Review Article

Intense Pulsed Light and Emerging Device Based Therapies for Dry Eye Disease: An Evidence Based Narrative Review

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Abstract

Intense pulsed light (IPL) has become an important device-based therapy for the management of evaporative dry eye disease that is associated with meibomian gland dysfunction (MGD). Unlike conventional medical treatment, which is largely directed toward symptomatic relief, IPL aims to restore meibomian gland function by targeting key mechanisms involved in disease pathophysiology. This review summarizes current evidence on IPL and other emerging device-based therapies used in ocular surface disease. A comprehensive search of PubMed, Medline, Scopus, Web of Science, Google scholar and other peer-reviewed literature was performed to identify studies evaluating the efficacy and safety of IPL, low-level light therapy (LLLT), radiofrequency (RF) therapy, and meibomian gland probing (MGP). Among the device-based modalities discussed in this review, IPL currently has the most extensive clinical evidence base, with studies reporting improvements in both subjective and objective measures, including meibomian gland function, tear break-up time, tear film stability, ocular surface staining and symptom assessment using validated questionnaires such as the ocular surface disease index (OSDI) and standard patient evaluation of eye dryness (SPEED). Other device-based interventions have also demonstrated clinical benefit, particularly in patients presenting with moderate-to-severe or treatment-resistant MGD, although differences in study design, treatment protocols, outcome measures, and duration of follow-up limit direct comparison among available modalities. Current evidence suggests that IPL represents a valuable supportive role in the management of evaporative dry eye, while complementary technologies expand therapeutic options and support individualized treatment strategies. Future multicenter randomized controlled trials long-term follow-up are required to establish comparative effectiveness, identify optimal patient selection, and determine the durability of treatment outcomes.

Keywords: Meibomian gland dysfunction, Dry eye disease, Tear breakup time, Low-level light therapy, Radiofrequency, Ocular surface disease, Intense pulsed light.

Introduction

Ocular surface disorders (OSDs), particularly dry eye disease (DED) and meibomian gland dysfunction (MGD), are common ophthalmic conditions that frequently impair visual comfort and reduce patient's quality of life.[1] These disorders are characterized by disturbance of tear film homeostasis, dysfunction of the meibomian glands, and chronic inflammation of the ocular surface.[2] As a result, affected individuals commonly experience symptoms such as foreign body sensation, irritation, fluctuating vision, burning, ocular dryness and visual fatigue. Conventional management typically consists of lubricating eye drops, eyelid hygiene, warm compresses, anti-inflammatory therapy, and, in selected cases, oral tetracyclines.[20,22] Although these measures provide symptomatic relief for many patients, a considerable proportion continue to have persistent symptoms because the underlying gland dysfunction is not adequately addressed. This limitation has encouraged the development and clinical use of device-based therapies aimed at enhancing meibomian gland function and restoring tear film stability. Among these,

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intense pulsed light (IPL) has gained widespread acceptance, particularly for the treatment of evaporative dry eye which is associated with MGD, owing to its ability to lessen periocular inflammation and enhance meibomian gland performance.[24,25] Other emerging technologies, including radiofrequency (RF) therapy, low-level light therapy (LLLT), and meibomian gland probing (MGP), have also shown promising therapeutic potential and are increasingly being incorporated into the management of patients with refractory disease.

Intense Pulsed Light (IPL)

Historical Background and Physics of Intense Pulsed Light

Intense pulsed light (IPL) was first introduced in dermatology for the treatment of vascular abnormalities, pigmented skin lesions, and cosmetic skin rejuvenation.[5] Its application in ophthalmology originated several years later after Rolando Toyos observed that patients undergoing facial IPL therapy for rosacea reported a noticeable reduction in dry eye symptoms.[3] This clinical observation prompted further investigation into the potential role of IPL in the management of meibomian gland dysfunction (MGD) and evaporative dry eye disease. Unlike conventional lasers, which emit a single coherent wavelength, IPL generates high-intensity, non-coherent light over a broad spectrum, typically ranging from 500 to 1200 nm.[5] The emitted wavelengths can be modified using optical cutoff filters to selectively target specific tissue chromophores, including oxyhemoglobin and melanin.[5] Through the process of selective photothermolysis, these chromophores absorb the light energy and convert it into heat.[4] The resulting thermal effect coagulates abnormal superficial blood vessels, reduces the release of inflammatory mediators, as well as improves meibomian gland function while minimizing damage to the surrounding healthy tissues.

Principle of Intense Pulsed Light

IPL is a non-invasive photothermal technology which employs xenon flash lamps to generate high-intensity, broad-spectrum light along with wavelengths typically ranging from 500 to 1200 nm.[5] Unlike laser systems, which emit coherent light at a single wavelength, IPL produces non-coherent, polychromatic light that can be modified using cutoff filters to match the optical properties of different target tissues. Its therapeutic action relies on the principle of selective photothermolysis, whereby endogenous chromophores primarily oxyhemoglobin and melanin, preferentially absorb the delivered light energy and convert it into heat. This localized thermal effect causes selective coagulation of abnormal telangiectatic vessels while minimizing injury to adjacent healthy tissues. In addition to reducing abnormal vascularization and inflammation, the generated heat promotes improved meibomian gland secretion and function, thereby enhancing tear film stability and making IPL an effective therapeutic option for evaporative dry eye resulting from meibomian gland dysfunction.

Mechanism of Action

IPL acts through several complementary mechanisms rather than a single therapeutic pathway See Figure 1.

Liquefaction of Meibum

One of the primary therapeutic effects of IPL is the generation of heat within the eyelid tissues, raising the local eyelid temperature into the approximately 40 to 42°C range, which is relevant to the phase-transition behavior of meibum.[30] This thermal effect reduces the viscosity of the inspissated gland secretions, allowing them to flow more freely through the meibomian gland ducts and improving gland patency.[25,30] Restoration of normal meibum outflow enhances both the quality and expressibility of gland secretions, reduces ductal obstruction, and contributes to the formation of a more stable lipid layer over the tear film, thereby enhancing tear film stability.

Photocoagulation of Telangiectatic Blood Vessels

In patients with ocular rosacea and chronic meibomian gland dysfunction (MGD), dilated superficial blood vessels contribute to persistent eyelid inflammation by serving as a source of pro-inflammatory mediators. IPL selectively targets these vessels because oxyhemoglobin preferentially absorbs the emitted light energy. The absorbed energy is converted into heat, resulting in photocoagulation and closure of abnormal vasculature. By reducing these inflammatory vascular networks. IPL decreases vascular permeability, suppresses the release of inflammatory cytokines, lowers matrix metalloproteinase (MMP) activity, and ultimately alleviates inflammation of the eyelid margin, creating a healthier environment for meibomian gland function.

Reduction of Ocular Surface Inflammation

Beyond its vascular effects, IPL exerts a significant anti-inflammatory action over the ocular surface. IPL has been proposed to exert anti-inflammatory effects through modulation of inflammatory mediators.[14] Suppression of these cytokines helps break the self-perpetuating inflammatory process associated with meibomian gland dysfunction and evaporative dry eye. Consequently, tear film stability is improved, ocular surface inflammation is reduced, and healing of the corneal as well as conjunctival epithelial tissues is enhanced.

Demodex Eradication

Infestation with demodex mites has been involved in the pathogenesis of chronic blepharitis and obstructive meibomian gland dysfunction. IPL-generated heat is believed to decrease both the number of mites and their eggs while simultaneously reducing the bacterial colonization associated with these parasites. This combined antiparasitic and antimicrobial effect leads to diminished cylindrical dandruff, lower bacterial lipase production, and improved eyelid hygiene, thereby contributing to better meibomian gland function and ocular surface health.[9]

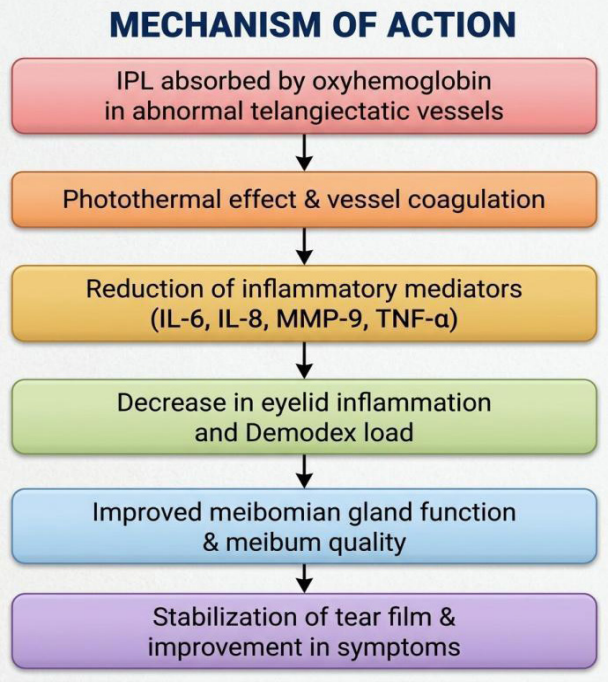

Figure 1: Proposed mechanism of action of Intense Pulsed Light (IPL) therapy in meibomian gland dysfunction and evaporative dry eye disease

Photobiomodulation

A proposed photobiomodulatory mechanism suggests that light exposure may influence mito-chondrial cytochrome c oxidase activity, potentially increasing ATP production and modulating cellular responses,[10,14] These effects have been proposed as one possible mechanism by which IPL may influence cellular function, although direct evidence in MGD remains limited.

Neuromodulation

A proposed neuromodulatory mechanism of IPL involves modulation of corneal sensory nerve activity. Clinical improvement in ocular pain has been reported following IPL treatment, although the underlying mechanism remains uncertain.[11]

Indications

- ***Primary indications***

Evaporative dry eye associated with MGD, particularly in patients with ocular rosacea or obstructive meibomian gland dysfunction,[14,25,27]

- Evaporative dry eye associated with MGD
- Obstructive MGD
- Ocular rosacea.
- Posterior blepharitis

- ***Potential secondary applications***

Refractory MGD, demodex-associated blepharitis, and selected patients with mixed-mechanism dry eye.[9,14,25]

Preoperative ocular surface optimization should not be considered a universal indication on the basis of the current reference set.

Patient Selection

Patients with mild-to-moderate evaporative dry eye associated with MGD, particularly those with persistent symptoms despite conventional therapy, may be considered for IPL.[21,25,27]

Mild-to-moderate evaporative dry eye associated with MGD

- Persistent symptoms despite conventional therapy.
- Ocular rosacea in appropriate patients.
- Meibography findings considered during treatment planning.

Poor candidates include

- Severe aqueous deficiency alone.
- Extensive meibomian gland atrophy.
- Active ocular infection.
- Very dark skin types depending on device.

Meibography in IPL

Infrared meibography is a valuable imaging modality used to assess the structural status of the meibomian glands before and after IPL therapy.[12] It enables assessment of the extent of meibomian gland dropout and may assist in treatment planning and longitudinal assessment. Serial imaging during follow-up allows clinicians to monitor structural changes and correlate them with clinical improvement. Since IPL mainly enhances gland function rather than regenerating atrophic glands, meibography can be useful for documenting treatment response and assessing gland morphology over time[12,25] (Figure 2).

Treatment Protocol

Although treatment protocols differ among studies and devices, commonly studied IPL regimens consist of three to four treatment sessions performed at intervals of approximately 2 to 4 weeks.[13,25] During each session, appropriate ocular protection is used, and coupling gel may be applied to the periocular skin according to the device protocol.See Figure 3 IPL pulses are delivered to the periocular region, followed in

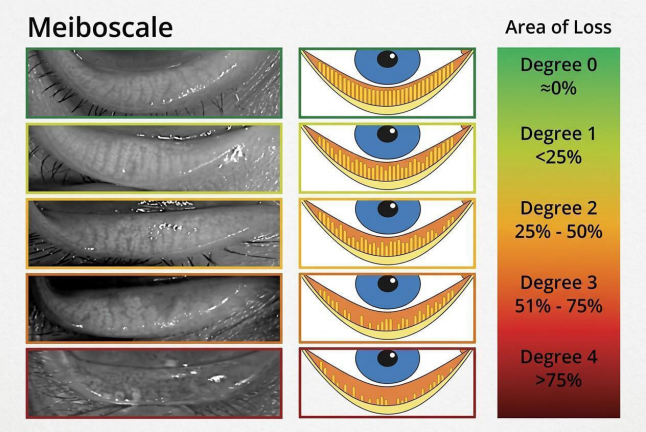

Figure 2: Meiboscale



Figure 3: Schematic illustration of the standard intense pulsed light (IPL) treatment procedure and lid massage for meibomian gland dysfunction, adapted from published treatment protocols.[13,23]



Figure 4: Common IPL devices

some protocols by meibomian gland expression.[13,23] Session duration and maintenance schedules vary among studies and devices; therefore, maintenance treatment at intervals of 6 to 12 months should be regarded as a possible clinical approach rather than a universal protocol.[25]

Advantages

- Non-invasive
- Outpatient procedure
- Short treatment duration
- Minimal discomfort
- Simultaneously treats ocular rosacea
- Reduces inflammation
- Improves meibomian gland function
- Can be combined with gland expression
- May provide sustained symptom improvement in some patients
- May reduce the need for symptomatic treatment in some patients

The advantages of IPL reported across the literature include its non-invasive nature, outpatient delivery, compatibility with gland expression, and potential for sustained symptom improvement in some patients.[21,25,27]

Contraindications

Contraindications and precautions are device dependent and should be checked against the manufacturer's instructions for use.[16]

- Active skin infection
- Active herpes simplex infection
- Skin malignancy over the treatment area
- Photosensitivity disorders
- Recent tanning or use of photosensitizing medications
- Fitzpatrick skin type V-VI, depending on the device and treatment parameters

Complications

Adverse events are uncommon and generally mild. Reported complications include:

- Transient erythema
- Mild edema
- Temporary discomfort
- Hyperpigmentation
- Superficial skin burns
- Blister formation (rare)
- Corneal injury if protective eye shields are not used properly

Reported adverse events are generally transient and mild, although safety depends on appropriate patient selection, treatment parameters, and ocular protection.[16,17,25,27]

Clinical Evidence

Clinical evidence from observational studies, randomized controlled trials, and systematic reviews supports the use of intense pulsed light (IPL) therapy for evaporative dry eye associated with meibomian gland dysfunction (MGD). IPL has been shown to improve both patient-reported symptoms and objective clinical parameters, particularly when combined with meibomian gland expression. Reported benefits include reductions in ocular surface disease index (OSDI) scores, improved tear breakup time (TBUT), meibomian gland expressibility and meibum quality, increased lipid layer thick ness, reduced corneal fluorescein staining, and improvement in standard patient evaluation of eye dryness (SPEED) scores.[6,7,13,15,21,24,27] Despite variations in treatment protocols, the available evidence supports IPL as an effective adjunctive therapy for MGD-related evaporative dry eye. The major clinical outcomes are summarized in Table 1.

Common IPL devices

Refer Table 2, See Figure 4

Emerging Techniques

Automated thermodynamic treatment systems have been investigated for the treatment of obstructive meibomian gland dysfunction, with controlled heating and mechanical forces used to facilitate meibum expression and improve gland function.[18]

Table 1: Summary of major clinical studies evaluating intense pulsed light therapy for meibomian gland dysfunction and dry eye disease

Author (Year)	*Study design*	*Study population*	*Intervention*	*Outcome measures*	*Major findings*
Toyos *et al.*[3] (2015)	Retrospective clinical study	Patients with ocular rosacea and evaporative dry eye	IPL	Dry eye symptoms, TBUT, patient satisfaction	Patients treated with IPL experienced noticeable relief from dry eye symptoms, particularly those with ocular rosacea. These early observations introduced IPL as a promising treatment for meibomian gland dysfunction.
Craig *et al.*[6] (2015)	Prospective, randomized, doublemasked, placebo controlled, paired-eye study	Patients with meibomian gland dysfunction	IPL	TBUT, lipid layer thickness, symptom scores	IPL improved tear film stability, increased tear break-up time and lipid layer thickness, and reduced dry eye symptoms, indicating better overall ocular surface health.
Arita *et al.*[8] (2019)	Prospective randomized controlled study	Patients with refractory meibomian gland dysfunction	IPL + Meibomian gland expression	TBUT, OSDI, meibomian gland function	Combining IPL with meibomian gland expression produced better outcomes than gland expression alone, with improvements in gland function, meibum quality, tear stability, ocular surface condition, and patient symptoms.
Liu *et al.*[15] (2020)	Meta-analysis	Multiple clinical studies	IPL	TBUT, OSDI, tear film stability	The meta-analysis found improvement in selected objective tear-film parameters, although evidence for subjective symptom improvement was less consistent and study heterogeneity limited direct comparison.
Peira *et al.*[21] (2025)	Systematic review and meta-analysis	13 randomized trials	IPL ± adjunctive therapies	OSDI and dry-eye symptoms	The systematic review and meta-analysis of 13 randomized studies found that IPL probably produces a clinically relevant reduction in dry-eye symptoms compared with placebo; the clinical relevance of its add-on benefit to standard care remains uncertain.

Low-Level Light Therapy (LLLT)

- *Principle*

low-level light therapy (LLLT) is a non-invasive photobiomodulation therapy that delivers low intensity red and near-infrared light (600 to 1000 nm) to enhance cellular function through photochemical mechanisms without causing thermal tissue damage. Unlike IPL, which achieves its therapeutic effects through the generation of heat, LLLT relies predominantly on photochemical mechanisms. The absorbed light energy interacts with intracellular chromophores, initiating cellular signaling pathways that enhance physiological function rather than producing a photothermal response.

- *Mechanism*

LLLT exerts its biological effects by stimulating mitochondrial cytochrome C oxidase, an enzyme involved in cellular respiration.[10] Activation of this enzyme increases ATP synthesis and enhances cellular metabolism, providing the energy required for tissue repair and regeneration. Furthermore, LLLT helps maintain cellular homeostasis by reducing oxidative stress and regulating inflammatory cytokine activity. These combined effects decrease chronic inflammation and contribute to improved meibomian gland function.

- *Procedure*

During LLLT, low-intensity light is delivered through a specialized mask or protective eyewear while the patient keeps the eyelids gently closed. Individual treatment sessions generally require 10 to 20 minutes, with treatment frequency and number of sessions varying among published protocols.[28] Because LLLT primarily enhances cellular function rather than mechanically relieving gland obstruction, it may be used as a standalone treatment; evidence supporting combination with IPL or meibomian gland expression remains limited.

- *Advantages*

The favorable safety profile of LLLT makes it an attractive option for the management of meibomian gland dysfunction and evaporative dry eye. The procedure is non-invasive and does not generate significant heat, reducing the risk of thermal injury. Clinical studies have reported benefit when LLLT is used as a standalone treatment, although evidence for combination therapy remains limited.[28]

- *Limitations*

Despite its potential therapeutic benefits, the clinical application of LLLT remains limited by the relatively small body of available evidence compared with IPL. In addition, various treatment parameters like wavelength, energy density, session duration, and treatment frequency have not yet been standardized across published studies. The widespread adoption of LLLT is also constrained by the high cost of the equipment and its limited availability, particularly outside specialized tertiary eye care centers.

Table 2: Comparison of advanced device-based therapies for meibomian gland dysfunction. Compiled by the authors based on published literature

Feature	OptiLIGHTR	Eye-lightR
Manufacturer	Lumenis	Espansione Group
Technology	Intense Pulsed Light (IPL) with OPT™[16]	IPL + Low-Level Light Therapy (LLLT)
Mechanism of Action	Reduces periocular inflammation and telangiectasia, decreases Demodex load, liquefies meibum, and improves meibomian gland function.	IPL reduces inflammation and abnormal vessels, while LLLT enhances cellular metabolism and meibomian gland activity.
Primary Indication	Evaporative dry eye due to MGD	Moderate-to-severe MGD and refractory evaporative dry eye
Treatment Protocol	Four treatment sessions at interval of 2–4 week intervals	Three to four IPL sessions with or without adjunctive LLLT
Advantages	FDA-approved IPL for dry eye secondary to MGD; device-specific indications and precautions are described in the manufacturer's instructions for use.[16]	Combines IPL with photobiomodulation, targeting multiple mechanisms involved in MGD.
Limitations	Requires multiple treatment sessions; efficacy may vary according to Fitzpatrick skin type and devicespecific treatment parameters.[16,25]	Limited long-term comparative clinical evidence.
Major Clinical Evidence	Randomized and multicenter clinical studies have reported improvements in OSDI, TBUT, and meibomian-gland-related outcomes.[17,26]	Prospective clinical studies have reported improvement in symptoms, TBUT, and gland function; however, larger randomized controlled trials are required.

Abbreviations: IPL = Intense Pulsed Light; OPT™ = Optimal Pulse Technology; LLLT = Low-Level Light Therapy; MGD = Meibomian Gland Dysfunction; OSDI = Ocular Surface Disease Index; TBUT = Tear Break-Up Time

- ***Clinical evidence***

Early clinical evidence suggests that LLLT may improve selected subjective and objective parameters in dry eye disease, although results across individual outcomes have been inconsistent.[28] The available evidence remains limited by small study populations, variable treatment parameters, and short follow-up periods. Evidence supporting routine combination of LLLT with IPL or meibomian gland expression remains limited, highlighting the need for larger multicenter randomized controlled trials.

- ***Future role***

LLLT may represent a potential adjunctive therapy for selected patients with meibomian gland dysfunction and evaporative dry eye, particularly as part of a multimodal treatment strategy.[28] Future research is needed to develop standardized treatment guidelines, define optimal patient selection criteria, evaluate combination therapies, and confirm long-term outcomes in well-designed randomized controlled trials.

Radiofrequency (RF) Therapy

Radiofrequency (RF) therapy is a non-invasive treatment modality that delivers controlled electromagnetic energy to the eyelids, producing localized therapeutic heating. The generated heat may facilitate meibomian gland secretion and reduce periocular inflammation. Some RF systems may also produce tissue-remodeling effects. Treatment parameters, including the number and duration of sessions and whether meibomian gland expression is performed, vary among devices and studies.

Clinical studies evaluating RF in combination with IPL and meibomian gland expression have reported improvements in patient-reported symptoms and selected ocular-surface and meibomian-gland measures.[29] Although these findings are encouraging, the evidence supporting RF therapy remains less extensive than that available for IPL.

Meibomian Gland Probing (MGP)

Meibomian gland probing (MGP) is a minimally invasive therapeutic approach used to restore the patency of obstructed meibomian gland ducts by mechanically relieving intraductal obstruction.[19] The procedure is performed under topical anesthesia using fine stainless-steel probes that are gently introduced through the natural gland orifices. Mechanical release of fibrotic constrictions improves ductal patency, facilitates the drainage of retained meibum, and reduces intraductal pressure. Consequently, MGP may be particularly useful in selected patients with obstructive or treatment-resistant meibomian gland dysfunction.[19]

Although the procedure requires technical expertise and may be associated with transient discomfort during or shortly after treatment, clinical studies, including those conducted by Steven L. Maskin and colleagues, have reported symptomatic improvement in patients with obstructive MGD.[19] MGP may be incorporated into multimodal treatment strategies alongside thermal therapies, although evidence for such combinations remains limited.

Future Directions

Future management of meibomian gland dysfunction (MGD) and evaporative dry eye disease (DED) is likely to focus on personalized, mechanism-based treatment rather than a uniform therapeutic approach. Advances in diagnostic

technologies, including artificial intelligence-assisted meibography, tear film biomarkers, and objective ocular surface assessment, may improve disease characterization and enable more targeted selection of device based therapies. Although intense pulsed light (IPL) currently has the most extensive clinical evidence base among the device based modalities discussed in this review.[21,25,27] Additional multicenter randomized controlled trials are required to standardize treatment protocols, compare different devices, evaluate long-term efficacy, and assess cost-effectiveness. Combination strategies incorporating IPL, radiofrequency (RF) therapy, low-level light therapy (LLLT), and meibomian gland probing (MGP) alongside conventional medical treatment may provide greater benefits, particularly in patients with moderate-to-severe or refractory MGD. Improving affordability, accessibility, and the development of indigenous technologies will be important for expanding the use of these therapies, especially in developing countries.

Conclusion

Meibomian gland dysfunction is a major cause of evaporative dry eye disease and requires treatment strategies that address both symptoms and the underlying pathophysiological changes.[1,2] Device-based therapies have broadened the therapeutic options available by targeting meibomian gland obstruction, ocular surface inflammation, and tear film instability. Among the device based modalities discussed in this review, Intense Pulsed Light (IPL) has the most extensive clinical evidence base.[21,25,27] Other modalities, including radiofrequency (RF) therapy, low-level light therapy (LLLT), and meibomian gland probing (MGP), have also shown encouraging clinical outcomes, although the supporting evidence remains comparatively limited because of variations in study design, treatment protocols, and follow-up duration. At present, most device-based therapies are best considered as adjuncts to conventional medical management, with treatment selection guided by disease severity, gland status, and individual patient characteristics. [20,21,25,27]

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