Clinical Optometry

Dovepress
open access to scientific and medical research

Open Access Full Text Article

REVIEW

Eyelid Warming Devices: Safety, Efficacy, and Place in Therapy

Brandon Bzovey[1], William Ngo[2,3]

[1]Centre for Ocular Research & Education, School of Optometry & Vision Science University of Waterloo, Waterloo, Ontario, Canada; [2]School of Optometry & Vision Science, University of Waterloo, Waterloo, Ontario, Canada; [3]Centre for Eye and Vision Research (CEVR), Hong Kong, People's Republic of China

Correspondence: William Ngo, School of Optometry & Vision Science, University of Waterloo, Waterloo, ON, N2L 3G1, Canada, Tel +519-888-4567 x 40857, Email wngo@uwaterloo.ca

Abstract: Meibomian gland dysfunction (MGD) is characterized by the obstruction and/or inflammation of the meibomian glands that result in decreased and altered meibum secretion. This results in deficiencies in the tear film lipid layer which contributes to increased evaporation and destabilization of the tear film. One of the mainstay therapies for MGD is medical devices that apply heat and/or pressure to the eyelids and promote the liquification and outflow of meibum into the tear film. Over the past two decades, there have been a surge of interest in diagnosing and managing MGD. As a result, numerous medical devices have been developed and each have their own unique approach to treating MGD. This narrative review was conducted to summarize the current state of knowledge on eyelid warming devices, specifically warm eye coverings, devices that direct heat and/or pressure to the eyelids, moisture chamber goggles, and light-based therapy. This review summarized 58 human clinical studies and found that most eyelid warming devices were efficacious in improving signs and symptoms in a wide range of MGD severities and were generally safe to use.

Keywords: dry eye, meibomian gland dysfunction, warm compresses, thermal pulsation, moisture chamber goggles, intense pulsed light

Introduction

Defined by The Tear Film and Ocular Surface Dry Eye Workshop II (TFOS DEWS II),

> Dry eye is a multifactorial disease of the ocular surface characterized by a loss of homeostasis of the tear film, and accompanied by ocular symptoms, in which tear film instability and hyperosmolarity, ocular surface inflammation and damage, and neurosensory abnormalities play etiological roles.[1]

Meibomian gland dysfunction (MGD) is the most common cause of dry eye disease[2] and is defined by The International Workshop on Meibomian Gland Dysfunction as

> … a chronic, diffuse abnormality of the meibomian glands, commonly characterized by terminal duct obstruction and/or qualitative/quantitative changes in the glandular secretion. It may result in alteration of the tear film, symptoms of eye irritation, clinically apparent inflammation, and ocular surface disease.[3]

In a recent report, MGD was recognized by the Osmoprotection in Dry Eye disease – Expert Opinion (OCEAN) group as six separate conditions; primary obstructive keratinization of the meibomian gland, abnormal meibomian gland secretion, eyelid inflammation, corneal and conjunctival inflammation and epithelial damage, microbiological changes, and DED.[4]

The clinical assessment of MGD involves quantifying symptoms, assessing the quality of meibum, examining the lid features and gland drop out, and examining tear film stability.[3] The ocular symptoms are typically burning, stinging, itching, irritation, light sensitivity and fluctuating blurred vision,[5] all of which could negatively impact quality of life and requires significant effort to manage.[6] The main outcomes are improved symptoms, meibomian gland function, and tear film stability.[7]

Received: 17 May 2022
Accepted: 28 July 2022
Published: 5 August 2022

The treatment of MGD involves heating the eyelids to improve meibomian gland function. Warm compresses (WC) are considered the first line of treatment for MGD.[7,8] The temperature required to soften or liquify pathological meibum is >40°C,[7] whereas the melting point for normal meibum is approximately 34.0°C.[9] While face cloths and towels are frequent recommendations for treating MGD in clinical care, Blackie et al (n = 32) showed that towels or cloths rapidly lose heat[10] and took approximately 6 minutes for the inner eyelid to reach a therapeutic temperature of 40.4 ± 0.3°C. This finding was corroborated by Bitton et al[11] and Lacroix et al,[12] who also demonstrated the rapid cooling of towel compresses. It was only by using the labour intensive "Bundle method" described in Murakami et al,[13] where multiple towels are rolled into each other, could towels retain a sufficiently elevated temperature ≥40°C.[13] However, it is important to note that temperatures above 45°C may increase the risk for thermal injury to the eye or eyelids.[14,15] A common side-effect experienced after heat and pressure from WC treatment is a transient visual blur from changes in the structure of the corneal epithelium. The transient phenomenon is known as the polygonal reflex of Fischer-Schweitzer.[16,17]

To address the deficiencies of cloth or towel warm compresses, numerous medical devices have been developed to treat MGD by maximizing heat retention and delivery to the eyelids while improving patient and practitioner convenience. Broadly, these medical devices consist of warm eye coverings, automated, or manually operated devices that deliver heat and/or pressure to the eyelids, moisture chamber goggles, and light-based therapies. This review aims to summarize the peer-reviewed literature on these eyelid warming devices along with their efficacy, safety, and place in therapy.

Materials and Methods

An informal search on PubMed was repeatedly conducted using a combination of terms "dry eye", "meibomian gland dysfunction", "warm compresses", "efficacy", "thermal pulsation", "intense pulsed light", "radiofrequency", and "moisture goggles", "low level light", "quantum molecular resonance", with the last search occurring on April 27th, 2022. The search was limited to human clinical studies with no limit on publication year. A study was discarded if it did not assess clinical efficacy of treatments, were not accessible, or were not full-length research articles. The studies were sorted into five types of treatment categories: heated eye coverings, moisture chamber goggles, devices that deliver heat and pressure, intense pulsed light (IPL), and others. For each category, a brief description of the nature of the treatment is discussed, along with a summary of their clinical efficacy and adverse events associated with the use of the treatment.

Review

A total of 58 studies were deemed eligible for this review. Since some studies had examined multiple treatment types, these studies were duplicated across the different treatment modalities, giving a total of 62 studies.

There was large variability in clinical testing and reporting of study outcomes. Therefore, to provide an informative yet readable overview on clinical efficacy against MGD, we collapsed the clinical outcomes into three categories:

1. Improved symptoms, where participants demonstrated a statistically significant improvement in any symptom assessment metric, eg, Ocular Surface Disease Index, Standard Patient Evaluation of Eye Dry, visual analogue scores, or other surveys.
2. Improved tear stability, where participants demonstrated a statistically significant improvement in non-invasive or invasive tear breakup time.
3. Improved meibomian gland function, where participants demonstrated a statistically significant improvement in meibomian gland obstruction, meibum quality, expressibility, meibography, and lid margin features.

The clinical outcomes of each study were examined and labeled with one or more of these categories. A lack of a category assignment indicates that the study either did not use those metrics or that there were no statistically significant treatment effects related to those categories.

The distribution of the studies and a summary of their clinical efficacy across the different devices are summarized in Table 1. A comprehensive list of the studies reviewed is detailed in Tables 2–5.

Table 1 Number of Studies per Treatment Modality

Treatment	Number of Studies	Clinical Improvement[a]
Heated eye coverings	9	S: 7/9 (78%)
		T: 5/9 (56%)
		M: 4/9 (44%)
Moisture chamber	13	S: 8/13 (62%)
		T: 6/13 (46%)
		M: 1/13 (8%)
Devices that deliver a combination of heat and pressure	20	S: 19/20 (95%)
		T: 17/20 (85%)
		M: 19/20 (95%)
Intense pulsed light	23	S: 22/23 (96%)
		T: 20/23 (87%)
		M: 20/23 (87%)
Low level light therapy	1	S: 0/1 (0%)
		T: 0/1 (0%)
		M: 1/1 (100%)
Quantum molecular resonance	1	S: 1/1 (100%)
		T: 1/1 (100%)
		M: 1/1 (100%)
Total	62	S: 52/62 (84%)
		T: 44/62 (71%)
		M: 41/62 (66%)

Notes: Symptoms = as assessed with symptom questionnaires or visual analogue scales, tear stability = invasive or non-invasive tear breakup time, Meibomian gland function = meibum quality, expressibility, lid margins, or meibography.
Abbreviations: [a]S, improved symptoms; T, improved tear stability; M, improved meibomian gland function.

Heated Eye Coverings

Heated eye coverings are typically employed as the first line of treatment for MGD.[7] They typically come in the form of a small sack or pouch containing seeds or beads that become warm when heated in the microwave oven. Alternatively, they may generate heat through a controlled chemical reaction.[18] Generally, they have the capability to hold a therapeutic temperature longer than towels.[11,12] Of the 9 studies reviewed (Table 2); 78% (7/9) reported improvement in symptoms,[19–25] 56% (5/9) reported improvement in tear stability,[19–21,25,26] and 44% (4/9) reported improvement in meibomian gland function.[18,20,21,23] Only 2 studies reported adverse events,[18,21] which were primarily related to discomfort using the devices.

Heated eye coverings are categorized under Stage 1 in the TFOS DEWS II staged management strategy,[2] which are treatments intended for mild MGD. The advantages of heated eye coverings are that they are relatively affordable and accessible; however, they require daily use and adherence to therapy to maintain treatment efficacy. It was reported that only 55% of patients are compliant with warm compresses and lid hygiene after six weeks of use.[27]

Table 2 Summary Heated Eye Coverings for the Treatment of MGD

Device	Paper	N	Clinical Outcomes That Were Improved[a]	Adverse Events Related to Treatment
Towel Hot Eye Mask Memoto Este Azuki no Chikara Eye Hot R	Arita et al 2015. Effects of Eyelid Warming Devices on Tear Film Parameters in Normal Subjects and Patients with Meibomian Gland Dysfunction.[20]	10	Improved symptoms Improved tear stability Improved meibomian gland function	Not reported
MGDRx EyeBag	Jeon et al 2021. Comparison of the efficacy of eyelid warming masks and artificial tears for dry eye symptoms in contact lens wearers.[22]	78	Improved symptoms	Not reported
EyeGiene	Sim et al 2014. A Randomized, Controlled Treatment Trial of Eyelid-Warming Therapies in Meibomian Gland Dysfunction.[18]	65	Improved meibomian gland function	Minor discomfort using EyeGiene
MGDRx EyeBag	Bilkhu et al 2014. Randomized masked clinical trial of the MGDRx EyeBag for the treatment of meibomian gland dysfunction-relate evaporative dry eye.[21]	25	Improved symptoms Improved tear stability Improved meibomian gland function	Transient stinging when heated EyeBag was placed on the upper eyelid
MGDRx EyeBag	Ngo et al 2019. An Eyelid Warming Device for the Management of Meibomian Gland Dysfunction.[24]	25	Improved symptoms	Not reported
Disposable eyelid warming steamer with menthol and without menthol	Arita et al 2017. Effects of Warm compress containing menthol on tear film in healthy subjects and dry eye patients.[19]	55	Improved symptoms Improved tear stability	No adverse events
TheraPearl	Olafsson et al 2021. TheraPearl Eye Mask and Blephasteam for the treatment of meibomian gland dysfunction: a randomized, comparative clinical trial.[25]	70	Improved symptoms Improved tear stability	Not reported
MGDRx OPTASE	Murphy et al 2020. The Efficacy of Warm Compresses in the Treatment of Meibomian Gland Dysfunction and Demodex Folliculorum Blepharitis.[23]	42	Improved symptoms Improved meibomian gland function	Not reported
MGDRx EyeBag	Turnbull et al 2018. Comparison of treatment effect across varying severities of meibomian gland dropout.[26]	81	Improved tear stability	Not reported

Notes: [a]Meibomian gland function = meibum quality, expressibility, lid margins, or meibography, tear stability = invasive or non-invasive tear breakup time, symptoms = as assessed with symptom questionnaires or visual analogue scale.

Moisture Chamber Goggles

Moisture chamber goggles function by producing moist heat in an enclosed goggle system that warms the eyelids and meibomian glands. A total of 13 studies (Table 3) have examined its efficacy in treating MGD, which found improved symptoms, improved tear stability, and improved meibomian gland function in 62% (8/13),[18,25,28–33] 46%

Table 3 Summary of Moisture Chamber Goggles for the Treatment of MGD

Device	Paper	N	Clinical Outcomes that Were Improved[a]	Adverse Events Related to Treatment
Blephasteam	Benitez del Castillo et al 2014. Evaluation of the efficacy, safety and acceptability of an eyelid warming device for the treatment of MGD.[28]	73	Improved symptoms	No adverse events
Custom device	Matsumoto et al 2006. Efficacy of a New Warm Moist Air Device on Tear Functions of Patients with Simple Meibomian Gland Dysfunction.[30]	35	Improved symptoms Improved tear stability	Not reported
Custom device	Spiteri et al 2007. Tear lipid layer thickness and ocular comfort with novel device in dry eye patients with and without Sjögren's syndrome.[32]	26	Improved symptoms	No adverse events
Custom device	Mitra et al 2005. Tear film lipid layer thickness and ocular comfort after meibomian therapy via latent heat with novel device in normal subjects.[92]	24	No improved symptoms, tear stability, or meibomian gland metrics	No adverse events
Blephasteam	Pult et al 2012. A Comparison of an Eyelid-Warming Device to Traditional Compress Therapy.[35]	20	No improved symptoms, tear stability, or meibomian gland metrics	Not reported
Blephasteam	Purslow et al 2013. Evaluation of the ocular tolerance of a novel eyelid-warming device used for meibomian gland dysfunction.[93]	25	No improved symptoms, tear stability, or meibomian gland metrics	No adverse events
Custom device + ATs	Ren et al 2018. Short-term effect of a developed warming moist chamber goggle for video display terminal-associated dry eye.[31]	22	Improved symptoms Improved tear stability	No adverse events
Blephasteam	Turnbull et al 2018. Comparison of treatment effect across varying severities of meibomian gland dropout.[26]	81	Improved tear stability	Not reported
Prototype	Wang et al 2020. Therapeutic profile of a latent heat eyelid warming device with temperature setting variation.[34]	15	Improved tear stability	No adverse events
Blephasteam + Optrex spray	Bilkhu et al 2021. Provocation of the ocular surface to investigate the evaporative pathophysiology of dry eye disease.[29]	40	Improved symptoms	Not reported
Blephasteam	Villani et al 2015. Evaluation of a novel eyelid-warming device in meibomian gland dysfunction unresponsive to traditional warm compress treatment: an in vivo confocal study.[33]	50	Improved symptoms Improved tear stability	No adverse events
Blephasteam	Sim et al 2014. A Randomized, Controlled Treatment Trial of Eyelid-Warming Therapies in Meibomian Gland Dysfunction.[18]	65	Improved symptoms Improved meibomian gland function	Minor discomfort using EyeGiene
Blephasteam	Olafsson et al 2021. TheraPearl Eye Mask and Blephasteam for the treatment of meibomian gland dysfunction: a randomized, comparative clinical trial.[25]	70	Improved symptoms Improved tear stability	Not reported

Notes: [a]Meibomian gland function = meibum quality, expressibility, lid margins, or meibography, tear stability = invasive or non-invasive tear breakup time, symptoms = as assessed with symptom questionnaires or visual analogue scale.

(6/13),[25,26,30,31,33,34] and 8% (1/13) of studies,[18] respectively. There were no adverse events reported with the use of moisture chamber goggles. Of the studies reviewed, the most common device encountered was the Blephasteam, making up 8 of the studies in this section.

Table 4 Summary of Devices That Deliver Heat and/or Pressure for the Treatment of MGD

Device	Paper	N	Clinical Outcomes That Were Improved[a]	Adverse Events Related to Treatment
LipiFlow	Greiner. 2012. A single LipiFlow thermal Pulsation System treatment improves meibomian gland function and reduces dry eye symptoms for 9 months.[45]	21	Improved symptoms Improved tear stability Improved meibomian gland function	No adverse events
iLux LipiFlow	Tauber et al 2020. Comparison of the iLUX and the LipiFlow for the Treatment of Meibomian Gland Dysfunction and Symptoms: A Randomized Clinical Trial.[38]	142	Improved symptoms Improved tear stability Improved meibomian gland function	iLux: some participants felt it was too hot. Petechial hemorrhage in lower palpebral conjunctiva. Corneal staining/reduced VA. LipiFlow: none
iLux	Schanzlin et al 2022. Efficacy of the Systane iLux Thermal Pulsation System for the Treatment of Meibomian Gland Dysfunction After 1 Week and 1 Month: A Prospective Study.[52]	30	Improved symptoms Improved tear stability Improved meibomian gland function	No adverse events
MiBoFlo LipiFlow	Li et al 2021. Effect of a Novel Thermostatic Device on Meibomian Gland Dysfunction: A Randomized Controlled Trial in Chinese Patients.[50]	54	Improved symptoms Improved meibomian gland function	No adverse events
LipiFlow	Zhao et al 2016. Clinical Trial of Thermal pulsation (LipiFlow) in Meibomian Gland Dysfunction with Pre-treatment Meibography.[53]	46	Improved symptoms Improved tear stability Improved meibomian gland function	No adverse events
LipiFlow	Blackie et al 2016. The sustained effect (12 months) of a single-dose vectored thermal pulsation procedure for meibomian gland dysfunction and evaporative dry eye.[43]	200	Improved symptoms Improved meibomian gland function	Eyelid/discomfort/pain/dermatitis
TearCare	Badawi et al 2019. TearCare system extension study: evaluation of the safety, effectiveness, and durability through 12 months of a second TearCare treatment on subjects with dry eye disease.[40]	12	Improved symptoms Improved tear stability Improved meibomian gland function	No adverse events
TearCare	Badawi et al 2018. A novel system, TearCare, for the treatment of the signs and symptoms of dry eye disease.[39]	24	Improved symptoms Improved tear stability Improved meibomian gland function	No adverse events
TearCare LipiFlow	Gupta et al 2022. TearCare for the Treatment of Meibomian Gland Dysfunction in Adult Patients with Dry Eye Disease: A Masked Randomized Controlled Trial.[41]	135	Improved symptoms Improved tear stability Improved meibomian gland function	Lipiflow: pain, injection TearCare: SPK, chalazion, blepharitis
TearCare	Karpecki et al 2020. A prospective, post-market, multicenter trial (CHEETAH) suggested TearCare system as a safe and effective blink-assisted eyelid device for the treatment of dry eye disease.[42]	29	Improved symptoms Improved tear stability Improved meibomian gland function	No adverse events

(*Continued*)

Table 4 (Continued).

Device	Paper	N	Clinical Outcomes That Were Improved[a]	Adverse Events Related to Treatment
LipiFlow	Godin et al 2018. Outcomes of Thermal Pulsation Treatment for Dry Eye Syndrome in Patients with Sjogren Disease.[55]	13	Improved tear stability Improved meibomian gland function	Not reported
LipiFlow	Hagen et al 2018. Comparison of a single-dose vectored thermal pulsation procedure with a 3-month course of daily oral doxycycline for moderate to severe meibomian gland dysfunction.[47]	28	Improved symptoms Improved tear stability Improved meibomian gland function	No adverse events
LipiFlow	Kim et al 2017. Effect of thermal pulsation treatment on tear film parameters in dry eye disease patients.[48]	98	Improved symptoms Improved tear stability	Not reported
LipiFlow	Schallhorn et al 2016. Effectiveness of an Eyelid Thermal Pulsation Procedure to Treat Recalcitrant Dry Eye Symptoms After Laser Vision Correction.[51]	57	Improved symptoms Improved tear stability Improved meibomian gland function	No adverse events
LipiFlow	Satjwatcharaphong et al 2015. Clinical Outcomes Associated with Thermal Pulsation system Treatment.[37]	32	Improved symptoms Improved tear stability Improved meibomian gland function	Not reported
LipiFlow	Zhao et al 2016. Evaluation of Monocular Treatment for Meibomian Gland Dysfunction with an Automated Thermodynamic System in Elderly Chinese Patients: A Contralateral eye Study.[54]	29	Improved symptoms Improved tear stability Improved meibomian gland function	Not reported
LipiFlow	Finis et al 2014. Evaluation of an Automated Thermodynamic Treatment (LipiFlow) System for Meibomian Gland Dysfunction: A Prospective, Randomized, Observer-Masked Trial.[44]	31	Improved symptoms Improved tear stability Improved meibomian gland function	Not reported
LipiFlow	Greiner J. 2013. Long-term (12-month) improvement in meibomian gland function and reduced dry eye symptoms with a single thermal pulsation treatment.[45]	18	Improved symptoms Improved meibomian gland function	Not reported
LipiFlow	Friedland et al 2011. A Novel Thermodynamic Treatment for Meibomian Gland Dysfunction.[36]	14	Improved symptoms Improved tear stability Improved meibomian gland function	Physical discomfort with treatment
LipiFlow	Lane et al 2012. A New System, the LipiFlow, for the Treatment of Meibomian Gland Dysfunction.[49]	139	Improved symptoms Improved tear stability Improved meibomian gland function	Eyelid discomfort Conjunctival injection

Notes: [a]Meibomian gland function = meibum quality, expressibility, lid margins, or meibography, tear stability = invasive or non-invasive tear breakup time, symptoms = as assessed with symptom questionnaires or visual analogue scale.

Table 5 Summary of Intense Pulsed Light for the Treatment of MGD

Device	Paper	N	Clinical Outcomes That Were Improved[a]	Adverse Events Related to Treatment
E>Eye	Craig et al 2015. Prospective trial of intense pulsed light for the treatment of meibomian gland dysfunction.[62]	28	Improved symptoms Improved tear stability	Not reported
E>Eye	Piyacomn et al 2020. Efficacy and Safety of Intense Pulsed Light in Patients With Meibomian Gland Dysfunction-A Randomized, Double-Masked, Sham-Controlled Clinical Trial.[68]	114	Improved symptoms Improved tear stability Improved meibomian gland function	No adverse events
Quadra4 + loteprednol	Gupta et al 2016. Outcomes of Intense Pulsed Light Therapy for Treatment of Evaporative Dry Eye Disease.[64]	100	Improved symptoms Improved tear stability Improved meibomian gland function	No adverse events
IPL Diamond Series Q4 + expression + 1 drop of steroid/ NSAID	Toyos et al 2015. Intense pulsed light treatment for dry eye disease due to meibomian gland dysfunction; a 3-year Retrospective Study.[72]	91	Improved symptoms Improved tear stability	Blistering, cheek swelling, conjunctival cyst, floaters, hair loss (brow and forehead), light sensitivity, redness
Quadra Q4 + expression + NSAID for 2 days	Vegunta et al 2016. Combination Therapy of Intense Pulsed Light Therapy and Meibomian Gland Expression (IPL/MGX) Can Improve Dry Eye Symptoms and Meibomian Gland Function in Patients With Refractory Dry Eye.[73]	35	Improved symptoms Improved meibomian gland function	No adverse events
E>Eye + expression	Albietz et al 2018. Intense pulsed light treatment and meibomian gland expression for moderate to advanced meibomian gland dysfunction.[58]	26	Improved symptoms Improved tear stability Improved meibomian gland function	No adverse events
Lumenis M22 + expression	Arita et al 2018. Multicenter study of intense pulsed light therapy for patients with refractory meibomian gland dysfunction.[60]	31	Improved symptoms Improved tear stability Improved meibomian gland function	Not reported
Lumenis M22 + expression	Arita et al 2019. Therapeutic efficacy of intense pulsed light in patients with refractory meibomian gland dysfunction.[59]	45	Improved symptoms Improved tear stability Improved meibomian gland function	No adverse events
Lumenis M22 + expression	Choi et al 2019. Meibum Expressibility improvement as a therapeutic target of intense pulsed light treatment in meibomian gland dysfunction and its association with tear inflammatory cytokines.[61]	30	Improved symptoms Improved tear stability Improved meibomian gland function	No adverse events
Lumenis M22 + expression	Dell et al 2017. Prospective evaluation of intense pulsed light and meibomian gland expression efficacy on relieving signs and symptoms of dry eye disease due to meibomian gland dysfunction.[63]	40	Improved symptoms Improved tear stability Improved meibomian gland function	Not reported

(*Continued*)

Table 5 (Continued).

Device	Paper	N	Clinical Outcomes That Were Improved[a]	Adverse Events Related to Treatment
E>Eye	Guilloto et al 2017. Effect of pulsed laser light in patients with dry eye syndrome.[80]	36	No statistical testing	Redness and light sensitivity
E>Eye	Jiang et al 2016. Evaluation of the safety and effectiveness of intense pulsed light in the treatment of meibomian gland dysfunction.[65]	40	Improved symptoms Improved tear stability Improved meibomian gland function	No adverse events
E>Eye	Karaca et al 2018. Intense regulated pulse light for the meibomian gland dysfunction.[66]	26	Improved symptoms Improved tear stability Improved meibomian gland function	No adverse events
Lumenis M22 Optima + expression	Seo et al 2018. Long-term effects of intense pulsed light treatment on the ocular surface in patients with rosacea-associated meibomian gland dysfunction.[69]	17	Improved symptoms Improved tear stability Improved meibomian gland function	No adverse events
Lumenis M22 + ATs	Yin et al 2017. Changes in the meibomian gland after exposure to intense pulsed light in meibomian gland dysfunction.[74]	35	Improved symptoms Improved tear stability Improved meibomian gland function	Not reported
Eye-light (IPL +LLLT)	Solomos et al 2021. Meibomian Gland Dysfunction: Intense Pulsed Light Therapy in Combination with Low-Level Light Therapy as Rescue Treatment.[70]	11	Improved symptoms Improved tear stability Improved meibomian gland function	No adverse events
Epi-C Plus (IPL +LLLT)	Stonecipher et al 2019. Combined low level light therapy and intense pulsed light therapy for the treatment of meibomian gland dysfunction.[71]	230	Improved symptoms Improved tear stability Improved meibomian gland function	No adverse events
Eye-light + MY MASK-E	Marta et al Intense Pulsed Plus Low-Level Light Therapy in Meibomian Gland Dysfunction.[67]	31	Improved symptoms Improved meibomian gland function	No adverse events
Icon Aesthetic System	Cheng et al Intense Pulsed Light Therapy for Patients with Meibomian Gland Dysfunction and Ocular Demodex Infestation.[75]	25	Improved symptoms Improved tear stability Improved meibomian gland function	Not reported
Thermaeye Plus	Verges et al Prospective evaluation of a new intense pulsed light, thermaeye plus, in the treatment of dry eye disease due to meibomian gland dysfunction.[78]	44	Improved symptoms Improved tear stability Improved meibomian gland function	No adverse events
Lumenis M22 alone Lumenis M22 + expression	Shin et al Intense pulsed light plus meibomian gland expression versus intense pulsed light alone for meibomian gland dysfunction: A randomized crossover study.[76]	72	Improved symptoms Improved tear stability Improved meibomian gland function	No adverse events

(*Continued*)

Table 5 (Continued).

Device	Paper	N	Clinical Outcomes That Were Improved[a]	Adverse Events Related to Treatment
Lumenis M22	Tang et al A Retrospective Study of Treatment Outcomes and Prognostic Factors of Intense Pulsed Light Therapy Combined With Meibomian Gland Expression in Patients With Meibomian Gland Dysfunction.[77]	44	Improved symptoms Improved tear stability Improved meibomian gland function	Not reported
Lumenis M22	Yan et al The Efficacy of Intense Pulsed Light Combined With Meibomian Gland Expression for the Treatment of Dry Eye Disease Due to Meibomian Gland Dysfunction: A Multicenter, Randomized Controlled Trial.[79]	120	Improved symptoms Improved tear stability Improved meibomian gland function	No adverse events

Notes: [a]Meibomian gland function = meibum quality, expressibility, lid margins, or meibography, tear stability = invasive or non-invasive tear breakup time, symptoms = as assessed with symptom questionnaires or visual analogue scale.

The Blephasteam can be tailored for use in-office or at-home.[35] The device consists of a goggle with disposable rings that are moistened with saline to increase humidity within the chambers.[35] A controller provides heat to the chambers. The treatment length is 10 minutes, during which the patient can have their eyes open or closed.[35] No mechanical pressure is applied to the meibomian glands.

Moisture chamber goggles are categorized under Stage 2 in the TFOS DEWS II staged management for dry eye,[2] targeting moderate dry eye and MGD. One advantage that moisture chamber goggles may have over heated eye coverings is the ability to retain moisture and provide consistent temperature control. However, they cost more and are not as readily accessible as heated eye coverings.

Devices That Deliver a Combination of Heat and or Pressure

A medical device applying a combination of thermal and mechanical energy to treat MGD was first described in 2011.[36] Applying a combination of heat and physical pressure to the eyelids promotes the liquification and expression of meibum. The most common device in the peer-reviewed literature by far is the Johnson and Johnson LipiFlow (Johnson & Johnson, FL, USA), which was represented in 17 studies in this section. Recently, treatment efficacy data for the iLux (Alcon TX, USA) and the TearCare (Sight Sciences, CA, USA) have started to emerge.

The LipiFlow directs heat to the inner eyelid while providing pulsatile mechanical pressure to the outer eyelids to facilitate the expression of the meibomian glands in an automated fashion.[37] The iLux is a hand-held device that uses light energy to heat the eyelids and a lever to facilitate manual expression. The device also contains a magnifier for the clinician to examine the meibomian gland orifices and expressed meibum.[38] The TearCare consists of a warming element that is attached to the outer eyelids to heat the eyelids. The temperature and duration of heating is controlled through a hub. However, the TearCare does not provide any mechanical pressure; therefore, any meibomian gland expression would need to be manually conducted.[39–42] While the LipiFlow was the first to demonstrate sustained treatment efficacy of signs and symptoms of MGD, the iLux and the TearCare each have demonstrated non-inferiority to the LipiFlow.[38,41]

Collectively, a total of 20 studies examined these heat and pressure devices for treating MGD (Table 4). An improvement in symptoms, tear stability, and meibomian gland function was reported in 95% (19/20),[36–54] 85% (17/20),[36–42,44,45,47–49,51–55] and 95% (19/20) of studies,[36–47,50–55] respectively. Of the 20 studies, 5 studies reported adverse events which were primarily related to discomfort.

In-office treatments are categorized under Stage 2 in the TFOS DEWS II staged management for dry eye,[2] targeted for individuals with moderate to severe dry eye and MGD. Due to the ability of these devices to sustain signs and symptoms over a long period of time, they may be suitable for patients who are non-adherent with daily warm compress treatment.

Intense Pulsed Light

IPL has been used in dermatology to treat various skin conditions such as rosacea, dyspigmentation, reducing telangiectasia, and fine wrinkles.[56] The delivery of non-coherent light (500 nm – 1200 nm) may treat MGD through these potential mechanisms:[57] the first is direct delivery of heat to the meibomian glands which serves to melt and facilitate meibum flow, the second is the photocoagulation of telangiectatic vessels along the lid margin, which reduces pro-inflammatory cytokine circulation in the area, thirdly, reduction of inflammation by reducing demodex infestation, and lastly, photomodulatory effect that alters intracellular metabolic activity of the meibomian glands.

This review found 23 studies examining the efficacy of IPL in treating MGD (Table 5). IPL improved symptoms, tear stability, and meibomian gland function in 96% (22/23),[58–79] 87% (20/23),[58–66,68–72,74–79] and 87% (20/23) of studies reviewed,[58–61,63–71,73–79] respectively. Two studies reported adverse events related to using IPL.[72,80] Notably, pigment in the iris absorbs light that is emitted by the IPL, therefore inappropriate eye protection while using IPL could lead to adverse events. A few case reports and reviews have documented ocular complications such as anterior uveitis, iris atrophy, pupillary defects and long-lasting pain and photophobia associated with IPL use.[81–83]

There are various IPL systems that have been used for treating MGD and the treatment protocol can vary greatly. For example, using the Lumenis M22 (Yokneam, Israel) involves applying ~13 flashes tragus to tragus which is then repeated again in a second pass;[60] in contrast, the E-swin E>Eye (Houdan, France) applies 5 flashes per eye using a single pass.[68] Indeed, the most common systems encountered in this review were the Lumenis M22 and the E>Eye, each representing 39% (9/23) and 26% (6/23), respectively, of the studies each in this section. While the efficacy of IPL in treating MGD has been demonstrated, there are no head-to-head studies to determine which system is superior. In addition to varied protocols for energy delivery, IPL may also be combined with other therapies, such as meibomian gland expression[58–61,63,69,76] and low-level light therapy.[67,70,71]

IPL is categorized under Stage 2 in the TFOS DEWS II staged management for dry eye,[2] and based on the severity of MGD and dry eye participants that have been enrolled in IPL trials IPL appears to be supported in the treatment of moderate to severe dry eye and MGD. Patients who do notrespond well to traditional eye warming therapy or have a history of ocular rosacea may be good candidates for IPL therapy.[69]

Others: Low Level Light and Quantum Molecular Resonance

LLLT takes advantage of photobiomodulation, a technique that involves applying red or near infra-red radiation using low power light sources to promote tissue repair, decrease inflammation, and relieve pain.[84] This technology was adapted from dermatological applications for rejuvenating skin.[85] The mechanism of action is hypothesized to be as follows: light is absorbed by mitochondrial cytochrome c oxidase, which promotes electron transport chain activity and ATP output, leading to increased expression of transcription factors associated with cell survival and repair.[85] Currently, there is only one study indexed in PubMed that examines the effect of LLLT on MGD (Table 6).[86] Park et al (n = 40) found that there were no significant differences in outcome variables between LLLT treatment and placebo; however, there was a significant improvement in upper lid meibography in the LLLT group compared to its baseline. More rigorous studies on the clinical efficacy of LLLT on treating MGD would be valuable for determining its place in therapy.

Quantum molecular resonance is a technique that applies high frequency, low intensity electrical currents to create magnetic fields that alter biological tissue function, which has been found to have anti-inflammatory[87] and tissue regeneration properties.[88] This review found only one study examining the effect of quantum molecular resonance on treating MGD (Table 6).[89] Ferrari et al (n = 25) found that quantum molecular resonance improved symptoms, tear stability, and meibomian gland function.[89] As with LLLT, more studies would be valuable learn more about its treatment efficacy.

Notably, radiofrequency technology has begun to emerge as a method for treating MGD and was also adapted from dermatology aimed at rejuvenating skin.[90,91] As of currently, there are no peer-reviewed literature indexed on PubMed examining radiofrequency and their efficacy in treating MGD in a clinical setting.

The most popular and overrepresented devices in the peer reviewed literature in each category are MGDRx EyeBag for heated eye coverings, Blephasteam for moisture chamber goggles, LipiFlow for heat and pressure, and the M22 for IPL. The reason for their popularity is speculative and may be related to the availability of the device for clinical use and

Table 6 Other Devices for the Treatment of MGD

Treatment Type	Device	Paper	N	Clinical Outcomes That Were Improved[a]	Adverse Events Related to Treatment
Low Level Light Therapy	Healite II	Park et al 2022. Effect of low-level light therapy in patients with dry eye: a prospective, randomized, observer-masked trial.[86]	40	Improved meibomian gland function	No adverse events
Quantum Molecular Resonance	Rexon-Eye	Ferrari et al 2019. High Frequency Electrotherapy for the Treatment of Meibomian Gland Dysfunction.[89]	25	Improved symptoms Improved tear stability Improved meibomian gland function	No adverse events

Notes: [a]Meibomian gland function = meibum quality, expressibility, lid margins, or meibography, tear stability = invasive or non-invasive tear breakup time, symptoms = as assessed with symptom questionnaires or visual analogue scale.

research funding. However, the implication is that the efficacy summary in this paper is largely driven by each of these devices, but these devices may not be representative of the whole category. Therefore, care should be taken in the interpretation of this data.

While there is not much known about LLLT, quantum molecular resonance, and radiofrequency, it should be noted that the mechanism of action for these technologies is likely based in stimulation of tissue function as opposed to the conventional "thermal" approaches for treating MGD. Since electromagnetic therapies have a uniquely different mechanism of action, it may be possible that they could be used in conjunction with conventional thermal-based MGD treatments to yield outcomes that are superior to an individual device alone (eg, combining heat and pressure with IPL and LLLT). However, as there are currently no studies that have tested this notion, it would be valuable for future work to focus on testing the effect using complementary strategies for treating MGD. Furthermore, more work investigating the basic and clinical science of these technologies and its applications would be valuable.

Conclusion

In summary, there are a variety of eyelid warming devices in the peer-reviewed literature that address the deficiencies of the classical warm cloth/towel compress. Not only do they improve the effectiveness of delivering heat and pressure to the eyelids, they also allow for sustained clinical improvements with a single treatment. Additionally, some newer devices using light and electromagnetic therapy can directly influence meibomian gland metabolic function; however, their precise mechanism has yet to be determined.

Disclosure

Over the past three years, the Centre for Ocular Research & Education has received research funding from the following companies: Alcon, Allergan, Allied Innovations, Aurinia Pharma, Azura Pharma, Bausch Health Canada, Brien Holden Vision Institute, CooperVision, GL Chemtec, i-Med Pharma, Johnson & Johnson Vision, Lubris, Menicon, Nature's way, Novartis, Ophtecs, Ote Pharma, PS Therapy, Santen, SightGlass, SightSage, Visioneering Tech. Dr Brandon Bzovey reports Research support to from listed companies: Alcon, Allergan, Allied Innovations, Aurinia Pharma, Azura Pharma, Bausch Health Canada, Brien Holden Vision Institute, CooperVision, GL Chemtec, i-Med Pharma, Johnson & Johnson Vision, Lubris, Menicon, Nature's way, Novartis, Ophtecs, Ote Pharma, PS Therapy, Santen, SightGlass, SightSage, Visioneering Tech. Dr William Ngo reports Research support paid to institution from Alcon, Allergan, Allied Innovations, Aurinia Pharma, Azura Pharma, Bausch Health Canada, Brien Holden Vision Institute, CooperVision, GL Chemtec, i-Med Pharma, Johnson & Johnson Vision, Lubris, Menicon, Nature's Way, Novartis, Ophtecs, Ote Pharma, PS Therapy, Santen, SightGlass, SightSage, Visioneering Tech, personal fees from Alcon, personal fees from Sun Pharma, outside the submitted work. The authors report no other conflicts of interest in this work.

References

1. Craig JP, Nichols KK, Akpek EK, et al. TFOS DEWS II definition and classification report. *Ocul Surf*. 2017;15(3):276–283. doi:10.1016/j.jtos.2017.05.008
2. Craig JP, Nelson JD, Azar DT, et al. TFOS DEWS II report executive summary. *Ocul Surf*. 2017;15(4):802–812. doi:10.1016/j.jtos.2017.08.003
3. Nichols KK, Foulks GN, Bron AJ, et al. The international workshop on meibomian gland dysfunction: executive summary. *Invest Ophthalmol Vis Sci*. 2011;52(4):1922–1929. doi:10.1167/iovs.10-6997a
4. Geerling G, Baudouin C, Aragona P, et al. Emerging strategies for the diagnosis and treatment of meibomian gland dysfunction: proceedings of the OCEAN group meeting. *Ocular Surf*. 2017;15(2):179–192. doi:10.1016/j.jtos.2017.01.006
5. Belmonte C, Nichols JJ, Cox SM, et al. TFOS DEWS II pain and sensation report. *Ocul Surf*. 2017;15(3):404–437. doi:10.1016/j.jtos.2017.05.002
6. Friedman NJ. Impact of dry eye disease and treatment on quality of life. *Curr Opin Ophthalmol*. 2010;21(4):310–316.
7. Jones L, Downie LE, Korb D, et al. TFOS DEWS II management and therapy report. *Ocul Surf*. 2017;15(3):575–628.
8. Geerling G, Tauber J, Baudouin C, et al. The international workshop on meibomian gland dysfunction: report of the subcommittee on management and treatment of meibomian gland dysfunction. *Invest Ophthalmol Vis Sci*. 2011;52(4):2050–2064.
9. Terada O, Chiba K, Senoo T, Obara Y. [Ocular surface temperature of meibomia gland dysfunction patients and the melting point of meibomian gland secretions]. *Nippon Ganka Gakkai Zasshi*. 2004;108(11):690–693. Japanese.
10. Blackie CA, Solomon JD, Greiner JV, Holmes M, Korb DR. Inner eyelid surface temperature as a function of warm compress methodology. *Optom Vis Sci*. 2008;85(8):675–683. doi:10.1097/OPX.0b013e318181adef
11. Bitton E, Lacroix Z, Léger S. In-vivo heat retention comparison of eyelid warming masks. *Contact Lens Anterior Eye*. 2016;39(4):311–315. doi:10.1016/j.clae.2016.04.002
12. Lacroix Z, Léger S, Bitton E. Ex vivo heat retention of different eyelid warming masks. *Contact Lens Anterior Eye*. 2015;38(3):152–156. doi:10.1016/j.clae.2015.01.005
13. Murakami DK, Blackie CA, Korb DR. All warm compresses are not equally efficacious. *Optom Vis Sci*. 2015;92(9):e327–e333. doi:10.1097/OPX.0000000000000675
14. Despa F, Orgill DP, Neuwalder J, Lee RC. The relative thermal stability of tissue macromolecules and cellular structure in burn injury. *Burns*. 2005;31(5):568–577. doi:10.1016/j.burns.2005.01.015
15. Moritz AR, Henriques FC. Studies of thermal injury: II. the relative importance of time and surface temperature in the causation of cutaneous burns. *Am J Pathol*. 1947;23(5):695–720.
16. Schweitzer NMJ, Fluorescein Colored A. Polygonal pattern in the human cornea: the reflectographic “furchenbild” of Fischer. *Arch Ophthalmol*. 1967;77(4):548–553. doi:10.1001/archopht.1967.00980020550021
17. Solomon JD, Case CL, Greiner JV, Blackie CA, Herman JP. Transient visual degradation and the polygonal reflex of Fischer-Schweitzer following warm compress application. *Invest Ophthalmol Vis Sci*. 2007;48(13):420.
18. Sim HS, Petznick A, Barbier S, et al. A randomized, controlled treatment trial of eyelid-warming therapies in meibomian gland dysfunction. *Ophthalmol Ther*. 2014;3(1–2):37–48. doi:10.1007/s40123-014-0025-8
19. Arita R, Morishige N, Sakamoto I, et al. Effects of a warm compress containing menthol on the tear film in healthy subjects and dry eye patients. *Sci Rep*. 2017;7:45848. doi:10.1038/srep45848
20. Arita R, Morishige N, Shirakawa R, Sato Y, Amano S. Effects of eyelid warming devices on tear film parameters in normal subjects and patients with meibomian gland dysfunction. *Ocul Surf*. 2015;13(4):321–330. doi:10.1016/j.jtos.2015.04.005
21. Bilkhu PS, Naroo SA, Wolffsohn JS. Randomised masked clinical trial of the MGDRx EyeBag for the treatment of meibomian gland dysfunction-related evaporative dry eye. *Br J Ophthalmol*. 2014;98(12):1707–1711. doi:10.1136/bjophthalmol-2014-305220
22. Jeon J, Park S. Comparison of the efficacy of eyelid warming masks and artificial tears for dry eye symptoms in contact lens wearers. *Cont Lens Anterior Eye*. 2021;44(1):30–34. doi:10.1016/j.clae.2020.02.013
23. Murphy O, O’ Dwyer V, Lloyd-Mckernan A. The efficacy of warm compresses in the treatment of meibomian gland dysfunction and demodex folliculorum blepharitis. *Curr Eye Res*. 2020;45(5):563–575. doi:10.1080/02713683.2019.1686153
24. Ngo W, Srinivasan S, Jones L. An eyelid warming device for the management of meibomian gland dysfunction. *J Optom*. 2019;12(2):120–130. doi:10.1016/j.optom.2018.07.002
25. Olafsson J, Lai X, Landsend ECS, et al. TheraPearl Eye Mask and Blephasteam for the treatment of meibomian gland dysfunction: a randomized, comparative clinical trial. *Sci Rep*. 2021;11(1):22386. doi:10.1038/s41598-021-01899-8
26. Turnbull PRK, Misra SL, Craig JP. Comparison of treatment effect across varying severities of meibomian gland dropout. *Contact Lens Anterior Eye*. 2018;41(1):88–92. doi:10.1016/j.clae.2017.09.004
27. Alghamdi YA, Camp A, Feuer W, Karp CL, Wellik S, Galor A. Compliance and subjective patient responses to eyelid hygiene. *Eye Contact Lens*. 2017;43(4):213–217. doi:10.1097/ICL.0000000000000258
28. Benitez Del Castillo JM, Kaercher T, Mansour K, Wylegala E, Dua H. Evaluation of the efficacy, safety, and acceptability of an eyelid warming device for the treatment of meibomian gland dysfunction. *Clin Ophthalmol*. 2014;8(2019–2027). doi:10.2147/OPTH.S68201
29. Bilkhu P, Wolffsohn J, Purslow C. Provocation of the ocular surface to investigate the evaporative pathophysiology of dry eye disease. *Contact Lens Anterior Eye*. 2021;44(1):24–29. doi:10.1016/j.clae.2020.03.014
30. Matsumoto Y, Dogru M, Goto E, et al. Efficacy of a new warm moist air device on tear functions of patients with simple meibomian gland dysfunction. *Cornea*. 2006;25(6):644–650. doi:10.1097/01.ico.0000208822.70732.25
31. Ren Y, Chen J, Zheng Q, Chen W. Short-term effect of a developed warming moist chamber goggle for video display terminal-associated dry eye. *BMC Ophthalmol*. 2018;18(1):33. doi:10.1186/s12886-018-0700-y
32. Spiteri A, Mitra M, Menon G, et al. Tear lipid layer thickness and ocular comfort with a novel device in dry eye patients with and without Sjögren’s syndrome. *J Fr Ophtalmol*. 2007;30(4):357–364. doi:10.1016/S0181-5512(07)89605-7
33. Villani E, Garoli E, Canton V, Pichi F, Nucci P, Ratiglia R. Evaluation of a novel eyelid-warming device in meibomian gland dysfunction unresponsive to traditional warm compress treatment: an in vivo confocal study. *Int Ophthalmol*. 2015;35(3):319–323. doi:10.1007/s10792-014-9947-3

34. Wang MTM, Liu LJ, McPherson RD, Fuller JR, Craig JP. Therapeutic profile of a latent heat eyelid warming device with temperature setting variation. *Contact Lens Anterior Eye*. 2020;43(2):173–177. doi:10.1016/j.clae.2019.09.004
35. Pult H, Riede-Pult BH, Purslow C. A comparison of an eyelid-warming device to traditional compress therapy. *Optom Vis Sci*. 2012;89(7):E1035–E1041. doi:10.1097/OPX.0b013e31825c3479
36. Friedland BR, Fleming CP, Blackie CA, Korb DR. A novel thermodynamic treatment for meibomian gland dysfunction. *Curr Eye Res*. 2011;36(2):79–87. doi:10.3109/02713683.2010.509529
37. Satjawatcharaphong P, Ge S, Lin MC. Clinical outcomes associated with thermal pulsation system treatment. *Optom Vis Sci*. 2015;92(9):e334–e341. doi:10.1097/OPX.0000000000000670
38. Tauber J, Owen J, Bloomenstein M, Hovanesian J, Bullimore MA. Comparison of the iLUX and the lipiflow for the treatment of meibomian gland dysfunction and symptoms: a randomized clinical trial. *Clin Ophthalmol*. 2020;14:405–418. doi:10.2147/OPTH.S234008
39. Badawi D. A novel system, TearCare®, for the treatment of the signs and symptoms of dry eye disease. *Clin Ophthalmol*. 2018;12:683–694. doi:10.2147/OPTH.S160403
40. Badawi D. TearCare® system extension study: evaluation of the safety, effectiveness, and durability through 12 months of a second TearCare® treatment on subjects with dry eye disease. *Clin Ophthalmol*. 2019;13:189–198. doi:10.2147/OPTH.S191588
41. Gupta PK, Holland EJ, Hovanesian J, et al. TearCare for the treatment of meibomian gland dysfunction in adult patients with dry eye disease: a masked randomized controlled trial. *Cornea*. 2022;41(4):417–426. doi:10.1097/ICO.0000000000002837
42. Karpecki P, Wirta D, Osmanovic S, Dhamdhere K. A prospective, post-market, multicenter trial (CHEETAH) suggested TearCare® system as a safe and effective blink-assisted eyelid device for the treatment of dry eye disease. *Clin Ophthalmol*. 2020;14:4551–4559. doi:10.2147/OPTH.S285953
43. Blackie CA, Coleman CA, Holland EJ. The sustained effect (12 months) of a single-dose vectored thermal pulsation procedure for meibomian gland dysfunction and evaporative dry eye. *Clin Ophthalmol*. 2016;10:1385–1396. doi:10.2147/OPTH.S109663
44. Finis D, Hayajneh J, König C, Borrelli M, Schrader S, Geerling G. Evaluation of an automated thermodynamic treatment (LipiFlow®) system for meibomian gland dysfunction: a prospective, randomized, observer-masked trial. *Ocul Surf*. 2014;12(2):146–154. doi:10.1016/j.jtos.2013.12.001
45. Greiner JV. A single LipiFlow ® thermal pulsation system treatment improves meibomian gland function and reduces dry eye symptoms for 9 months. *Curr Eye Res*. 2012;37(4):272–278. doi:10.3109/02713683.2011.631721
46. Greiner JV. Long-term (12-month) improvement in meibomian gland function and reduced dry eye symptoms with a single thermal pulsation treatment. *Clin Experiment Ophthalmol*. 2013;41(6):524–530. doi:10.1111/ceo.12033
47. Hagen KB, Bedi R, Blackie CA, Christenson-Akagi KJ. Comparison of a single-dose vectored thermal pulsation procedure with a 3-month course of daily oral doxycycline for moderate-to-severe meibomian gland dysfunction. *Clin Ophthalmol*. 2018;12:161–168. doi:10.2147/OPTH.S150433
48. Kim MJ, Stinnett SS, Gupta PK. Effect of thermal pulsation treatment on tear film parameters in dry eye disease patients. *Clin Ophthalmol*. 2017;11:883–886. doi:10.2147/OPTH.S136203
49. Lane SS, DuBiner HB, Epstein RJ, et al. A new system, the Lipiflow, for the treatment of meibomian gland dysfunction. *Cornea*. 2012;31(4):396–404. doi:10.1097/ICO.0b013e318239aaea
50. Li S, Yang K, Wang J, et al. Effect of a novel thermostatic device on meibomian gland dysfunction: a randomized controlled trial in Chinese patients. *Ophthalmol Ther*. 2022;11(1):261–270.
51. Schallhorn CS, Schallhorn JM, Hannan S, Schallhorn SC. Effectiveness of an eyelid thermal pulsation procedure to treat recalcitrant dry eye symptoms after laser vision correction. *J Refract Surg*. 2017;33(1):30–36.
52. Schanzlin D, Owen JP, Klein S, Yeh TN, Merchea MM, Bullimore MA. Efficacy of the systane iLux thermal pulsation system for the treatment of meibomian gland dysfunction after 1 week and 1 month: a prospective study. *Eye Contact Lens*. 2022;48(4):155–161.
53. Zhao Y, Veerappan A, Yeo S, et al. Clinical trial of thermal pulsation (LipiFlow) in meibomian gland dysfunction with preteatment meibography. *Eye Contact Lens*. 2016;42(6):339–346.
54. Zhao Y, Xie J, Li J, et al. Evaluation of monocular treatment for meibomian gland dysfunction with an automated thermodynamic system in elderly Chinese patients: a contralateral eye study. *J Ophthalmol*. 2016;2016:9640643.
55. Godin MR, Stinnett SS, Gupta PK. Outcomes of thermal pulsation treatment for dry eye syndrome in patients with sjogren disease. *Cornea*. 2018;37(9):1155–1158.
56. Goldberg DJ. Current trends in intense pulsed light. *J Clin Aesthet Dermatol*. 2012;5(6):45–53.
57. Cote S, Zhang AC, Ahmadzai V, et al. Intense pulsed light (IPL) therapy for the treatment of meibomian gland dysfunction. *Cochrane Database Syst Rev*. 2020;3:CD013559.
58. Albietz JM, Schmid KL. Intense pulsed light treatment and meibomian gland expression for moderate to advanced meibomian gland dysfunction. *Clin Exp Optom*. 2018;101(1):23–33.
59. Arita R, Fukuoka S, Morishige N. Therapeutic efficacy of intense pulsed light in patients with refractory meibomian gland dysfunction. *Ocul Surf*. 2019;17(1):104–110.
60. Arita R, Mizoguchi T, Fukuoka S, Morishige N. Multicenter study of intense pulsed light therapy for patients with refractory meibomian gland dysfunction. *Cornea*. 2018;37(12):1566–1571.
61. Choi M, Han SJ, Ji YW, et al. Meibum expressibility improvement as a therapeutic target of intense pulsed light treatment in meibomian gland dysfunction and its association with tear inflammatory cytokines. *Sci Rep*. 2019;9(1):7648.
62. Craig JP, Chen Y-H, Turnbull PRK. Prospective trial of intense pulsed light for the treatment of meibomian gland dysfunction. *Invest Ophthalmol Vis Sci*. 2015;56(3):1965–1970.
63. Dell SJ, Gaster RN, Barbarino SC, Cunningham DN. Prospective evaluation of intense pulsed light and meibomian gland expression efficacy on relieving signs and symptoms of dry eye disease due to meibomian gland dysfunction. *Clin Ophthalmol*. 2017;11:817–827.
64. Gupta PK, Vora GK, Matossian C, Kim M, Stinnett S. Outcomes of intense pulsed light therapy for treatment of evaporative dry eye disease. *Can J Ophthalmol*. 2016;51(4):249–253.
65. Jiang X, Lv H, Song H, et al. Evaluation of the safety and effectiveness of intense pulsed light in the treatment of meibomian gland dysfunction. *J Ophthalmol*. 2016;2016:1910694.
66. Karaca EE, Evren Kemer Ö, Özek D. Intense regulated pulse light for the meibomian gland dysfunction. *Eur J Ophthalmol*. 2018;30(2):289–292.

67. Marta A, Baptista PM, Heitor Marques J, et al. Intense pulsed plus low-level light therapy in meibomian gland dysfunction. *Clin Ophthalmol*. 2021;15:2803–2811.
68. Piyacomn Y, Kasetsuwan N, Reinprayoon U, Satitpitakul V, Tesapirat L. Efficacy and safety of intense pulsed light in patients with meibomian gland dysfunction-a randomized, double-masked, sham-controlled clinical trial. *Cornea*. 2020;39(3):325–332.
69. Seo KY, Kang SM, Ha DY, Chin HS, Jung JW. Long-term effects of intense pulsed light treatment on the ocular surface in patients with rosacea-associated meibomian gland dysfunction. *Cont Lens Anterior Eye*. 2018;41(5):430–435.
70. Solomos L, Bouthour W, Malclès A, Thumann G, Massa H. Meibomian gland dysfunction: intense pulsed light therapy in combination with low-level light therapy as rescue treatment. *Medicina*. 2021;57(6):619.
71. Stonecipher K, Abell TG, Chotiner B, Chotiner E, Potvin R. Combined low level light therapy and intense pulsed light therapy for the treatment of meibomian gland dysfunction. *Clin Ophthalmol*. 2019;13:993–999.
72. Toyos R, McGill W, Briscoe D. Intense pulsed light treatment for dry eye disease due to meibomian gland dysfunction; a 3-year retrospective study. *Photomed Laser Surg*. 2015;33(1):41–46.
73. Vegunta S, Patel D, Shen JF. Combination therapy of intense pulsed light therapy and meibomian gland expression (IPL/MGX) can improve dry eye symptoms and meibomian gland function in patients with refractory dry eye: a retrospective analysis. *Cornea*. 2016;35(3):318–322.
74. Yin Y, Liu N, Gong L, Song N. Changes in the meibomian gland after exposure to intense pulsed light in Meibomian Gland Dysfunction (MGD) Patients. *Curr Eye Res*. 2018;43(3):308–313.
75. Cheng SN, Jiang FG, Chen H, Gao H, Huang YK. Intense pulsed light therapy for patients with meibomian gland dysfunction and ocular demodex infestation. *Curr Med Sci*. 2019;39(5):800–809.
76. Shin KY, Lim DH, Moon CH, Kim BJ, Chung TY. Intense pulsed light plus meibomian gland expression versus intense pulsed light alone for meibomian gland dysfunction: a randomized crossover study. *PLoS One*. 2021;16(3):e0246245.
77. Tang Y, Liu R, Tu P, et al. A retrospective study of treatment outcomes and prognostic factors of intense pulsed light therapy combined with meibomian gland expression in patients with meibomian gland dysfunction. *Eye Contact Lens*. 2021;47(1):38–44.
78. Verges C, Salgado-Borges J, Ribot FM. Prospective evaluation of a new intense pulsed light, thermaeye plus, in the treatment of dry eye disease due to meibomian gland dysfunction. *J Optom*. 2021;14(2):103–113.
79. Yan X, Hong J, Jin X, et al. The efficacy of intense pulsed light combined with meibomian gland expression for the treatment of dry eye disease due to meibomian gland dysfunction: a multicenter, randomized controlled trial. *Eye Contact Lens*. 2021;47(1):45–53.
80. Guilloto Caballero S, García Madrona JL, Colmenero Reina E. Effect of pulsed laser light in patients with dry eye syndrome. *Arch Soc Esp Oftalmol*. 2017;92(11):509–515.
81. Crabb M, Chan WO, Taranath D, Huilgol SC. Intense pulsed light therapy (IPL) induced iritis following treatment for a medial canthal capillary malformation. *Aust J Dermatol*. 2014;55(4):289–291.
82. Giannaccare G, Taroni L, Senni C, Scorcia V. Intense pulsed light therapy in the treatment of meibomian gland dysfunction: current perspectives. *Clin Optom*. 2019;11:113–126.
83. Lee WW, Murdock J, Albini TA, O'Brien TP, Levine ML. Ocular damage secondary to intense pulse light therapy to the face. *Ophthal Plast Reconstr Surg*. 2011;27(4):263–265.
84. Markoulli M, Chandramohan N, Papas EB. Photobiomodulation (low-level light therapy) and dry eye disease. *Clin Exp Optom*. 2021;104 (5):561–566.
85. Avci P, Gupta A, Sadasivam M, et al. Low-level laser (light) therapy (LLLT) in skin: stimulating, healing, restoring. *Semin Cutan Med Surg*. 2013;32(1):41–52.
86. Park Y, Kim H, Kim S, Cho KJ. Effect of low-level light therapy in patients with dry eye: a prospective, randomized, observer-masked trial. *Sci Rep*. 2022;12(1):3575.
87. Costin GE, Birlea SA, Norris DA. Trends in wound repair: cellular and molecular basis of regenerative therapy using electromagnetic fields. *Curr Mol Med*. 2012;12(1):14–26.
88. Sella S, Adami V, Amati E, et al. In-vitro analysis of Quantum Molecular Resonance effects on human mesenchymal stromal cells. *PLoS One*. 2018;13(1):e0190082.
89. Ferrari G, Colucci A, Barbariga M, Ruggeri A, Rama P. High frequency electrotherapy for the treatment of meibomian gland dysfunction. *Cornea*. 2019;38(11):1424–1429.
90. Gold MH. Noninvasive Skin Tightening Treatment. *J Clin Aesthet Dermatol*. 2015;8(6):14–18.
91. Boisnic S, Divaris M, Branchet MC, Nelson AA. Split-face histological and biochemical evaluation of tightening efficacy using temperature- and impedance-controlled continuous non-invasive radiofrequency energy. *J Cosmet Laser Ther*. 2017;19(3):128–132.
92. Mitra M, Menon GJ, Casini A, et al. Tear film lipid layer thickness and ocular comfort after meibomian therapy via latent heat with a novel device in normal subjects. *Eye*. 2005;19(6):657–660.
93. Purslow C. Evaluation of the ocular tolerance of a novel eyelid-warming device used for meibomian gland dysfunction. *Contact Lens Anterior Eye*. 2013;36(5):226–231.