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Use of a handheld ultrasound device for detecting orbital inflammation

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ABSTRACT

Purpose: Orbital inflammatory disease has been historically diagnosed with computed tomography (CT) and magnetic resonance imaging (MRI). Orbital ultrasound has served as a non-radiation alternative that has been successful at diagnosing many orbital pathologies but is not commonly used in clinical practice due to need for specialized ultrasound training and equipment needs. We demonstrate use of handheld ultrasound for detecting orbital inflammation.

Observations: We present five patients with orbital inflammation where a handheld ultrasound probe was able to capture features consistent with concurrent CT scans.

Conclusions and importance: Handheld ultrasound is an accessible and portable method that can assist in the diagnosis and monitoring of orbital pathology.

Orbital inflammatory disease (OID) is a spectrum of inflammation that includes conditions such as dacryoadenitis, myositis, cellulitis, optic perineuritis, periscleritis, orbital apicitis and focal mass.[1] OID accounts for 6 % of diseases involving the orbit and is the third most common orbital disease after Grave's orbitopathy and lymphoproliferative disease.[2] Though uncommon, OID can be associated with severe sequelae including vision loss, oculomotor dysfunction, cavernous sinus thrombosis, intracranial extension and even death.[3–5]

Generally, acute OID presents with proptosis, extraocular motility disturbance, pain, erythema and chemosis but radiographic imaging is critical in determining the involved structures.[6] Classically CT, MRI with fat suppression and diffusion-weighted imaging play a role in distinguishing OID from other orbit-involving pathologies.[1] However, these techniques are limited by availability, high cost, and radiation, thus frequent use or monitoring is a matter of caution, particularly for pediatric populations.[3]

In recent years, orbital sonography has emerged as a safe, non-invasive, and rapid alternative, making it feasible for bedside imaging. Limited previous work has demonstrated that ultrasound is able to identify echogenic fat, subperiosteal abscesses and orbital abscess consistent with diagnoses of orbital cellulitis in CT-confirmed cases.[7–9] Ultrasound has also been used to distinguish between pre-septal and post-septal orbital infection as well as localize orbital masses.[10,11] However, conventional cart-based ultrasound devices, particularly ophthalmic-specific ones, remain relatively cost-prohibitive, limiting their accessibility.

Here we present a case series of 5 eyes of 5 patients initially diagnosed with orbital cellulitis at Harborview Medical Center between April and June 2023 who were imaged with a handheld ultrasound device. The Butterfly iQ (Butterfly Network, Burlington, MA; Fig. 1) transducer-on-a-chip device is significantly more affordable than traditional devices. In the United States, this device has been used to characterize shunt and deep vein thromboses, assess articular and periarticular pathologies, evaluate for lung involvement in COVID-19, self-administer hemarthrosis imaging, measure carotid artery diameter and measure the lumbar multifidus muscle.[12–17] It has shown utility in low-access settings, including the military frontline and in rural east Africa.[14,18] The device is portable, lightweight, and can be directly connected to a smartphone or tablet, making it a promising tool for point of care ophthalmic imaging, particularly in resource-limited settings or for frequent monitoring in a pediatric population.

Our series aims to provide insight into the feasibility and accuracy of handheld ultrasound devices for orbital imaging. The adoption of handheld ultrasound devices in ophthalmology could potentially enhance real-time orbital evaluations and facilitate monitoring of orbital inflammatory conditions.

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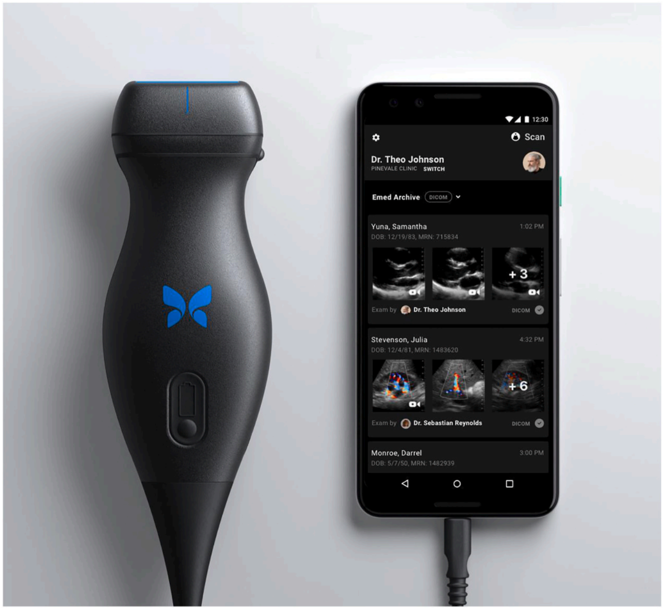

Fig. 1. Butterfly IQ + device with ultrasound probe and smartphone application. Image from Butterfly Network.

1. Case series

This research was approved by the University of Washington Institutional Review Board (STUDY00014817) and informed consent was obtained from all subjects. All patients with diagnoses of orbital inflammation between April and June 2023 at Harborview Medical Center were examined by a trained operator using a technique modified from Beam et al. 2021[19] to scan the bilateral orbits of participants in two planes at a fixed depth of 4 cm. The ophthalmic setting for the Butterfly IQ + probe was used for image acquisition, with I_{SPTA} of 44 mW/cm^2 and thermal index (TI) of 0.289. Dynamic video recordings of exams were stored in a secure HIPAA complaint cloud and each patient's clinical exam findings and ophthalmic diagnoses were recorded.

2. Case 1

A 67-year-old male patient with a history of right eye endogenous endophthalmitis treated with vitrectomy and retinal detachment developed worsening eye pain, edema and vision loss on post-operative day 2 at an outside hospital. He was treated with topical and intravenous (IV) antibiotics and referred to this hospital on post-operative day 5. Exam then was notable for light perception acuity, an elevated intraocular pressure, a relative afferent pupillary defect, complete visual field restriction, and diffusely restricted ductions in all gazes. Physical exam revealed moderate edema and erythema surrounding the orbit and there was concern for orbital cellulitis. Maxillofacial CT on admission demonstrated concern for cellulitis, posterior scleritis and possible subconjunctival abscess. Same-day handheld ultrasound imaging demonstrated both scleral thickening suggestive of scleritis and post-septal mixed hyper- and hypo-echoic tissue thickening suggestive of cellulitis (Fig. 2).

3. Case 2

A 24-year-old female presented with a 5-day history of headache and dull/throbbing pain in her right eye, which later progressed to pain with eye movements, periorbital swelling, and redness. She sought medical attention at an outside hospital and was initially treated with oral amoxicillin-clavulanic acid and trimethoprim/sulfamethoxazole and topical ofloxacin drops. However, her symptoms continued to progress.

On presentation, physical exam revealed moderate edema and erythema of the upper and lower lids, most tender over the lacrimal gland, and temporal chemosis. CT revealed a right-sided preseptal periorbital and postseptal orbital cellulitis, with a crescent-shaped fluid collection suggestive of an abscess. Handheld ultrasound was performed to demonstrate the same crescent shaped fluid along the posterior lateral aspect of the globe, consistent with abscess (Fig. 3). She was admitted for IV vancomycin treatment for 4 days and her condition improved with symptom resolution 7 days after admission.

4. Case 3

A 68-year-old female with a past ocular history of left punctal stenosis and recurrent sinusitis presented with 4 days of worsening left eye pain, redness, drainage and swelling treated with 2 days of amoxicillin without symptom improvement at outside hospital. Ocular exam was notable for an intraocular pressure of 26 mmHg and diffusely restricted ductions in all gazes in the left eye. External exam was notable for erythema of lower and upper lids extending to the maxillary region, edema and tenderness of the lids and 360-degree chemosis.

Maxillofacial CT demonstrated a peripherally enhancing fluid collection concerning for abscess in the inferomedial extraconal left

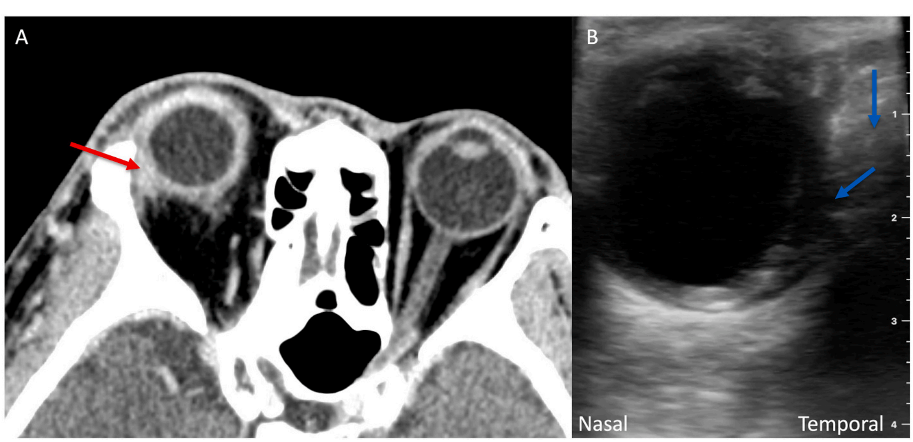

Fig. 2. Case 1 Maxillofacial CT (Image A) and corresponding handheld ultrasound image (Image B). CT scan demonstrates the periorbital enhancement and soft tissue swelling with post-septal changes (red arrow). There is also scleral thickening suggestive of scleritis and asymmetric proptosis. On the corresponding ultrasound scan, posterior lateral post-septal mixed hyper- and hypo-echoic tissue thickening (blue arrows) can be seen, also consistent with cellulitis. Additionally, scleral thickening can be faintly appreciated, and vitreous opacities can be seen which correlate with the patient's diagnosis of endogenous klebsiella endophthalmitis. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Fig. 3. Case 2 Maxillofacial CT (Image A) and corresponding handheld ultrasound image (Image B). CT demonstrates orbital cellulitis with a crescent-shaped fluid collection worrisome for abscess along the posterior lateral aspect of the right globe (red arrow). Ultrasound scan demonstrates hyperechoic intraconal tissue thickening seen between the optic nerve and lateral rectus (green arrow) as well as the clear crescent-shaped hypo-echoic mass along the posterior lateral aspect of the globe (blue arrows) most consistent with abscess. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

orbit extending to the lacrimal duct and extensive swelling in the medial extraconal left orbit resulting in proptosis of the left globe. She was started on topical Neomycin/Polymxin B/Dexamethasone ointment, IV antibiotics, and IV steroids. She was managed with an incision and drainage of the lacrimal duct on admission and orbitotomy and abscess drainage on day 1 of admission.

Patient felt subjectively better with reduced eye pain, but with persistent mild restriction in abduction with decreased visual acuity of 20/50 four days after incision and drainage. She was imaged with handheld ultrasound on day five, illustrating small persistent fluid collection. Repeat CT exam on the same day demonstrated improvement and decreased size in the medial extraconal non-walled off fluid collection. Corresponding ultrasound similarly demonstrated a medial hypoechoic area with scattered hyperechoic densities consistent with abscess (Fig. 4). Symptoms and exam continued to improve on antibiotics.

5. Case 4

A 33-year-old female with six days of right eye pain and four days of pain with eye movements, swelling around the eye and tearing presented to an outside hospital where she was admitted for 48 hours of IV antibiotic treatment and was discharged on oral antibiotics. A maxillofacial CT scan at this hospital was interpreted as a small rim-enhancing fluid collection associated with the right lateral rectus muscle suspicious for infection or orbital inflammation.

Her symptoms worsened and she developed new binocular diplopia after discharge. At presentation to the hospital, she was found to have a severe right eye abduction deficit. External exam revealed periorbital fullness, a slightly proptotic and inferiorly displaced globe, an enlarged and tender lacrimal gland and temporal chemosis. Repeat CT scan of the orbits revealed a decreased size of the possible fluid collection. Handheld ultrasound was performed with findings of a diffusely enlarged lateral rectus muscle with some internal scattered hyper-echogenicity without clear evidence of abscess (Fig. 5). MRI of the orbits demonstrated marked thickening and enhancement of the right lateral rectus muscle involving the tendinous insertion. Although initial concern had been for abscess due to CT findings, MRI and ultrasound found no evidence of abscess. She was initiated on IV steroids due to concern for noninfectious inflammatory etiology. Inflammatory workup included a chest x-ray and CT that demonstrated scattered bilateral granulomas and non-calcified scattered micronodules consistent with sarcoidosis. Her eye pain and diplopia improved within two days of initiating steroids and her symptoms remained stable after discontinuation of antibiotics.

6. Case 5

A 61-year-old male blew dust into his right eye with a shop vacuum

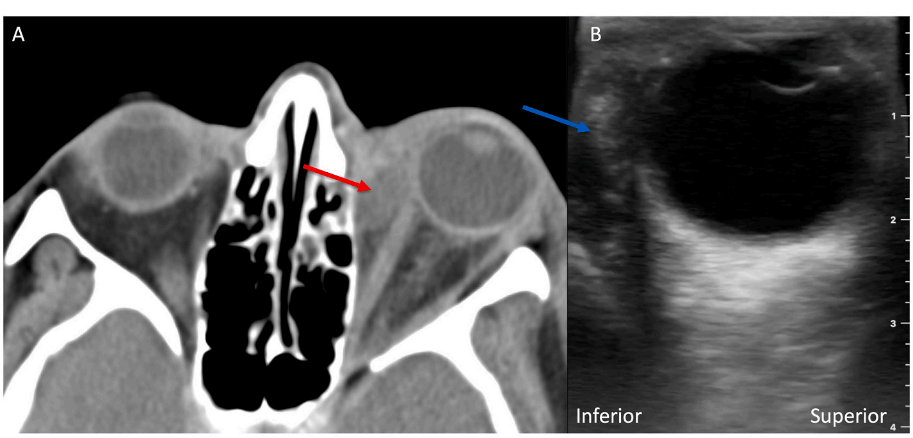

Fig. 4. Case 3 Repeat maxillofacial CT on day 5 of admission (Image A) and corresponding handheld ultrasound image (Image B). The CT demonstrates an orbital abscess, seen as a peripherally enhancing fluid collection (red arrow) in the inferomedial extraconal left orbit, extending to the nasolacrimal duct. On handheld ultrasound scan, this manifests again as a hypo-echoic area (blue arrow) with scattered hyper-echoic contents. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

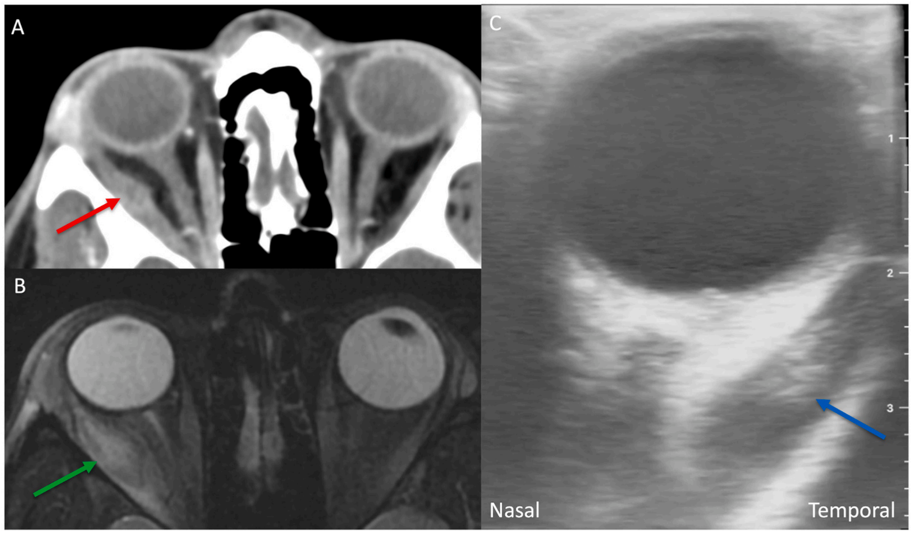

Fig. 5. Case 4 Maxillofacial CT (Image A), MRI orbits (Image B) and corresponding handheld ultrasound image (Image C). The CT scan was interpreted as a rim-enhancing fluid collection involving the right lateral rectus muscle representing likely abscess and adjacent retro-ocular fat stranding. MRI orbits with T2 fat suppression demonstrates marked thickening and enhancement of the right lateral rectus muscle without enhancing fluid collections or diffusion restriction. Some circular imaging artifact can be seen adjacent to the orbits in images A and B. Ultrasound demonstrates a diffusely enlarged lateral rectus muscle with some internal scattered hyper-echogenicity but no evident signs of abscess. Clinically, this patient had signs of unilateral extraocular inflammation without intraocular pathology.

and the eye became increasingly red, irritated, and swollen, followed by decreased visual acuity and pain with eye movements. He presented to multiple outside hospitals and was trialed on topical, oral, intramuscular, and intravenous antibiotics. CT at outside hospital demonstrated right periorbital cellulitis with a 12 mm phlegmon/abscess in the right orbital cavity. Ten days after symptom onset he was transferred to a tertiary care facility. External exam demonstrated moderate upper and lower lid edema with 2+ hemorrhagic chemosis. At that time, patient was only able to open his eye 2–3 mm with assistance. Repeat CT scan demonstrated substantial right periorbital cellulitis with right intra-orbital and extraconal cellulitis surrounding the medial and inferior rectus muscles, without definite intraconal extension, but with a developing 11 mm rim-enhancing fluid collection in the inferior medial post-septal intraorbital space, leading to proptosis of the right globe without obvious tethering of the optic nerve or tenting of the globe. He was continued on broad spectrum antibiotics.

After 2 days he noted improvement in eye pain and irritation. Repeat CT on day 4 of admission demonstrated improving phlegmon. Ultrasound was captured on day 5 of admission which demonstrated hypoechoic collection of fluid with internal hyperechoic contents consistent with CT findings (Fig. 6). On day 10 of admission, he was transitioned to oral antibiotics and discharged after improvement of symptoms.

7. Discussion

Ultrasound was first used in the eye by Mundt and Hughes in 1956 to identify intraocular tumors.[20] Diagnostic orbital sonography has grown considerably since then with Ossoinig pioneering a standardized ultrasonography method in 2001 that allowed detection of more than 60 orbital and periorbital conditions including globe motility disorders, lacrimal gland swelling, endocrine orbitopathy and muscle inflammation.[21,22] Despite advances in ophthalmic sonography machinery and techniques, application continues to be limited by cost and mobility-barriers, as ophthalmic-specific ultrasound technology can be is not always easily accessible in emergency department or clinic settings.[21] Hand-held ultrasound allows for noninvasive point of care imaging for diagnosis and monitoring by a clinician without radiation exposure or a lengthy MRI exam that may require sedation.

Here, we present five patients with orbital inflammation where the Butterfly iQ + handheld ultrasound probe was able to capture features consistent with concurrent CT or MRI scans and with previously reported ultrasonic orbital inflammation findings.[8,10] In case 4, handheld ultrasound was more sensitive than CT, demonstrating an enlarged rectus muscle where fluid collection was suspected on CT. Interestingly, this may indicate a diagnostic efficacy for handheld ultrasound that is more in line with MRI than with CT in that case.

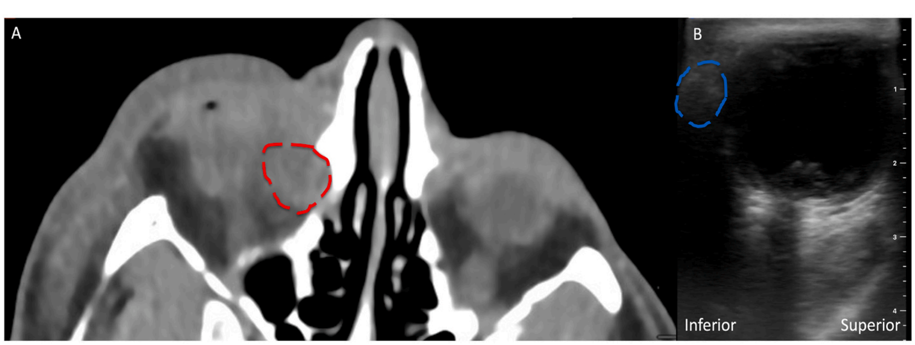

Fig. 6. Case 5 Maxillofacial CT (Image A) and corresponding handheld ultrasound image (Image B). Maxillofacial CT shows phlegmon/abscess in the right orbital cavity outlined in red. Ultrasound shows a hypoechoic collection with internal hyperechoic contents (blue outline) corresponding to abscess. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

The handheld ultrasound was an effective aid in identifying orbital inflammation, but the accuracy of any ultrasound device is dependent on the operator and reader's expertise. Unlike CT and MRI counterparts, the efficacy of handheld ultrasound is highly dependent on the training and skill of the operator. Ophthalmologists may not be as well-oriented to interpreting orbital ultrasound findings compared to ocular findings, and training is necessary for accurate diagnosis and monitoring of orbital disease. The Butterfly IQ probe was not specifically designed for orbital use and has a relatively large head compared to traditional B-scan. The large probe head may be limited to use in patients with normal to shallow orbits, as there may be difficulty achieving adequate contact with the eyelid when the probe is placed vertically for individuals with prominent brows and very deep orbits.

8. Conclusions

Despite these limitations, orbital sonography, especially with highly portable devices, offers valuable supplementary diagnostic information for orbital inflammation, and it may be particularly useful in identifying orbital abscesses. Moreover, the non-invasive, non-radiation nature of ultrasound makes it promising for serial scans and follow-up to monitor patients' response to treatment over time, especially in the pediatric population. Future work will aim to recruit additional patients, operators, and readers to validate the probe's diagnostic capabilities in orbital cellulitis and compare the effectiveness of handheld ultrasound devices to traditional ophthalmic ultrasound modalities. Additionally, the probe should be validated for other orbital pathologies to assess its broader capabilities.

Patient consent

The patients consented to publication of the case in writing.

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Authorship

All authors attest that they meet the current ICMJE criteria for Authorship.

CRediT authorship contribution statement

Aashka Damani: Writing – original draft, Methodology, Investigation. **Connor Nathe:** Writing – review & editing, Investigation, Data curation, Conceptualization. **Preston Thomas:** Writing – review & editing, Investigation, Data curation. **Alexa Van Brummen:** Writing – review & editing, Methodology, Investigation, Conceptualization. **Kasra Attaran Rezaei:** Writing – review & editing, Supervision, Funding acquisition. **Shu Feng:** Writing – review & editing, Writing – original draft, Supervision, Investigation.

Declaration of competing interest

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