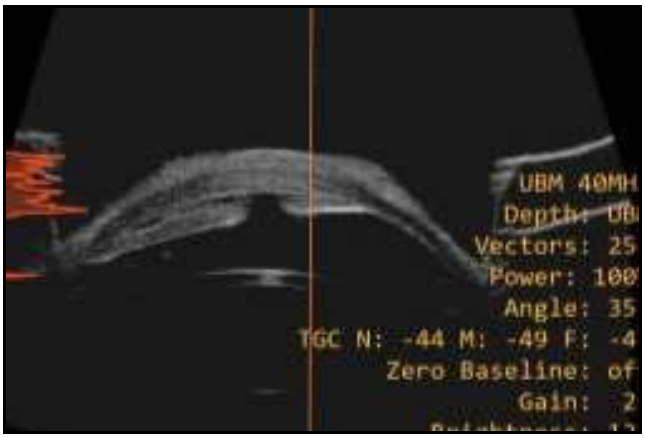

Fig 6: Anterior synechiae post perforated corneal ulcer

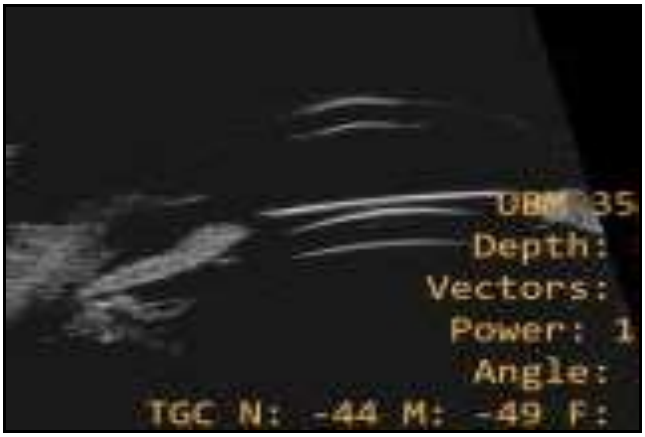

Fig 7: Implantable collamer lens

Table 1: Distribution of cases

Case	No. of eyes
Angle closure glaucoma	23
Corneal opacity	13
Pseudoexfoliation syndrome	8
Blunt ocular trauma	4
Limbal swelling	1
Iris cyst	2
Posterior embryotoxon	2
Evaluate IOL position	2
Total	55

5. Conclusion

In conclusion, UBM is an invaluable diagnostic tool for various conditions, including angle closure disease, corneal opacity, and iris cysts. UBM enabled critical assessments of anterior segment anatomy, such as measuring lens vault thickness, evaluating corneal opacity depth, and identifying the origins of iris cysts, thus facilitating informed surgical planning, particularly in complex cases like traumatic angle recession and limbal swelling.

Our research underscores UBM's transformative role in enhancing diagnostic accuracy and management of anterior segment disorders. Its capacity for detailed visualization promotes early detection and effective management, impacting surgical outcomes positively. The versatility of UBM suggests it could become standard practice for both routine and complex cases, paving the way for future innovations in imaging technologies and personalized ophthalmic care.

7. Acknowledgements

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8. Conflict of Interest:

None.

9. Financial Disclosure

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