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

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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 disease² 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
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. The temperature required to soften or liquify pathological meibum is >40°C, whereas the melting point for normal meibum is approximately 34.0°C. 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 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 and Lacroix et al, who also demonstrated the rapid cooling of towel compresses. It was only by using the labour intensive “Bundle method” described in Murakami et al, where multiple towels are rolled into each other, could towels retain a sufficiently elevated temperature ≥40°C. However, it is important to note that temperatures above 45°C may increase the risk for thermal injury to the eye or eyelids.

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.

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.
Heated Eye Coverings

Heated eye coverings are typically employed as the first line of treatment for MGD. 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. Generally, they have the capability to hold a therapeutic temperature longer than towels. Of the 9 studies reviewed (Table 2); 78% (7/9) reported improvement in symptoms, 56% (5/9) reported improvement in tear stability, and 44% (4/9) reported improvement in meibomian gland function. Only 2 studies reported adverse events, 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, 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.

### Table 1 Number of Studies per Treatment Modality

| Treatment                                           | Number of Studies | Clinical Improvement |
|-----------------------------------------------------|-------------------|----------------------|
| 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**: S, improved symptoms; T, improved tear stability; M, improved meibomian gland function.
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 2 Summary Heated Eye Coverings for the Treatment of MGD

| Device                        | Paper                                                                 | N  | Clinical Outcomes That Were Improved* | 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. 32 | 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 tear stability | 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: *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.
and 8% (1/13) of studies, 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 3 Summary of Moisture Chamber Goggles for the Treatment of MGD

| Device | Paper                                                                 | N  | Clinical Outcomes that Were Improved* | Adverse Events Related to Treatment |
|--------|-----------------------------------------------------------------------|----|---------------------------------------|------------------------------------|
|        | Benitez del Castillo et al 2014. Evaluation of the efficacy, safety and | 73 | Improved symptoms                      | No adverse events                   |
|        | acceptability of an eyelid warming device for the treatment of MGD.26   |    |                                       |                                    |
| Custom | Matsumoto et al 2006. Efficacy of a New Warm Moist Air Device on Tear  | 35 | Improved symptoms, Improved tear stability | Not reported                       |
| device | Functions of Patients with Simple Meibomian Gland Dysfunction.30       |    |                                       |                                    |
| Custom | Spiteri et al 2007. Tear lipid layer thickness and ocular comfort       | 26 | Improved symptoms                      | No adverse events                   |
| device | with novel device in dry eye patients with and without Sjögren’s        |    |                                       |                                    |
|        | syndrome.92                                                             |    |                                       |                                    |
| Custom | Mitra et al 2005. Tear film lipid layer thickness and ocular comfort    | 24 | No improved symptoms, tear stability,  | No adverse events                   |
| device | after meibomian therapy via latent heat with novel device in normal     |    | or meibomian gland metrics              |                                    |
|        | subjects.93                                                             |    |                                       |                                    |
| Blephasteam | Pult et al 2012. A Comparison of an Eyelid-Warming Device to Traditional | 20 | No improved symptoms, tear stability,  | Not reported                       |
|        | Compress Therapy.35                                                     |    | or meibomian gland metrics              |                                    |
| Blephasteam | Purslow et al 2013. Evaluation of the ocular tolerance of a novel eyelid- | 25 | No improved symptoms, tear stability,  | No adverse events                   |
|        | warming device used for meibomian gland dysfunction.93                  |    | or meibomian gland metrics              |                                    |
| Custom | Ren et al 2018. Short-term effect of a developed warming moist chamber   | 22 | Improved symptoms                      | No adverse events                   |
| device + ATs | goggles for video display terminal-associated dry eye.31              |    |                                       |                                    |
| Blephasteam | Turnbull et al 2018. Comparison of treatment effect across varying      | 81 | Improved tear stability                | Not reported                       |
|        | severities of meibomian gland dropout.26                               |    |                                       |                                    |
| Prototype | Wang et al 2020. Therapeutic profile of a latent heat eyelid warming    | 15 | Improved tear stability                | No adverse events                   |
|        | device with temperature setting variation.34                          |    |                                       |                                    |
| 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      | 50 | Improved symptoms                      | No adverse events                   |
|        | meibomian gland dysfunction unresponsive to traditional warm compress treatment: an in vivo confocal study.13 |    |                                       |                                    |
| Blephasteam | Sim et al 2014. A Randomized, Controlled Treatment Trial of Eyelid-    | 65 | Improved symptoms, Improved meibomian gland function | Minor discomfort using EyeGiene |
|        | Warming Therapies in Meibomian Gland Dysfunction.18                    |    |                                       |                                    |
| Blephasteam | Olafsson et al 2021. TheraPearl Eye Mask and Blephasteam for the        | 70 | Improved symptoms                      | Not reported                       |
|        | treatment of meibomian gland dysfunction: a randomized, comparative    |    | Improved tear stability                |                                    |
|        | clinical trial.25                                                       |    |                                       |                                    |

**Notes:** *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.
| Device | Paper | N  | Clinical Outcomes That Were Improved* | 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 | 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 |
| LipiFlow | 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 |
| Li | 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 | 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 | 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* | Adverse Events Related to Treatment |
|--------|-----------------------------------------------------------------------|----|--------------------------------------|-------------------------------------|
| LipiFlow | Godin et al 2018. Outcomes of Thermal Pulsation Treatment for Dry Eye Syndrome in Patients with Sjogren Disease. | 13 | Improved tear stability               | Not reported                         |
|        |                                                                        |    | Improved meibomian gland function     |                                     |
| 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. | 28 | Improved symptoms                     | No adverse events                    |
|        |                                                                        |    | Improved tear stability                |                                     |
|        |                                                                        |    | Improved meibomian gland function     |                                     |
| LipiFlow | Kim et al 2017. Effect of thermal pulsation treatment on tear film parameters in dry eye disease patients. | 98 | Improved symptoms                     | Not reported                         |
|        |                                                                        |    | Improved tear stability                |                                     |
| LipiFlow | Schallhorn et al 2016. Effectiveness of an Eyelid Thermal Pulsation Procedure to Treat Recalcitrant Dry Eye Symptoms After Laser Vision Correction. | 57 | Improved symptoms                     | No adverse events                    |
|        |                                                                        |    | Improved tear stability                |                                     |
|        |                                                                        |    | Improved meibomian gland function     |                                     |
| LipiFlow | Satjwatcharaphong et al 2015. Clinical Outcomes Associated with Thermal Pulsation system Treatment. | 32 | Improved symptoms                     | Not reported                         |
|        |                                                                        |    | Improved tear stability                |                                     |
|        |                                                                        |    | Improved meibomian gland function     |                                     |
| 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. | 29 | Improved symptoms                     | Not reported                         |
|        |                                                                        |    | Improved tear stability                |                                     |
|        |                                                                        |    | Improved meibomian gland function     |                                     |
| LipiFlow | Finis et al 2014. Evaluation of an Automated Thermodynamic Treatment (LipiFlow) System for Meibomian Gland Dysfunction: A Prospective, Randomized, Observer-Masked Trial. | 31 | Improved symptoms                     | Not reported                         |
|        |                                                                        |    | Improved tear stability                |                                     |
|        |                                                                        |    | Improved meibomian gland function     |                                     |
| LipiFlow | Greiner J. 2013. Long-term (12-month) improvement in meibomian gland function and reduced dry eye symptoms with a single thermal pulsation treatment. | 18 | Improved symptoms                     | Not reported                         |
|        |                                                                        |    | Improved meibomian gland function     |                                     |
| LipiFlow | Friedland et al 2011. A Novel Thermodynamic Treatment for Meibomian Gland Dysfunction. | 14 | Improved symptoms                     | Physical discomfort with treatment   |
|        |                                                                        |    | Improved tear stability                |                                     |
|        |                                                                        |    | Improved meibomian gland function     |                                     |
| LipiFlow | Lane et al 2012. A New System, the LipiFlow, for the Treatment of Meibomian Gland Dysfunction. | 139 | Improved symptoms                     | Eyelid discomfort                    |
|        |                                                                        |    | Improved tear stability                | Conjunctival injection              |
|        |                                                                        |    | Improved meibomian gland function     |                                     |

Notes: *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 | Adverse Events Related to Treatment |
|--------|-----------------------------------------------------------------------|-----|-------------------------------------|------------------------------------|
| E>Eye  | Craig et al 2015. Prospective trial of intense pulsed light for the treatment of meibomian gland dysfunction. | 28  | Improved symptoms                   | Not reported                        |
|        |                                                                       |     | Improved tear stability              |                                     |
|        | Piyacomp et al 2020. Efficacy and Safety of Intense Pulsed Light in Patients With Meibomian Gland Dysfunction: A Randomized, Double-Blinded, Sham-Controlled Clinical Trial. | 114 | Improved symptoms                   | No adverse events                   |
|        |                                                                       |     | Improved tear stability              |                                     |
|        |                                                                       |     | Improved meibomian gland function    |                                     |
| Quadra4 + loteprednol | Gupta et al 2016. Outcomes of Intense Pulsed Light Therapy for Treatment of Evaporative Dry Eye Disease. | 100 | Improved symptoms                   | No adverse events                   |
|        |                                                                       |     | Improved tear stability              |                                     |
|        |                                                                       |     | Improved meibomian gland function    |                                     |
| 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. | 91  | Improved symptoms                   | Blistering, cheek swelling, conjunctival cyst, floaters, hair loss (brow and forehead), light sensitivity, redness |
|        |                                                                       |     | Improved tear stability              |                                     |
|        |                                                                       |     | Improved meibomian gland function    |                                     |
| 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. | 35  | Improved symptoms                   | No adverse events                   |
|        |                                                                       |     | Improved meibomian gland function    |                                     |
| E>Eye + expression | Albietz et al 2018. Intense pulsed light treatment and meibomian gland expression for moderate to advanced meibomian gland dysfunction. | 26  | Improved symptoms                   | No adverse events                   |
|        |                                                                       |     | Improved tear stability              |                                     |
|        |                                                                       |     | Improved meibomian gland function    |                                     |
| Lumenis M22 + expression | Arita et al 2018. Multicenter study of intense pulsed light therapy for patients with refractory meibomian gland dysfunction. | 31  | Improved symptoms                   | Not reported                        |
|        |                                                                       |     | Improved tear stability              |                                     |
|        |                                                                       |     | Improved meibomian gland function    |                                     |
| Lumenis M22 + expression | Arita et al 2019. Therapeutic efficacy of intense pulsed light in patients with refractory meibomian gland dysfunction. | 45  | Improved symptoms                   | No adverse events                   |
|        |                                                                       |     | Improved tear stability              |                                     |
|        |                                                                       |     | Improved meibomian gland function    |                                     |
| 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. | 30  | Improved symptoms                   | No adverse events                   |
|        |                                                                       |     | Improved tear stability              |                                     |
|        |                                                                       |     | Improved meibomian gland function    |                                     |
| 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. | 40  | Improved symptoms                   | Not reported                        |
|        |                                                                       |     | Improved tear stability              |                                     |
|        |                                                                       |     | Improved meibomian gland function    |                                     |

(Continued)
Table 5 (Continued).

| Device | Paper                                                                 | N  | Clinical Outcomes That Were Improved | Adverse Events Related to Treatment |
|--------|-----------------------------------------------------------------------|----|--------------------------------------|-------------------------------------|
| E>Eye  | Guilloto et al 2017. Effect of pulsed laser light in patients with dry eye syndrome. | 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. | 40 | Improved symptoms                    | No adverse events                   |
| E>Eye  | Karaca et al 2018. Intense regulated pulse light for the meibomian gland dysfunction. | 26 | Improved symptoms                    | 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. | 17 | Improved symptoms                    | 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. | 35 | Improved symptoms                    | Not reported                        |
| Eye-light (IPL + LLLT) | Solomos et al 2021. Melbomian Gland Dysfunction: Intense Pulsed Light Therapy in Combination with Low-Level Light Therapy as Rescue Treatment. | 11 | Improved symptoms                    | 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. | 230 | Improved symptoms                    | No adverse events                   |
| Eye-light + MY MASK-E | Marta et al Intense Pulsed Plus Low-Level Light Therapy in Meibomian Gland Dysfunction. | 31 | Improved symptoms                    | No adverse events                   |
| Icon Aesthetic System | Cheng et al Intense Pulsed Light Therapy for Patients with Meibomian Gland Dysfunction and Ocular Demodex Infestation. | 25 | Improved symptoms                    | 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. | 44 | Improved symptoms                    | 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. | 72 | Improved symptoms                    | No adverse events                   |
The Blephasteam can be tailored for use in-office or at-home. The device consists of a goggle with disposable rings that are moistened with saline to increase humidity within the chambers. A controller provides heat to the chambers. The treatment length is 10 minutes, during which the patient can have their eyes open or closed. 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, 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. 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. 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. 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. 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.

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), 85% (17/20), and 95% (19/20) of studies, 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, 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.

Table 5 (Continued).

| Device | Paper | N | Clinical Outcomes That Were Improved* | 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. | 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. | 120 | Improved symptoms Improved tear stability Improved meibomian gland function | No adverse events |

Notes: *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.
Intense Pulsed Light

IPL has been used in dermatology to treat various skin conditions such as rosacea, dyspigmentation, reducing telangiectasia, and fine wrinkles. The delivery of non-coherent light (500 nm – 1200 nm) may treat MGD through these potential mechanisms: the first is direct delivery of heat to the meibomian glands which serves to melt and facilitate meibum flow, the second is the photococagulation 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), 87% (20/23), and 87% (20/23) of studies reviewed, respectively. Two studies reported adverse events related to using IPL. Notably, pigmentation 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.

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; in contrast, the E-swin E>Eye (Houdan, France) applies 5 flashes per eye using a single pass. 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, magnetic fields that alter biological tissue function, which has been found to have anti-inflammatory and tissue regeneration properties. This review found only one study examining the effect of quantum molecular resonance on treating MGD (Table 6). Ferrari et al (n = 25) found that quantum molecular resonance improved symptoms, tear stability, and meibomian gland function. As with IPL, 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. 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

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. This technology was adapted from dermatological applications for rejuvenating skin. 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. Currently, there is only one study indexed in PubMed that examines the effect of LLLT on MGD (Table 6). 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 and tissue regeneration properties. This review found only one study examining the effect of quantum molecular resonance on treating MGD (Table 6). Ferrari et al (n = 25) found that quantum molecular resonance improved symptoms, tear stability, and meibomian gland function. 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. 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
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.

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