Silicone oil emulsification: A literature review and role of widefield imaging and ultra-widefield imaging with navigated central and peripheral optical coherence tomography technology

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Abstract:

Silicone oil (SO) emulsification is a significant concern in vitreoretinal surgery, leading to various complications. Despite the high prevalence of SO emulsification within the eye, there is currently no standardized method for its early detection. The recent introduction of widefield (WF) imaging and ultra-WF (UWF) imaging with navigated central and peripheral optical coherence tomography (OCT) techniques have shown promising results in providing high-resolution images of the peripheral vitreous, vitreoretinal interface, retina, and choroid. This enhanced visualization capability enables the early identification of emulsified SO droplets, facilitating a proactive therapeutic approach, and mitigating associated adverse events. This comprehensive literature review aims to provide an updated overview of the topic, focusing on the role of WFimaging and UWF imaging and navigated central and peripheral swept-source OCT (SS-OCT) in the early detection and management of SO emulsification. The review discusses the current understanding of SO emulsification, its associated complications, and the limitations of existing detection methods. In addition, it highlights the potential of WF and UWF imaging and peripheral OCT as advanced imaging modalities for improved visualization of SO emulsification. This review serves as a valuable resource for clinicians and researchers, providing insights into the latest advancements in the field of vitreoretinal surgery and the promising role of WF imaging and UWF imaging and navigated central and peripheral SS-OCT in the management of SO.

Keywords:

Emulsification, navigated optical coherence tomography, optical coherence tomography, peripheral optical coherence tomography, retina imaging, retinal detachment, silicone oil, ultra-widefield, vitrectomy surgery, vitreous substitutes, widefield

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Introduction

Management strategies for vitreoretinal disorders have experienced significant improvements owing to the continuous advancements in imaging technology and the refinement of therapeutic options.[1-3] These advancements have significantly transformed the landscape of vitreoretinal surgical interventions, with the evolution of pars plana vitrectomy (PPV) playing a particularly pivotal role.[2,4,5]

However, PPV necessitates the intraoperative use of agents to fill the vitreous cavity as temporary tamponing ones or permanent vitreous substitutes.[6] Over time, a variety of vitreous substitutes have been developed and utilized during PPV, including balanced salt solution, air, gases, and silicone oil (SO).[6,7] Each of these substitutes possesses unique chemical and physical properties.[6] The diversity in available vitreous substitutes provides surgeons the flexibility to tailor the selection of the most appropriate intraocular tamponade based on the underlying condition, circumstances, and

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duration of tamponade required within the eye.[6] It is important to note that while each compound offers distinct advantages, they also may have specific disadvantages that can potentially lead to severe and irreversible adverse events.[6]

Although SO has a distinctive role given its capacity to serve as either a temporary or permanent vitreous replacement,[8,9] it has been more frequently associated with certain adverse events stemming from the well-known process of emulsification.[9] It has been demonstrated that the vast majority of SO emulsification cannot be detected by standard examinations such as slit-lamp biomicroscopy or gonioscopy, as the majority of emulsified SO droplets are <2 μm in diameter.[10] This presents a significant limitation in the detection and management of SO emulsification.

To address these challenges, researchers have undertaken investigations into a range of imaging modalities, each with varying levels of success in detecting SO emulsification.[10-18] Nevertheless, there is significant heterogeneity in study design, retrospective approach to data collection, lack of standardized inclusion criteria and imaging acquisition protocols, and inconsistent duration of follow-up, all of which are notable limitations that can potentially influence the outcomes and further complicate the interpretation of the results.[19]

In addition, the peripheral retina has been overlooked in these studies, due to a lack at the time of innovative imaging technologies such as widefield (WF) or ultra-WF (UWF) and navigated peripheral optical coherence tomography (OCT) imaging. Therefore, the standard approach so far used may suffer from inherent limitations, primarily due to a restricted field of view that potentially fails to detect smaller and peripheral emulsified SO droplets.

In response to these challenges, we have conducted a comprehensive review of the existing literature. Our objective is not only to consolidate the current knowledge regarding SO emulsification but also to identify limitations and areas where knowledge gaps exist, thus paving the way for future research in this field.

Moreover, we emphasize the significant potential of modern imaging techniques, such as WF, UWF, and navigated peripheral OCT imaging. By harnessing the expansive visual capabilities offered by UWF and WF imaging, in combination with the high-resolution cross-sectional imaging provided by OCT, a more comprehensive and precise examination of peripheral vitreoretinal involvement can be achieved. This innovative approach holds great promise in advancing our understanding of SO emulsification, thus significantly contributing to the field of vitreoretinal surgery.

Methods

This comprehensive review of the literature included the following databases: *PubMed*, *Web of Science*, *Scopus*, *Elsevier*, *Redalyc*, *Google Academic*, *SciElo,* and *Embase*. The search aimed to gather information to achieve a review about "Imaging Technology to Evaluate Silicone Oil Emulsification," covering literature from 1994, when SO was Food and Drug Administration (FDA) approved as a vitreous substitute, to January 2023.

Potentially relevant articles were sought using the search terms in combination with Medical Subject Headings (MeSH) terms and text words: "Retina Imaging," "Optical Coherence Tomography," "Silicone Oil," "Emulsification," "Widefield," and "Ultra widefield."

In addition to original research articles, we have also examined related reviews, commentaries, and discussions to gain a more comprehensive understanding of the topic.

To ensure that no relevant articles were overlooked, we also scrutinized the reference lists of all retrieved publications and supplemented our search with the "Related Articles" feature available on MEDLINE.

Language restrictions to English search were applied to ensure the quality and clarity of the information gathered. Following the identification of potential articles, we carefully reviewed the abstracts of each paper to ascertain their relevance and significance to our review. This meticulous approach ensured that our review was both comprehensive and focused, providing a thorough overview of the current state of knowledge on the use of imaging technology in evaluating SO emulsification and its complications.

Silicone Oil in Vitreoretinal Surgery

SO was first introduced as an internal vitreous substitute agent by Cibis *et al*. in 1962.[20] Initially, SO was injected into non-vitrectomized eyes to overcome tractional forces and assist in the dissection of preretinal membranes. Thereafter, this vitreous tamponade became widely used in PPV, especially for complicated cases of retinal detachment with or without proliferative vitreoretinopathy (PVR). The indications for the use of SO have extended to include the treatment of several and complex pathologies such as ocular trauma, giant retinal tears, proliferative diabetic retinopathy, viral retinitis, and endophthalmitis, among others.[6,8,9,21,22] Moreover, the unique properties of SO have made it the most popular choice for long-term vitreous replacement in challenging cases.

However, the use of SO has not been without controversy due to its potentially toxic retinal effects. This led many surgeons, particularly in the United States, to discontinue its use.[9] Despite these concerns, some surgeons demonstrated higher anatomic success rates and persevered using this compound in complex vitreoretinal disorders.[9]

The advent of other tamponade agents, such as short- and long-acting intraocular gases (SF_6 and C_3F_8, respectively), inevitably led to comparative studies. The most notable head-to-head comparison was the Silicone Study, first reported in 1992.[23-33] This research involved a series of randomized and controlled trials that compared the efficacy and safety of

SO with that of intraocular gases sulfur hexafluoride (SF_6) and perfluoropropane (C_3F_8) in the management of retinal detachments with PVR. Contrary to prevailing assumptions, the results demonstrated no significant differences and concluded that both SO and long-acting gases have their own advantages and disadvantages, without one being clearly superior to the others.[10,26-30]

Following these findings, the United States FDA approved the use of SO as an intraocular tamponade in 1994.[9] Nevertheless, its use and indications continue to be controversial and a topic of debate among vitreoretinal specialists, with SO being primarily considered for complex vitreoretinal cases such as RD with PVR, high-risk postoperative PVR, or in re-operations, including giant retinal tears, ocular trauma, uveitis and/or necrotizing retinitis, amongst others.[19] Additional indications such as persistent hypotony, primary repair of large macular hole, suprachoroidal hemorrhage, surgical management of choroidal melanoma, and toxic tumor syndrome have been described.[19]

The diverse applications underscore the versatility of SO in vitreoretinal surgery, despite the ongoing debates surrounding its use and its related complications such as emulsification.

A thorough understanding of the properties of SO is essential to reduce adverse events and assist in the development of other less toxic long-term tamponades.

Chemical and Physical Silicone Oil properties

Silicone oils are synthetic polymers composed of repetitive Si-O units, specifically referred to as polydimethylsiloxane (PDMS).[6,9,34] These oils exhibit a linear relationship between their molecular weight and the dynamic viscosity (η), wherein both parameters increase with the length of the PDMS chains.[34] It has been observed that higher viscosity is associated with increased resistance of SO to emulsification *in vitro*, but also with more difficulty intraoperative handling of the substance.[34]

Ensuring the purification of PDMS is also vital in obtaining a stable and non-toxic SO that minimizes adverse events.[6] Finding a solution to this remains an ongoing topic of research. The use of novel technology such as UWF imaging and navigated SS-OCT may help us to understand the pathophysiology of SO-related complications caused by different SO compound formulations.[6]

The physical properties of SO that hold significant importance include density (0.97 g/cm^3 at 25°C), surface tension (21.2–21.3 mN/m), interfacial tension with water (mN/m), dynamic viscosity (1000–5700 mPas), and refractive index (n = 1.4).[34,35] These unique properties, including any modifications resulting from emulsification, can influence both the acquisition and interpretation of fundus and OCT imaging results.

Of relevance, is the refractive index of SO which is similar to that of the vitreous (n = 1.34) and ensures minimal distortion during image acquisition.[36] SO offers improved retinal visualization compared to other vitreous substitutes such as gas.

Specific gravity and buoyancy are two properties that contribute to the floating nature of SO. Due to the low specific gravity, SO droplets tend to rise and accumulate in the upper regions of the retina.[37] This characteristic distribution can have implications for the imaging assessment of SO emulsification.

As both WF and UWF imaging provide a wide panoramic view of the retina, imaging a larger area beyond the conventional 30–50-degree field enables the visualization of upper peripheral regions where SO droplets may be more prevalent.[37,38] Navigated peripheral OCT complements UWF imaging by providing high-resolution cross-sectional imaging of those areas. The high interfacial tension and surface tension of SO can facilitate the creation of clear interfaces in OCT imaging which allow for accurate SO and retinal layer differentiation.

However, clinicians should be aware that SO can potentially create image registration artifacts in the observed retinal structures, mainly in the periphery. These factors should be taken into consideration when interpreting images obtained in the presence of SO.

Silicone Oil Emulsification

SO emulsification is a well-known complication characterized by the fragmentation of SO into small droplets, which can migrate and damage various ocular structures.[9,19,39]

Several studies have reported cases of emulsification occurring either during SO tamponade or after SO removal.[8,9,40,41] The onset of emulsification of SO *in vivo* has been reported with an average of 13.2 ± 4.8 months (ranging from 5 to 24 months).[9,19] Although the precise mechanism of emulsification is not completely understood, it is widely accepted that shear forces, such as saccadic eye movements, contribute to the separation of small droplets of SO from the main bubble, significantly shortening the time until emulsification occurs.[42,43] Certain factors, such as combined surgeries (phacoemulsification with PPV), incompletely filled vitreous cavities, use of perfluorocarbon liquids (PFLCs) in conjunction with SO resulting in turbulence at the interface between PFLC and SO, and longer axial length (more interface area between SO and intraocular fluid), are believed to increase the susceptibility for SO to emulsify.[10,40,44-47]

Emulsified SO droplets play a critical role in the pathogenesis of various complications associated with SO tamponade, including intraocular inflammation, keratopathy, glaucoma, or optic neuropathy, epiretinal membranes (ERM), and fibrosis.[9,19,48] Migration of emulsified SO is a significant concern, as these droplets have been detected in different extraocular locations, including the orbit, optic chiasm, and brain.[49-51] Intraocularly, SO is known to migrate to sclera and conjunctiva, forming cysts of emulsified SO accompanied by inflammatory infiltration over a period of approximately

4 months.[52] New imaging techniques such as anterior segment (AS)-OCT, UWF, and navigated SS-OCT may provide a better characterization of these adverse events, especially in the anterior chamber (AC) angle and the peripheral retina.

There is no doubt that an earlier and more accurate detection of SO emulsification is imperative to avoid these detrimental outcomes. Assessing SO emulsification poses considerable challenges and is likely to be underestimated when relying on routine clinical examinations, such as slit lamp biomicroscopy or gonioscopy.[53]

Sophisticated imaging methods including phase-contrast microscopy,[54] ultrasound biomicroscopy (UBM),[10] B-scan ultrasonography,[55] and the use of Coulter counters have been proposed to quantitatively assess SO emulsification.[56] However, there is no consensus on which method is the most reliable.[40]

The inconsistency among vitreoretinal surgeons regarding SO emulsification assessment prompted a study specially designed to address this challenging issue, the ITEMS study, which included imaging techniques such as UWF and posterior pole OCT imaging.[57]

However, the subsequent advent of new imaging technologies, such as simultaneous UWF imaging and navigated central and peripheral SS-OCT has opened new avenues in vitreoretinal diagnostics.[58] These new imaging techniques offer a more holistic view of the retina and enable clinicians to assess areas that were previously inaccessible, potentially leading to increased understanding of SO, its emulsification and related adverse events.[38,58,59]

Widefield and Ultra-widefield Imaging and Silicone Oil

For many decades, fundus photography has played a critical role in identifying, diagnosing, and managing retinal and choroidal conditions.[60] It has proven to be invaluable in documenting the progression over time of retinal lesions and response to treatment.[12]

Traditional fundus imaging provides a limited field of view that ranges from 30° to 50°.[60] This limitation becomes significant when aiming to assess pathological changes occurring in the peripheral retina.[38] Consequently, these abnormalities may be undiagnosed or underestimated using standard imaging technologies.

The evolving necessity for effective visualization of peripheral vitreous, vitreoretinal interface (VRI), and retina has sparked heightened interest among eye care professionals. In response to this increasing demand, UWF imaging techniques have emerged as essential everyday diagnostic imaging technologies providing a panoramic view of almost the entirety of the retina.

The terms WF and UWF imaging are often used interchangeably. However, as defined by an expert consensus, WF imaging refers to a single-capture (not montage) image centered on the fovea, which captures retinal anatomic features beyond the posterior pole but posterior to the vortex vein ampullas in all four quadrants. In contrast, UWF offers the ability to capture beyond this anatomical landmark in a single-capture image.[61]

Most of these devices, such as OptosSilverstone (Optos PLC, Dunfermline, Scotland, United Kingdom), operate based on the principle of scanning laser ophthalmoscopy and combine several UWF imaging methods, including red–green fundus imaging, fundus autofluorescence, fundus fluorescein and indocyanine green angiography and simultaneous navigated central and peripheral SS-OCT.[58] This multiwavelength and multimodal approach provides improved assessment and a better understanding of vitreous, VRI, retinal, and choroidal diseases, not only within the posterior pole but also of the peripheral retina.[58]

The utility of WF and UWF imaging to visualize the peripheral retina has been consistently demonstrated in several pathologies such as diabetic retinopathy,[62-66] retinal vein occlusion,[67-71] uveitis,[72-77] pediatric vitreoretinal disorders, and inherited retinal diseases, among others.[78,79]

As SO is the preferred tamponade for complex vitreoretinal diseases, improved visualization and assessment of the peripheral SO-retina interface and retina in these conditions may help to better understand when SO should be used.

The use of WF and UWF imaging has proven valuable in assessing postoperative cases of PPV with or without using SO tamponade.[80,81] These technologies enable the documentation and comparison of retinal findings over time, this being significant for the evaluation of response to treatment. Furthermore, WF and UWF imaging provide a more comprehensive assessment of postoperative complications such as hypotony (choroidal folds) and retinal re-detachments, determining the need of intervention.[80,82,83]

The presence of emulsified SO and its side effects have been extensively reported.[9,84,85] However, the existing literature has been focusing only on effects on the macula and optic nerve as most studies used standard (non-WF or UWF) imaging devices.[85,86] The use of new UWF devices may therefore play a pivotal role in identifying SO emulsification and its related complications, leading to new insights into how SO affects the peripheral retina.[58]

The optical properties of SO droplets make them appear as hyperreflective spots over the retinal surface, and Delhiwala *et al*. demonstrated the presence of large clusters of emulsified SO droplets using UWF imaging in a 22-year-old female, only 3-week following PPV with injection of 1300 centistokes (cs) SO. They also observed at 6 weeks a rapid increase in the number and size of clusters, as well as changes in their location, resembling an aerial view of "floating islands."[37]

Emulsified SO droplets merge into larger clusters and have been identified as a large SO bubble (LSOB) mimicking "islands on the global map"[37,87] [Figure 1]. Qualitative evaluation of SO emulsification was demonstrated by Hong *et al*. using UWF and OCT imaging.[88]

In the ITEMS study, there was an absolute consensus on the need to include dilated funduscopic examination and UWF fundus imaging as a complementary tool to detect the extent of SO microbubbles that can be seen as small "creamy bubbles" on the retinal surface and grade SO emulsion. All experts unanimously agreed on the feasibility of a topographic quantification system within three concentric zones: posterior pole (zone 1), the area between the outer edge of zone 1 and the posterior edge of the vortex vein ampulla (zone 2), and the area between the outer edge of zone 2 and the ora serrata (zone 3). The authors also proposed the quantification of SO emulsification based on the extent measured in clock hours, in zones 2 and 3. Furthermore, the number and size (the presence of LSOBs [>125 μm]) of emulsified microbubbles of SO floating in the vitreous cavity, specifically observed after the removal of SO (ROSO), were considered significant.[57]

However, large studies using UWF imaging for the detection of SO emulsification and its complications have not yet been performed and the importance of this imaging technology has only been demonstrated in small clinical case series.[37,87]

In addition, these devices' capacity to capture non-mydriatic WF and UWF images adds substantial value in clinical management, as these patients often undergo multiple surgeries which sometimes lead to inadequate pupil dilation due to both anterior and posterior synechiae. Rapid acquisition times are also advantageous for patients with poor fixation, providing improved visualization of the retina compared to biomicroscopy, or even under challenging circumstances such as in the presence of akeratoprosthesis.[89]

Optical Coherence Tomography and Silicone Oil

OCT, a widespread noninvasive low-coherence interferometry technique, has become an indispensable imaging tool in ophthalmology since its invention in 1991, yielding high-resolution *in vivo* images of the cortical vitreous, VRI, neuroretina, and choroid.[90]

The first generation of OCT was time domain (TD-OCT) based and, though a game changer was limited by a low speed (400 A-scans/second) and axial resolution (10–15 μm). The second generation of OCT was spectral domain (SD-OCT) based with improved image acquisition speed (20,000–70,000 A-scans/second) and axial resolution (3–5 μm).[91] The advent of swept-source OCT (SS-OCT), a derivative of SD-OCT, enabled even higher resolution (6–8 μm) and faster image acquisition speed (100,000 A-scans/second).[91,92]

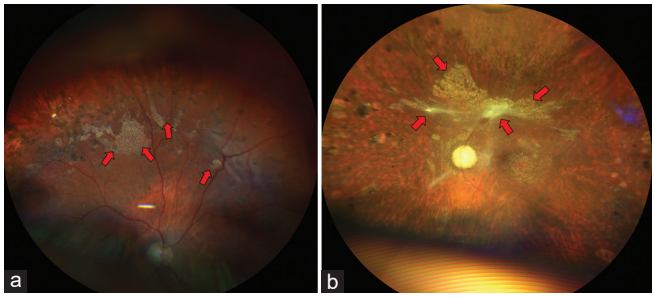

Figure 1: (a and b) Widefield image (Clarus, Carl Zeiss Meditech, Germany) showing clusters of emulsified SO droplets (red arrows), resembling an aerial view of "floating islands"

The feasibility of SS-OCT for the assessment of vitreoretinal diseases has been extensively demonstrated and is now routinely used by vitreoretinal surgeons in pre- and post-operative follow-up examinations.[93,94]

OCT can be used not only for qualitative but also for quantitative assessments in SO-filled eyes or after ROSO, for instance, the quantity of SO droplets may be calculated, facilitating quantitative comparative studies.

Anterior segment optical coherence tomography

AS-OCT is increasingly influencing clinical practice and is playing a key role in the clinical evaluation of the AS of the eye.[95]

AS-OCT can be used to detect the presence of emulsified SO in the AC, which is considered to play a critical role in SO-associated corneal complications.[95] As most SO droplets have a median size of <2 μm and cannot be detected by slit lamp,[13] AS-OCT may be helpful to detect smaller-size emulsified SO droplets that can pass through anatomical compromised areas into the AC.

AS-OCT may also be helpful to detect emulsified SO droplets adhering to the corneal endothelium and/or within corneal layers [Figure 2].[96] These droplets can lead to SO-keratopathy, such as band keratopathy or bullous keratopathy, which prevalence ranges from 7% to 29%.[97]

Moreover, SO droplets within the AC have also been associated with increased intraocular pressure and glaucoma.[57] Madanagopalan *et al*. demonstrated emulsified SO droplets in the Schlemm's canal using AS-OCT.[98] In addition, AS-OCT can provide a more comprehensive assessment of glaucoma in the presence of peripheral anterior synechiae.[99]

An important limitation of AS-OCT is its inability to visualize the ciliary body due to its limited penetration, whereas UBM provides better visualization of it.[100]

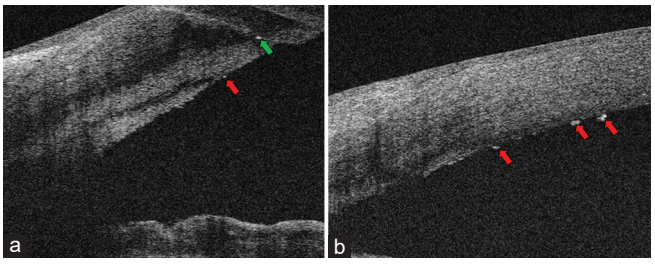

Figure 2: (a) Swept-source anterior segment optical coherence tomography (OCT) (DRI OCT Triton, Topcon Corporation, Japan) revealing emulsified SO droplets within the stroma (green arrow), as well as on the posterior surface of the cornea (red arrow). The presence of a discernible break in the corneal endothelium and Descemet's membrane has facilitated the infiltration of emulsified silicone oil (SO) into the deeper layers of the cornea. (b) Noteworthy on this image are the large emulsified SO droplets on the corneal endothelium (red arrows)

Posterior pole optical coherence tomography

OCT imaging provides high-resolution cross-sectional and three-dimensional images, regardless of the presence of SO within the vitreous cavity.[101,102]

The OCT identification of emulsified SO droplets within the vitreous cavity has been well documented. Chung and Spaide first observed intraretinal SO droplets using TD-OCT in a patient who underwent PPV surgery and temporary SO tamponade to repair a macular hole.[103] Errera *et al*. subsequently showed hyperreflective spherical bodies in ten of the 11 SO-filled eyes (90.91%) using SD-OCT.[17]

Purified and nonemulsified SO shows as hyporeflective on OCT scans,[104] whereas the reflectivity of the SO droplets is heterogeneous because of the different proportions within a given scan of emulsified SO droplets, fibrotic tissue, and inflammatory infiltrates, among others.[104]

Zewar and Lochhead classified oil droplets using OCT imaging as hetero geneicmacro droplets or bubbles (50–300 μm), which seem to occur and increase within the vitreous cavity with a longer duration of intraocular SO tamponade, and as hyperreflective spherical microdroplets or dots (<50 μm).[105]

Independent of their reflectivity and size, OCT imaging allows the identification of emulsified SO droplets in various locations, such as epiretinally, including beneath an ERM,[18] intraretinally (within the posterior border of retinectomies, ERM area, or intraretinal macular cystoid spaces), or subretinally (in the presence of a detached retina under SO) [Figure 3]. The deeper the penetration of SO into the retina, the more significant the disorganization of the latter.[17,105,106]

The prevalence of emulsified droplets in SO-filled eyes has not yet been established. However, the appearance of hyperreflective bubbles may be time dependent, as their incidence appears to increase with longer follow-up periods.[85] Although this supports the thought that chronic inflammation is involved in the development of SO emulsification, it remains unclear whether the hyperreflective dots within retinal layers represent migrated emulsified SO, especially in the presence of iatrogenic defects of the inner limiting membrane, or phagocytosed droplets emulsified SO [Figure 3]. Histopathologic studies have proposed that intraocular inflammation is the main factor of droplet development, as there is histopathological evidence of macrophagic infiltrates, fibrosis, and silicone vacuoles within the basement membrane in samples of peeled ERM.[104]

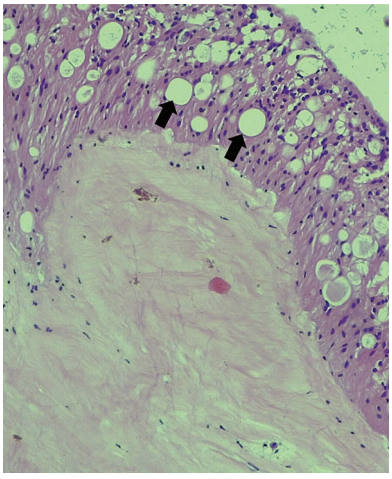

Figure 3: Human histopathologic specimen (hematoxylin and eosin staining) of disorganized retinal material obtained during an evisceration surgery and showing silicone oil vacuoles (black arrows) within the retina

Another finding is yellowish preretinal deposits which can be observed on OCT imaging as preretinal hyperreflective material, with or without underlying hyperreflective changes in the inner retina, have been described at the SO-retina interface of SO-filled eyes. The correlation of the preretinal hyperreflective material with the severity of preoperative PVR has been demonstrated.[104]

Early detection of SO emulsification plays an important role in visual prognosis. For instance, persistent preretinal droplets detected by OCT imaging have been statistically associated with microcystic macular changes, cystoid macular edema, and ERM [Figure 4].[107,108] In addition, these preretinal droplets may also be a source of intraretinal SO, whose presence is noteworthy because of potential vision-threatening effects. Nagpal *et al*. 2016 correlated the removal of hyperreflective SO droplets with an increase in best-corrected visual acuity and fewer related complications.[109]

Recent publications agree that SD-OCT and SS-OCT are capable of identifying SO emulsification. Macular OCT imaging to detect SO-associated hyperreflective dots was considered a mandatory investigation in the ITEMS study grading system. However, nonunanimous consensus was reached on the inclusion of OCT imaging of the optic disc, while navigated peripheral OCT was not evaluated.[57]

Navigated central and peripheral optical coherence tomography

Although several studies using standard central field OCT have detected the presence of SO near the posterior pole, they do not

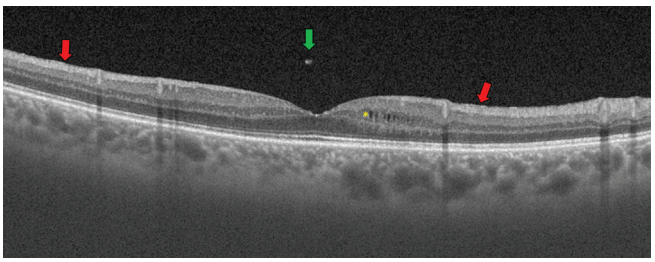

Figure 4: Posterior pole swept-source optical coherence tomography (OCT) (DRI OCT Triton, Topcon Corporation, Japan) scan showing a hyperreflective dot within the vitreous cavity and in front of the fovea, that corresponds with an emulsified silicone oil (SO) droplet (green arrow) having remained after the removal of the SO. Cystoid macular edema (yellow asterisk) and epiretinal membranes (red arrows) can also be observed

provide detailed information about the timing of emulsification and the peripheral retinal status.[17,18,108,110]

Hence, this lack of information can be addressed using WF-navigated central and peripheral OCT. Stanga *et al*. demonstrated that navigated cross-sectional WF SS-OCT scans provide detailed anatomical information of the mid and peripheral neuroretina and VRI.[111] Navigated OCT has demonstrated clear visualization of vitritis and contributed to assess the activity of inflammation in retinochoroiditis.[112] Moreover, navigated OCT can provide high-resolution cross-sectional images of the peripheral retina even in SO-filled eyes, facilitating the detection of emulsified SO droplets and its associated complications, such as peripheral ERM, gliosis, or retinal atrophy, among others [Figure 5]. This may be particularly beneficial in cases where emulsification occurs in its early stages and the droplets are not yet visible through standard posterior pole OCT examination.

Navigated peripheral OCT also offers a noninvasive and efficient method to objectively monitor patients' post-vitreoretinal surgical outcomes, measure retinal and choroidal thickness, as well as detect possible biomarkers of interest. Periodic imaging of the peripheral SO-retinal interface and retina may not only allow for the early detection of SO emulsification but also enable timely intervention, potentially preventing further complications.

However, as promising as peripheral OCT may be, it is important to acknowledge its limitations. Peripheral OCT provides high-quality and detailed images of the peripheral retina, but the resolution may not be as high as that of central field OCT images.

Optical coherence tomography angiography

OCT Angiography deserves a special brief mention as it uses the data collected using non-invasive OCT technology to provide anatomical information on vascular structures.[113,114] Despite the OCTA perhaps not yet being as clinically utilized on an everyday basis as conventional cross-sectional OCT, with careful interpretation and understanding, it is possible to obtain clinically useful information about pathogenesis, as well as disease progression and treatment response.[115,116]

The effect of SO on macular microstructure and vascular density has been extensively studied using OCTA.[117] Kubicka-Trzaska *et al*. showed that macular microcirculation significantly decreases after 1 month of SO tamponade.[118] Recent studies which compared superficial and deep retinal blood flow using OCTA, also observed that SO tamponade led to a higher decrease in both of them during the follow-up time.[119] However, perfused macular vessel density, foveal avascular zone, and choroidal flow areas did not seem to be affected by SO in some studies.[120]

While noninvasive, perhaps an important limitation of OCTA is that it only provides anatomical vascular information, whereas it does not provide functional one, such as leakage.[121] However, this need may be supplanted in the future by Doppler OCT.[122]

Limitations of Widefield, Ultra-widefield, and Navigated Peripheral Imaging Systems

Despite the aforementioned benefits, these technologies are not without limitations, such as the inability to capture the entire retina from ora-to-ora in a single acquisition, peripheral distortion, and registration artifacts.

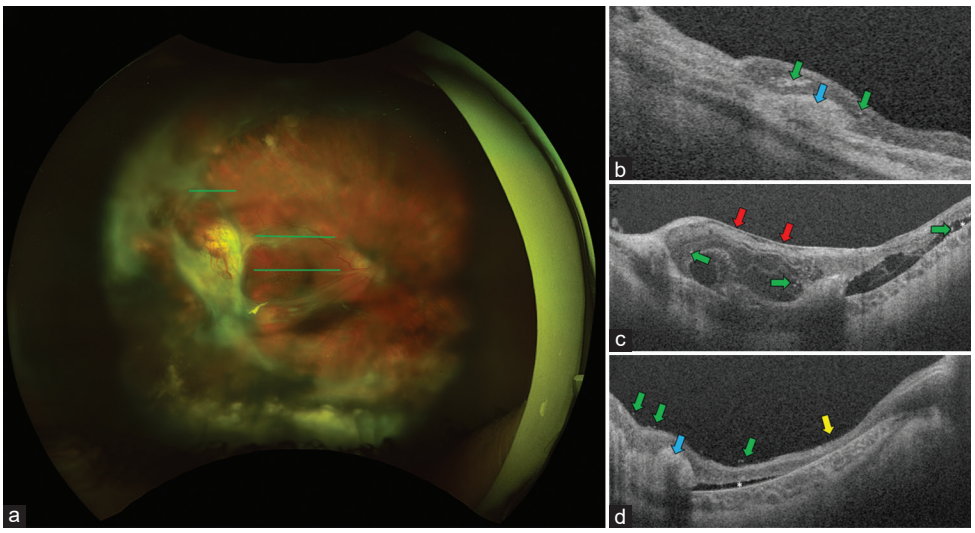

Figure 5: (a) Ultra-widefield pseudocolor imaging (Silverstone, Optos plc, UK) of an adult patient showing the postoperative retinal appearance under silicone oil (SO) after retinal detachment surgery as a late complication of retinopathy of prematurity treated at onset. (b) Navigated peripheral swept-source optical coherence tomography (SS-OCT) scan showing intraretinal SO droplets (green arrows) with disruption and gliosis of the outer retinal layers (blue arrow). (c) Navigated posterior pole SS-OCT scan of the superotemporal arcade area showing an epiretinal membrane (red arrows) and intraretinal emulsified SO droplets (green arrows). (d) Posterior pole SS-OCT scans showing pre-retinal SO emulsification (green arrows), gliosis (blue arrow), retinal thinning (yellow arrow), and persistence of subretinal fluid (SRF) (white asterisk)

Furthermore, patient factors such as media opacity can affect the quality of UWF images, potentially limiting their usefulness in some cases.

The use of UWF imaging technology with or without navigated OCT in SO-filled eyes presents additional difficulties. One major challenge is the interpretation of peripheral images, which requires specialized training.

The current high cost of UWF and navigated peripheral imaging equipment may also limit its accessibility.

Future Directions

The application of UWF imaging technology with navigated central and peripheral OCT in detecting and monitoring SO, its emulsification and related complications, is a new concept and a promising avenue for future research. Further research is also needed to establish its clinical benefit.

Several potential directions may be explored. For instance, studies could investigate the optimal timing and frequency of imaging of eyes tamponade with SO to establish biomarkers and timing of SO emulsification. Future studies should aim to determine the sensitivity and specificity of UWF imaging and peripheral OCT in detecting SO emulsification and to establish guidelines for its use in this context.

The use of a topographic quantification system and the identification of different SO bubble characteristics may provide a clearer understanding of the SO emulsification process.

The creation of automated algorithms based on artificial intelligence (AI) can potentially assist clinicians in the decision-making process, as well as in objective monitoring, thus optimizing treatment outcomes.

Conclusion

This review revealed significant limitations in the current understanding of SO emulsification process and detection methods, as well as heterogeneity in study design, retrospective data collection, and lack of standardized criteria and imaging protocols. This underscores the need for advances in imaging technology to improve the early detection and objective monitoring of SO emulsification.

UWF imaging, combiined with navigated central and peripheral OCT technology, has revolutionized the way we assess vitreoretinal diseases. This advanced may provide new insights into the understanding of the pathophysiological processes underlying SO emulsification.

The implementation of UWF imaging with navigated central and peripheral OCT technology in clinical practice can significantly contribute to improved patient care. These advanced imaging modalities offer enhanced visualization, enabling clinicians to make informed and objective decisions in the management of SO emulsification. The ability to promptly detect emulsified SO droplets will allow for timely therapeutic interventions with a reduction in associated adverse events.

In summary, the integration of UWF imaging with navigated central and peripheral OCT technology has the potential to revolutionize the detection and management of SO emulsification. By addressing the limitations of current detection methods and leveraging these advanced imaging techniques, clinicians will be able to improve outcomes in vitreoretinal surgery. To achieve this goal, future research and validation through prospective studies and clinical trials will further establish the utility of UWF imaging with navigated central and peripheral OCT technology in the management of SO emulsification.

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Conflicts of interest

There are no conflicts of interest.

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