Archives of Dermatological Research (2019) 311:653–672
https://doi.org/10.1007/s00403-019-01951-8

REVIEW

Carrier oils in dermatology

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Received: 26 March 2019 / Revised: 24 June 2019 / Accepted: 4 July 2019 / Published online: 18 July 2019

Abstract

Wounds are a common medical infliction. With the increase in microbial resistance and a shift of interest towards complementary medicines, essential oils have been shown to be beneficial in suppressing microbial growth. However, in practice, essential oils are more often diluted into a base due to the risk of topical adverse effects, such as dermatitis. There is a lack of collated evidence-based information on toxicity and efficacy of carrier oils. The current information on the subject matter is restricted to generic, aroma-therapeutic books and pamphlets, based on anecdotal evidence rather than an experimental approach. Therefore, this review aimed at identifying the recommended carrier oils used in dermatology and thereafter collating the scientific evidence to support the use of carrier oils together with essential oils recommended for dermatological use. *Aloe vera* gel had multiple studies demonstrating the ability to enhance wound healing; however, several other carrier oils have been largely neglected. It was observed that the extracts for certain plant species had been used to justify the use of the carrier oils of the same plant species. This is an inaccurate cross assumption due to the difference in chemical composition and biological activities. Lastly, despite these carrier oils being recommended as a base for essential oils, very little data was found on the interactive profile of the carrier oil with the essential oil. This review provides a platform for further studies, especially if essential oils are to receive credence in the scientific field.

Keywords Fixed oils · Essential oils · Aromatherapy · Skin · Healing · Infection

Introduction

The skin is the largest organ of the body and is repeatedly exposed to injury and infection causing a disruption of the normal anatomical structure, creating a wound. There is a process followed in wound healing, which is essential in preventing chronic wounds, secondary infection, or fatal wounds. If the sequential stages are not adequately followed, then progress in healing is retarded [137, 208]. These healing phases comprise the following stages:

- Inflammatory phase (plugs the wound and facilitates white cell entry, clearance of bacteria). One of the main causes for this prolonged delay is local infection [155, 208], due to the inflammatory stage. Although inflammation is a natural occurrence, once injury has occurred, it has a tendency to hinder the rate of healing [212].
- Proliferative phase (allows for new skin structure, and fibroblast formation which becomes collagen for wound strength, where blood vessels are formed) [208].
- Contraction (reinforces wounds strength) [208].
- Maturation and remodelling [208].

Healing usually follows from the moment injury occurs to the skin. Wounds that heal within an expected timeframe (5 days to 3 weeks) are known as acute wounds [137]. Injured skin permits pathogens into the body, resulting in an impediment of the healing process. Accelerated wound healing is required to decrease the risk of infection and to improve patient quality of life through the reduction of medical costs associated with prolonged injury [23]. Wound management is still an area of conjecture and difficulty as despite progresses in surgery, prolonged healing and death still occur [25].

Burns are considered as one of the most severe skin inflictions that often result in treatment difficulty, incapacity or death. To improve patient mortality, the infection needs to be

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prevented or diminished and wound healing augmented [7, 42, 50, 112, 258]. Burn wounds are treated with the goal of increasing blood flow to the burn, decreasing inflammation, and most importantly inhibiting infection. All burn wound dressings should incorporate antimicrobial properties [7]. Epithelialization is the final step in the proliferative phase, a process delayed in full thickness burns (where the burnt tissue involves the epidermal, dermal and varying amounts of the subcutaneous layers) [241]. With infections being the main cause of mortality in these types of injuries, research is aimed at curbing the development of resistance and augmenting the rate of healing. In current practice, the main topical antimicrobial agent applied to burn wounds is an ointment comprising 1% silver sulfadiazine [50]. Unfortunately, the application of this ointment is limited in patients with a sulphur allergy, or to those that experience skin irritation, which reduces skin restoration and thus reduces the rate of healing [258].

Currently, natural products have become a popular alternative in the treatment and management of health where the "green generation" emphasising natural product development is constantly being developed. Several reviews exist discussing the potential of natural products for wound care [168, 198, 201, 211]. Natural products such as "Dragon's Blood" (*Dracaena cinnabari* Balf.f.) and "Jack in the Bush" (*Chromolaena odorata* (L.) R.M.King & H.Rob.) have been demonstrated to slow bleeding, speed up wound healing, treat burns, and alleviate other conditions associated with healing [106, 108, 138, 169, 202, 204]. In a literature review by Bodeker et al. [26], a common feature noted for increased wound healing by natural products is the innate antimicrobial activity, highlighting the usefulness of these natural products as wound healing agents. It is important to control infections and wounds on the skin from micro-organisms such as *Staphylococcus aureus*, *Escherichia coli*, *Streptococcus pyogenes*, *Corynebacterium* spp., and *Pseudomonas aeruginosa* for successful healing to occur [106, 130, 197, 217]. With one of the most popular natural products in dermatology being essential oils, numerous studies have been collated and reviewed for commercial essential oil use against skin pathogens [187]. Since then, further studies [18, 186, 188, 223, 259] have added to the knowledge of commercial essential oils and antimicrobial activity against pathogens of the skin. The review by Orchard, van Vuuren [187], however, identified that in spite of these studies, there is still a lack of information regarding the specific application of essential oils.

Essential oils are seldom used neat (undiluted) directly upon the skin. They are generally blended into a base before application as a means to dilute the essential oils, potentially (according to the aroma-therapeutic literature [43, 45, 46, 68, 96, 136]) making them less toxic to the skin. Essential oils are also frequently blended with a base in the belief that the combination may slow down the rate of essential oil evaporation and increase essential oil absorption through the skin [46, 132]. In addition, some bases may contribute to the therapeutic effects, such as to add to skin healing, moisturising and nourishment [32, 43]. The possible bases that essential oils can be diluted in for dermatological use include creams, gels, or other fixed carrier oils [32, 45, 128]. Carrier oils act as a medium into which essential oils are mixed and are believed to be capable of enhancing skin absorption of the diluted essential oil due to their composition of small molecules identified as being closely related to sebum, the skins naturally producing oil [96]. Carrier oils and essential oils are distinctly separate. Essential oils are aromatic (fragrant) oils that evaporate and are made up of multiple constituents such as oxygenated compounds (e.g. phenols, alcohols), terpene hydrocarbons (e.g. monoterpene hydrocarbons, sesquiterpenes), ketones, phenylpropanoids, aldehydes, etc. These are obtained via different distillation methods from the fragrant parts of a plant. Carrier oils, also known as fixed oils, "vegetable" oils, macerated oils or oily extracts, are predominantly made up of different lipids such as fatty acids or waxes, vitamins and minerals, (structurally, essential oils do not contain fatty acids, vitamins, or minerals). Carrier oils are obtained via maceration, centrifugation, cold press or extraction from the fatty portion of a plant and do not evaporate (hence the term, fixed oil) and are therefore less volatile than essential oils.

There are numerous carrier oils identified that are frequently used and mentioned for the skin within the aroma-therapeutic books and pamphlets (Table 1). Due to the common use of carrier oils in aroma-therapeutic practice, there is a need to collate available data to identify the gaps in research and highlight scientific evidence to endorse use. The contributory activities for dermatology, in order to increase healing rates, include the antimicrobial, anti-inflammatory, anti-oxidant and fibroblast enhancement potential [125, 219].

Thus, this literature review serves to provide dermatologists, aromatherapists and other skin practitioners with an evidence-based review of research documenting carrier oils and serves to identify natural therapeutic options incorporating carrier oils for treating dermatological conditions. Furthermore, gaps in research are highlighted providing researchers with leads for future investigation.

Methods

Searching strategy/selection of papers

On examining the scientific evidence pertaining to factors involved in wound and skin healing properties of carrier oils, a summary of the potential of carrier oils was proposed and recommendations for further research were proposed. The first step of analysis was to examine several aromatherapy resources

Table 1 Carrier oils recommended for the skin according to the aroma-therapeutic literature

Scientific name	Common name	Use	References
Aleurites moluccana	Kukui nut	Chapped and dry skin, eczema, psoriasis and **wounds**[a]	[96]
Aloe vera	Aloe vera	Demonstrates **anti-inflammatory** and **healing** properties. Is used on **burns**, **cuts**, eczema, **infected cuts**, shingles, sunburn, **psoriasis**[b] and **wounds**	[96]
Borago officinalis	Borage	Contains vitamin E and possesses **cell regenerating** and **healing properties**. Used in skincare cosmetics for aged, damaged, dry and wrinkled skin	[45, 96, 136]
Calendula officinalis	Calendula	Demonstrates **anti-inflammatory** and **healing** properties. Is used for **athlete's foot**, **bed sores**, chapped/cracked skin, eczema, **injured skin**, **rashes**, scars, sunburn, **ulcers**, varicose veins and **wounds**	[46, 67, 68]
Cocos nucifera	Coconut	As emollient to treat dry skin and the scalp	[43, 46]
Corylus avellana	Hazelnut	Astringent and good skin penetration properties. Aids in treating **acne**, ageing and dry skin, **inflammation** and scars	[43, 46, 68, 136]
Hypericum perforatum	St John's wort	As an analgesic, **antiseptic** and **healing agent** in treating **burns**, **injured skin**, **shingles**, **ulcers** and **wounds**	[46]
Helianthus annuus	Sunflower oil	Not usually recommended for aromatherapy. It has, however, been found to be useful for **acne**, blemishes, healing scar tissue, seborrhoea and **ulcers**	[43, 96]
Juglans regia	Walnut	For **inflammatory**, peeling and **pruritic** conditions	[43]
Linum usitatissimum	Linseed	As an emollient	[43]
Macadamia ternifolia	Macadamia	**Cell regenerator**, emollient, **healing agent** and nourisher for treating aged, damaged, dry or hardened skin	[43, 96]
Oenothera biennis	Evening primrose	Assists in **cell regeneration**, **healing** and moisturising; thus, is useful in beauty care for aged skin, blemishes, dry skin, eczema, **psoriasis**, skin problems and wrinkles	[43, 45, 46, 68, 96, 136]
Persea americana	Avocado	Demonstrates **cell regeneration**, **healing** and nourishing abilities; it also allows for good penetration into the skin. Used in beauty care for aged, damaged, dehydrated and dry skin; eczema, sunburn and wrinkles	[43, 45, 46, 68, 96, 136]
Prunus armeniaca	Apricot kernel	Allows for good absorption of essential oils. Used in beauty care for delicate, dry and sensitive skin, eczema, facials, **inflammation**, massages and oily conditions	[43, 45, 46, 68, 96, 136, 149]
Prunus dulcis/Prunus amygdalis	Sweet almond	**Healing** and nourishing abilities in treating cradle cap, dandruff, eczema, chapped and dry skin, dermatitis, **inflammation**, **pruritus**, **psoriasis**, seborrhoea dermatitis, sensitive skin and sunburn	[32, 43, 45, 67, 68, 96]
Prunus persica/Prunus vulgaris	Peach kernel	Allows for good absorption of the essential oil by the skin, for oily skin conditions or as an emollient for aged or dry skin	[43, 45, 136]
Simmondsia chinensis	Jojoba	Demonstrates **antifungal, cell regenerating**, emollient, **healing** and moisturising properties thus often used in cosmetics. It is a popular base that resembles sebum and allows for good absorption of essential oils, thus it is used in treating **acne**; dehydrated, dry, oily, problematic and sensitive skin; eczema, **inflammation**, **psoriasis** and scars	[32, 43, 45, 46, 68, 95, 96, 136]
Triticum vulgare	Wheatgerm	Has cell regenerating properties and vitamin E to treat aged, dry and damaged skin, dermatitis, stretch marks and sunburn	[43, 46, 67, 136]
Vitis vinifera	Grapeseed	Demonstrates astringent, **cell regenerating**, **healing** and toning properties; it contains vitamin E and is used in skin creams as a softener. Used for treating **acne**, oily or **injured skin** conditions	[32, 43, 46, 67, 96, 149]

[a]Conditions related to wounds are highlighted in bold

[b]Psoriasis and rashes are included due to the risk of secondary infection leading to wounds

available to the layman; these included books and online sources (such as "blogs"). This was necessary so that a list of the carrier oils used in dermatology could be compiled. Thereafter, scientific articles were examined from three electronic databases (Pubmed, Science-Direct and Scopus) during the periods of 2016–May 2018. No other reviews of carrier oils were found/identified; thus, as this appears to be the first review of carrier oils, no limitation was applied to publication source date. The filters used included "carrier oils" or the scientific or common name of each carrier oil as listed in Table 1. Additional filters

included “antimicrobial”, “antibacterial”, “skin”, “infection”, “dermatology”, “acne”, “wounds”, “anti-inflammatory”, “anti-oxidant”, “oily extract”, “macerate” and “toxicity”.

Inclusion and exclusion criteria

Due to the scarcity of research conducted on the majority of carrier oils, and in order to effectively evaluate the biological potential, a broad selection criterion was stipulated. Inclusion criteria for this study included:

1. In vitro studies for bacterial and fungal pathogens of carrier oils. Although the broth micro-dilution is the preferred method for determining the antimicrobial activity of oily substances [187], reports of antimicrobial investigation using the disc diffusion are still included due to the scarcity of articles containing the broth dilution technique.
2. In vivo studies.
3. Case reports.
4. Animal studies.
5. All clinical trials.
6. Reviews
7. General aroma-therapeutic internet sources were avoided in most cases due to the lack of peer review.

Publications were excluded for the following reasons:

1. Lack of accessibility to the complete paper.
2. If no relevance to the carrier oils could be identified.
3. If in a language not understood by the authors of the review.
4. Pathogens studied are not relevant to skin disease.
5. Extracts and essential oils were excluded due to the variance in chemical composition.

One of the challenges faced was the lack of clarity on what form of the plant was being used, for example, whether the study made use of the fixed oil or macerated oil, the essential oil, or the extract. Effort was made to contact the authors of the original articles where this was not clear and, if uncertainty remained due to lack of response from the original authors, the study was excluded.

Findings and results

Description of studies

After the initial database search, 608 articles were identified. After the removal of duplicate studies obtained from different search engines, the article count was reduced to 309. Abstracts were then analysed and additional reports were removed according to the inclusion and exclusion criteria, which brought the final count of articles reviewed to 216. Of this 82 were in vitro studies, 42 in vivo studies, 48 clinical trials/human studies/human reports, and 34 reviews. The process that was followed is summarised in Fig. 1.

Carrier oils

Table 1 lists the carrier oils used on the skin as recommended in the aroma-therapeutic literature. These recommendations have been taken from popular essential oil books, available to the layman, where recommended blends for therapeutic application are made. What follows is a full analysis of the scientific literature to determine if any scientific evidence exists that supports the therapeutic use of these carrier oils on the skin. Extracts and essential oils were excluded. The disc diffusion assay for testing the antimicrobial activity of plant extracts is an acceptable method; however, for the carrier oils and gels, the broth micro-dilution should be used due to the poor diffusion of oily substances through agar. This is also the preferred method for essential oils, is the least wasteful, and produces high output of accurate results [91, 187].

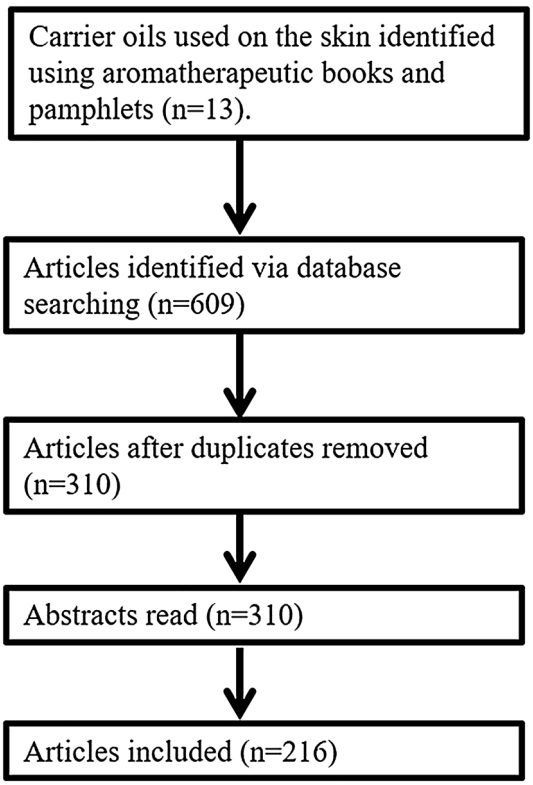

Fig. 1 Flow diagram of review approach

Aleurites moluccana (L.)

Aleurites moluccana (kukui nut syn. candlenut) contains oleic acid (15.5–47.98%), linoleic acid (34.4–51.12%), palmitic (5.51–7.2%), linolenic (26.3–29.4%), and stearic acid (2.38–9.30%), and has been demonstrated to display anti-oxidant activity, which was attributed to the presence of γ-tocopherol (vitamin E) [9, 35, 234]. No studies were found pertaining to the anti-inflammatory, antimicrobial or wound healing abilities of *A. moluccana* carrier oil; however, one pilot study found the oil to improve psoriasis, although there was no statistical significance compared to the placebo mineral oil [30]. Anti-inflammatory and wound healing studies have been limited to the extracts [38, 152, 176].

Aloe vera Mill./*Aloe barbadensis* Mill.

Aloe vera (aloe vera) is a popular carrier for diluting essential oils [208]. The gel is the more popular form used, as opposed to the carrier oil (a macerate oil of aloe vera) [80, 82, 96, 214]. The plant is used worldwide and is one of the most popular natural products used for wound healing [201]. The plant is approved as a hydrogel for pressure ulcers by the Food and Drug Administration (FDA), and the gel is often recommended for burn wounds globally and has been used since Roman times for various skin ailments [47, 143, 254, 256].

The gel has been shown in vivo and in clinical trials to be effective in wounds (burns, leg ulcers, diabetic ulcers, pressure ulcers, caesarean and episiotomy) healing and pain relief [7, 20, 34, 41, 47, 64, 65, 81, 100–102, 107, 120, 121, 161, 163, 190, 212, 237, 248, 254, 256, 260, 262].

Furthermore, studies have denoted the ability of the gel to treat wounds unresponsive to conventional antibiotics such as those colonised by *S. aureus* (penicillin, clindamycin, co-trimoxazole and cefoxitin resistant) and *P. aeruginosa* (amoxiclav, ceftizoxime, co-trimoxazole and ofloxacin resistant) [15, 17]. *Aloe vera* gel was also found to absorb malodour, proving it to be useful for foul-smelling wounds [139]. One study did, however, report *A. vera* gel, compared to the control of silver sulfadiazine cream to hinder healing [119]. However, on reviewing the study, it was indicated that if compared to the control, the healing was merely slower than that of the control commercial product and not entirely delayed.

There are numerous commercial products, such as those by Nivea®, Organics® and Vaseline®, that make use of this substance in gels, creams, and hair products [83]. The use of *A. vera* gel in dermatology has been extensively investigated and it has been reported that topical *A. vera* gel is also useful in treating atopic dermatitis [72], dry skin, erythema [77], and radiation dermatitis [182]. The gel has also been shown to increase the permeation of anti-inflammatories [78]. The soothing properties of the gel have been incorporated in impregnating surgical gloves with the aim to reduce skin irritation [126]. Furthermore, the constituents have shown immune system enhancement [206].

The healing and repairing actions may partly be attributed to the antimicrobial activity against pathogens such as *S. aureus, P. aeruginosa, E. coli,* and Methicillin-resistant *S. aureus* (MRSA) [17, 71, 91, 212, 255].

The wound healing abilities may also be due to the ability to decrease inflammation, increase human fibroblast intracellular communication and proliferation, increasing or maturation of collagen, and enhance epithelialization and granulation tissue or angiogenesis [1, 14, 21, 102, 107, 110, 163, 190, 249, 251, 262].

The components found in *A. vera* gel include anthracene hydroxyl derivatives such as aloins A and B_2, sugars such as glucose, mannose, and cellulose and various enzymes like oxidase, amylase, and catalase. It also includes vitamins and minerals such as B1, B2, B6, C, E, calcium, chrome, copper, folic acid, sodium, magnesium, and zinc [97, 163, 245]. The mucilage contains vitamin E and vitamin C and some of amino acids, contributing to its anti-oxidant, anti-inflammatory and accelerated wound healing abilities [93, 216]. Lupeol and salicylic acid are present in the gel and have been identified as being responsible for antimicrobial activity [28, 160, 216]. Aloesin in *A. vera* gel is known to contribute towards anti-oxidant and anti-inflammatory activity [266].

Aloe vera gel is also popular with several reviews evident emphasising anti-inflammatory, accelerated wound healing, anti-oxidant and anti-pruritic activities. There has been a contribution towards including *A. vera* into hydrogels and polymers [21, 28, 71, 76, 88, 143, 147, 160, 177, 212, 230, 240, 245, 264]. One thorough review by Dat et al. [51] on *A. vera* for wound treatment concluded that there is insufficient evidence to advocate the use for acute and chronic wounds due to the lack of high quality trials. Evidence, however, does highlight *A. vera* for its potential as certain trials did find *A. vera* to heal wounds at the same rate or faster than the comparator.

The carrier oil (macerate of *A. vera*) has been reported to contain high levels of linoleic acid (59.8%) and oleic acid (23.0%) and has been shown to exhibit noteworthy antimicrobial activity ($\leq$ 1.00 mg/ml) against *P. aeruginosa* and *Brevibacterium epidermidis*, however, poor antimicrobial activity has been found against *Propionibacterium acnes*, *S. epidermidis*, *S. aureus* (including antibiotic resistant strains), *E. coli* and *Candida albicans* reference strains. The macerated oil was reported to display no toxicity at 24 h, using the brine shrimp lethality assay [185].

There is no shortage of evidence that *A. vera* gel is a product of great potential. It is in fact a well-studied natural

product with clinical trials and reviews reporting it as an effective agent with the potential to accelerate wound healing; however, research regarding the specific carrier oil is lacking and should be possibly given the equivalent attention [7, 20, 34, 41, 64, 71, 76, 100, 107, 120, 121, 160, 161, 177, 190, 237, 240, 245, 248, 260].

Borago officinalis L.

Borago officinalis (borage) seed oil is a rich source of γ-linolenic acid (GLA) (omega 6) (11.65–16.89%) which is known for its natural anti-inflammatory activities and lack of common side effects [13, 57, 115, 127, 165]. It also contains other fatty acids such as oleic acid, palmitic acid, stearic acid, eicosenoic acid and erucic acid [13, 127]. The oil has displayed anti-inflammatory activity [118] and has been shown to be non-toxic [252]. *Borago officinalis* seed oil improves skin conditions by decreasing dryness and itchiness [156] and has been demonstrated in two separate studies to cause a significant improvement in clinical symptoms in children with atopic dermatitis [113, 114]. The oral supplement of this oil has also been shown to assist with mild atopic dermatitis [75].

Calendula officinalis L.

Calendula officinalis (calendula) is often used for wound care and is approved by the German Health Commission for healing wounds and leg ulcers. An ointment of *C. officinalis* is used globally for treating atopic dermatitis and pruritus, with little reported side effects [178]. The carrier oil contains fatty acids such as calendic acid (51.47–57.63%), linoleic acid (28.50–66.8%), oleic (4.44–24.6%) and palmitic acid (3.86–4.55%) [62, 185]. It has been shown to enhance the healing process of diabetic foot ulcers via the acceleration of the tissue repairing process [52] and *C. officinalis* formulated into a lamellar gel emulsion was shown to increase the rate of wound healing by exerting anti-inflammatory activity and increasing collagen production [180]. The lamellar gel was also reported to be non-toxic. An ointment containing *C. officinalis* carrier oil has been shown to increase episiotomy wound healing [64]. The carrier oil was investigated in vitro and has been reported to display poor antimicrobial activity against *P. aeruginosa, Brevibacterium* spp., *P. acnes*, *S. epidermidis*, *S. aureus* (including antibiotic resistant strains), *E. coli* and *C. albicans* reference strains. Using the brine shrimp lethality assay, no toxicity was reported at 24 h [185].

Cocos nucifera L.

Cocos nucifera (coconut) oil has shown increased healing of wounds in the rat model, which is attributed to its anti-oxidant ability and increase in collagen cross-linking [175]. It is also beneficial in the treatment of burn wounds, as it has been shown to increase the rate of epithelialization [238]. *Cocos nucifera* appears to be effective for the treatment of atopic dermatitis, and was shown, along with its main compound (monolaurin), to inhibit the growth of colonising *S. aureus* [37, 261]. *Cocos nucifera* has been shown to possess antimicrobial (*C. albicans*, *S. aureus* and *P. aeruginosa*) and antiviral activity against pathogens such as herpes simplex virus-1 [5, 109, 179, 192, 231, 253]. It is a useful carrier oil for the herbal treatment for wounds due to its short chain and saturated fatty acids preventing the concoction from becoming oxidised and rancid [220]. The carrier oil contains 92% saturated fatty acids, with approximately 50% lauric acid, followed by capric acid and caprylic acid [196, 199]. Monolaurin, a component of *C. nucifera,* is able to alter the cell wall and penetrate and disrupt cell membranes of bacteria [261].

Corylus avellana Thunb.

No studies were found pertaining the antimicrobial, anti-inflammatory, anti-oxidant, or wound healing abilities of *Corylus avellana* (hazelnut) carrier oil. However, the oil is reported to contain oleic (68.0–85.0%) and linoleic (7.0–15.0%) acids and vitamin E, B1, B2, B6, niacin, ascorbic acid, and folic acid [44, 66]. Anti-inflammatory and antimicrobial investigation is limited to the aqueous extract [181].

Hypericum perforatum L.

The *Hypericum perforatum* (St John's wort) extract has been used in folk medicine for skin injuries and burns [208, 226, 273]. *Hypericum perforatum* macerate oil (carrier oil) has been shown to enhance the healing rate of caesarean wounds and minimized scar formation as a result. The carrier oil was also found to display no irritation, and in fact assists in preventing pruritis [222]. Another macerate of *H. perforatum* was shown to be effective in treatment of diabetic wounds [69]. *Hypericum perforatum* macerate incorporated into an ointment was also shown to be beneficial with no signs of skin irritation [205]. Another study also demonstrated wound healing activity, which was attributed to the anti-inflammatory activity and enhancement of collagen formation [243, 244]. This may likely be the mechanism of enhanced wound healing considering that the oil macerate has displayed poor to no antimicrobial activity against different *S. aureus* strains [142]. Another study found that the oral use of the oily extract (syn. for macerated oil) was also beneficial for diabetic wounds [11]. The carrier oil was reported in vitro to display noteworthy antimicrobial activity against *B. epidermidis*, however, poor antimicrobial

activity against *P. aeruginosa*, *P. acnes*, *S. epidermidis*, *S. aureus* (including antibiotic resistant strains), *E. coli* and *C. albicans* reference strains. Using the brine shrimp lethality assay, low toxicity was reported at 24 h [185]. A literature review on the beneficial biological activities of the plant extract is available [265].

Helianthus annuus L.

Helianthus annuus (sunflower) carrier oil predominantly contains linoleic fatty acid [2]. The ozonised form of this carrier oil (OLEOZON ®) was presented as an effective alternative in treating onychomycosis as shown in a controlled randomised trial [154]. The carrier oil has been shown to inhibit the growth of *E. coli*, *S. aureus* and *C. albicans* [2, 247]. The ozonised form was also shown to display anti-inflammatory and moderate antimicrobial activity against *S. aureus*, *P. aeruginosa*, *E. coli* and *C. albicans*. The carrier oil was shown to increase the healing of excision wounds on rats [218]. Two randomised control trials have been reported using *H. annuus* carrier oil as a prophylaxis for decreasing new-born infections when used as an emollient three times a day [48, 49]. The carrier oil has also been reported as being a useful agent for removing tar from tar burns [116, 144, 257].

Juglans regia L.

The carrier oil of *J. regia* (walnut) contains the fatty acids: linoleic acid (45.0–60.0%), γ-linolenic acid (10.75–13.37%) and oleic acid (17.66–35.0%) [66, 117, 225]. Little to no antibacterial activity has been reported against *S. aureus*, *S. pyogenes* and *E. coli* [117, 225] and no inhibition has been observed against *C. albicans* [5]. No further studies of this carrier oil potential in wound treatment were found. Research into the anti-oxidant activity is limited to the essential oil activity and extract [6, 10, 195, 210, 227, 272].

Linum usitatissimum Griseb.

Linum usitatissimum (linseed) carrier oil predominantly contains polyunsaturated fatty acids (PUFA) and essential fatty acids (EFA), such as linolenic acid and linoleic acid; with monounsaturated fatty acid (MUFA) such as oleic acid also present [140, 191]. *Linum usitatissimum* carrier oil has been shown to enhance cell proliferation and to facilitate wound healing in vitro [140]. The carrier oil was also found to increase wound contraction of second degree burns in rat models (more than the control) and it was concluded that *L. usitatissimum* potentially stimulated angiogenesis [19]. The pharmacological properties, whereby growth factors, fibroplasia and neovascularization are stimulated by this carrier oil, are as a result of the oil containing PUFAs and MUFAs [98, 146]. In previous studies, a low concentration of *L. usitatissimum* carrier oil (10%) was tested in rat models and reported to increase the rate of wound healing in tested subjects [55]. The study, however, only compared the activity of *L. usitatissimum* oil to petroleum, which is not as suitable a control, as petroleum has been shown to retard the rate of wound healing [63]. Investigation regarding the antimicrobial activity of *S. aureus* and *Staphylococcus epidermidis* is limited to the extract [170, 171].

Macadamia ternifolia F. Muell.

Macadamia ternifolia (macadamia carrier oil) is used for the skin, predominantly as a cosmetic agent (used in lipstick, anti-acne products, hair and skin conditioners, etc.) and is mentioned in the International Cosmetic Ingredient Dictionary and Handbook [8, 33]. Oleic acid 54–68%, palmitoleic acid 16–23% and palmitic acid 7–10% are the main fatty acids found in *M. ternifolia* [8, 29]. Despite the claim that the carrier oil is beneficial in skin healing and nourishment [43, 96], no studies were found pertaining to the anti-inflammatory, anti-oxidant, or wound healing abilities; however, poor antibacterial activity (> 2.00% v/v) against *Acinetobacter baumannii*, *E. coli*, *P. aeruginosa* and *S. aureus* has been reported [94]. The high levels of palmitoleic acid are theorised to contribute towards the nourishing nature of the carrier oil [8].

Oenothera biennis L.

Oenothera biennis (evening primrose) carrier oil is predominantly made up of gamma linoleic acid (GLA) (70.0–77.0%) [66]. The topical application of *O. biennis* in a water-in-oil emulsion was found to permeate into the skin and stabilize the stratum corneum while modulating cell kinetic profiles [85, 164], making the topical application of *O. biennis* an effective moisturizer. The carrier oil of *O. biennis* is used in acne treatment [228] and has been shown to decrease inflammation [270]. One of the constituents of this carrier oil, gallic acid, has previously been reported to demonstrate phytotoxic and mild antifungal activity [233]; however, poor antimicrobial activity of *O. biennis* against *A. baumannii*, *E. coli*, *P. aeruginosa* and *S. aureus* has been reported [94].

Persea americana Mill.

Persea americana (avocado) carrier oil contains a variety of components including oleic (31.8-75.0%), linoleic (6.1-22.9%), palmitic (12.0-20.0%), palmitoleic (2.0-10.0%) and linolenic (0.4-4.0%) acids, β-sitosterol, β-carotene, lecithin,

squalene, proteins, beta-carotene, minerals, and vitamins A, C, D, and E [66, 148, 173, 189, 221, 236, 246, 250]. The carrier oil was reported to display poor antimicrobial activity against *P. aeruginosa*, *Brevibacterium* spp., *P. acnes*, *S. epidermidis*, *S. aureus* (including antibiotic resistant strains), *E. coli* and *C. albicans* reference strains. Using the brine shrimp lethality assay, no toxicity was reported at 24 h [185]. The carrier oil has been shown to increase wound healing by increasing collagen synthesis [173]. de Oliveira et al. [53] reported that a dilution of 50% *P. americana* carrier oil (containing oleic acid at 47.20%, followed by 23.66% palmitic acid and linoleic acid at a concentration of 13.46%) demonstrated an increased rate in the proliferative phase to improve wound healing within rat subjects. The results demonstrated anti-inflammatory activity, increased re-epithelisation and increased collagen density. Future studies should consider using the 100% concentration of the carrier oil, as it is used in aromatherapy as the diluent.

Prunus armeniaca Blanco.

Prunus armeniaca (apricot kernel) carrier oil contains predominantly oleic (55.0–70.0%) and linoleic (20.0–35.0%) acids [66] and has been reported to display noteworthy antimicrobial activity against *B. epidermidis* and poor antimicrobial activity (> 2.00% v/v) against *E. coli*, *P. aeruginosa*, *S. aureus* (including antibiotic resistant strains), *P. acnes*, *S. epidermidis*, *C. albicans* and *A. baumannii* [94, 185]. Very low toxicity (4.35%) was reported at 24 h using the brine shrimp assay [185]. Reports on the anti-oxidant activity are limited to the extract [207, 269].

Prunus dulcis D.A.Webb syn. *Prunus amygdalus* Stokes.

Prunus amygdalus (almond) carrier oil contains oleic acid (60.00–75.0%) and linoleic acid (20.0–67.5%) [66, 117, 224], vitamin E [162], as well as numerous oligosaccharides such as arabinose, galactose, xylose, rhamnose, glucose, and mannose [27]. Oligosaccharides are contributory towards the wound healing as demonstrated in a study where oligosaccharides (extracted from almond gum) were shown to enhance the healing rate of wounds in a rat model with complete epithelial regeneration with no reported side effects. The augmented healing was speculated, by the study, to be due to increased neo-blood vessels and collagen formation by the oligosaccharides [27]. *Prunus amygdalus* carrier oil has been shown to effectively permeate to the outer layer of the subcutaneous level of the skin and act as a moisturiser [239]. However, the carrier oil was shown to display poor to no antimicrobial activity against pathogens such as *C. albicans*, *E. coli*, *P. aeruginosa*, *S. aureus* and *A. baumanii* [5, 94, 117].

Prunus persica (L.) Batsch syn. *Prunus vulgaris* Schur.

Prunus persica (peach kernel) carrier oil has been found to contain high levels of oleic and linoleic acid [158]; however, this carrier oil has not yet been investigated for antimicrobial activity or its wound healing potential. Research regarding the antimicrobial and anti-oxidant activity of this plant is limited to the extract [22, 141].

Simmondsia chinensis C.K. Schneid.

Simmondsia chinensis (jojoba) is a non-comedogenic and non-irritating liquid wax which has been used in numerous skin products [111]. The carrier oil contains the fatty acids eicosenoic (65.0–80.0%), erucic (10.0–20.0%) and palmitic (3.0%) acid [158] and is used regularly for the treatment of sores and wounds [24]. *Simmondsia chinensis* carrier oil is also indicated for the improvement of acne, psoriasis, and inflammation [90, 166, 209]. The clay facial mask has been shown to decrease inflammation and significantly improve acne [151]. This liquid wax has not only been reported as a non-toxic substance in animal studies, but has been found to display moderate absorption where it effectively permeates into the outer layer of the subcutaneous level of the skin and increases water content, lending to its ability to exert a moisturising effect [157, 239, 268]. Due to its chemical similarity to sebum, it is also an established effective skin surface lipid that aids in the restoration of the skin barrier function, while increasing skin hydration, elasticity, and firmness [3]. *Simmondsia chinensis* carrier oil has been shown in animal studies to possess anti-inflammatory activity via a significant decrease in PGE_2 content in exudates, while preventing TNF-α formation [90].

According to the layman aromatherapy literature, *S. chinensis* [32] is expected to exhibit antimicrobial activity, while scientific evidence indicates that the carrier oil displays noteworthy antimicrobial activity, in vitro, against *B. epidermidis*, yet poor to no inhibition against *P. acnes*, *S. epidermidis*, *S. aureus* (including antibiotic resistant strains), *E. coli* and *C. albicans* reference strains. Very low toxicity (3.04%) was reported at 24 h using the brine shrimp assay [5, 54, 185].

Triticum vulgare Vill.

This carrier oil predominantly contains linoleic (28.8–57.0%), oleic (12.0–39.0%) and palmitic (11.0–16.0%) acids [66, 117]. Very little research has been done on *T. vulgare* carrier oil and only one study reported no wound healing improvement by *T. vulgare* (wheatgerm) oil [135] and another reported no inhibition against *C. albicans* [5].

Vitis vinifera Marshall.

Vitis vinifera (grapeseed) is made up of polyunsaturated fats and predominantly contains linoleic acid (60.0–75.0%), oleic acid (12.0–25.0%) and polyphenols [66]. The carrier oil was found to either act poorly or not at all to inhibit pathogens such as *E. coli*, *P. aeruginosa*, *S. aureus*, *C. albicans* and *Clostridium perfringens*. A few studies have, however, reported on the augmentation of wound healing by the carrier oil via anti-oxidant activity, enhancement of collagen formation and increasing the rate of contraction [117, 159, 232].

Combinations

It is well known that allopathic medicine as well as natural products are often used in various combinations for an improved therapeutic effect. An example includes MEDIHONEY® Calcium Alginate Dressing or MEDIHONEY® Hydrogel Colloidal Sheets [59]. Further, the use of selected carrier oils and their associated combinations in various applications have previously been studied. These are as follows:

Burn wounds

Burn wounds are devastating wounds that often lead to mortality for the patient due to infections and often require debridement [215]. *Aloe vera* gel combined with honey in a milk ointment was shown to be effective in accelerating the healing of second degree burn wounds [70]. A formula containing a combination of *Sesamum indicum* L. (sesame), wild *Pistacia atlantica* Desf. (pistachio), *Cannabis sativa* L. (hemp), and *J. regia* L. (walnut) was shown to increase the rate of third degree burn wound healing [150]. Formulations available to the market have also been proven to be beneficial as demonstrated in a retrospective study using a plant-based spray (PrimaryWoundCare dressing®) on the Swiss market containing *H. perforatum* and *A. indica* carrier oils to treat burn wounds in paediatrics, with the added benefit of pain reduction [145]. Carrier oils have also been shown to be effective as a carrier for current commercial antibiotics as shown when silver sulphadiazine in combination with *C. nucifera* was shown to be beneficial in the treatment of burn wounds [238].

Ulcers and common wounds

Diabetic, pressure and venous ulcers are globally the most common chronic wounds, with very little effective therapies available [129]. A few combinations with *A. vera* gel have been formulated, including the design of a medical membrane with chitosan [235]. An in vivo study using *A. vera* gel and a microcurrent applied to rat wound models showed increased healing [153]. An *A. vera* gel and olive oil combination cream has been shown to accelerate wound healing of necrotic pressure ulcers, diabetic wounds and venous ulcers [193]. Another study highlighted how an aloe-alginate film increases wound healing via increasing collagen type 1 fibres [125, 200]. A scaffold with the combination of *H. perforatum* flower extract and *A. indica* carrier oil has proven to be beneficial in the recovery of diabetic foot ulcers [104]. A combination herbal ointment of *Allium sativum* L. (garlic) extract, *H. perforatum* extract, and *C. officinalis* carrier oil showed epithelizing, anti-erythematous, and anti-oedematous activity with an overall increase in wound healing activity of venous ulcers [131]. A combination ointment of *H. perforatum* olive oil macerate/carrier oil combined with *Origanum minutiflorum* Schwrd. et Davis (origanum) and *Salviae trilobae* L. (Greek sage) essential oils was studied. The ointment increased the formation of collagen, exhibited anti-inflammatory activity, and displayed antimicrobial activity against *S. aureus*, *P. aeruginosa* and *C. albicans*, which all lead to an augmented rate of wound healing [243].

Postpartum wounds

The delay in healing of postpartum wounds can lead to bleeding, pain, painful intercourse and anxiety [79], highlighting the need for medicines that may accelerate healing. Carrier oils, such as a topical combination of *H. perforatum* and *Calendula arvensis* L. carrier oil, showed an increase in surgical wound healing in women who had undergone caesareans [135].

Scalp wounds

Open scalp wounds are difficult to treat and may at times require tissue-engineered skin substitutes [31, 122]. A combination of *H. perforatum* and *A. indica* carrier oil was tested on scalp wounds with exposed bone. For the majority of the cases, the exposed bone was covered within 4 weeks with no infection occurring, while overall healing occurred within 4–20 weeks [134]. Further, a combination commercial product called ONE on the Swiss market containing *H. perforatum* and *A. indica* carrier oil was also tested in a retrospective study on post-surgical scalp wounds and deemed safe and effective, as all nine test patients had complete closure of wound [133].

Antimicrobial activity

Any conventional medicine or natural product that exhibits its antibacterial activity is potentially beneficial for wound

treatment and several carrier oil combinations have demonstrated antibacterial activity. Examples include studies where *Melaleuca alternifolia* Cheel (tea tree) oil diluted in *S. chinensis* carrier oil displayed inhibition against *E. coli*, *S. aureus* and *P. aeruginosa* [54]. *Hypericum perforatum* carrier oil-incorporated chitosan films were also shown to inhibit *S. aureus* and *E. coli* [89]. A scaffold containing a combination of *H. perforatum* flower extract and *A. indica* carrier oil has displayed antimicrobial activity against *S. aureus* and *P. aeruginosa* [105]. An alginate–chitosan matrice loaded with silver nanoparticles and *A. vera* gel demonstrated antimicrobial activity against *S. aureus* and *P. aeruginosa* [87]. One recent study could report a positive in vitro antimicrobial interaction of six different carrier oils (*A. vera*, *S. chinensis, H. perforatum C. officinalis, P. americana, P. americana)* combined with 23 different essential oils, against 11 skin pathogens. The antimicrobial was maintained and several synergistic interactions were reported for *A. vera*, *S. chinensis, H. perforatum C. officinalis,* and *P. americana* against respective pathogens, including *B. epidermidis*, *B. linens,* and *P. aeruginosa*. No antagonistic antimicrobial activity was reported. The toxicity was decreased for the majority of the essential oils. *Aloe vera* and *S. chinensis* were identified as exerting the most positive influence on essential oil antimicrobial activity and toxicity [185].

Diaper rash and dermatitis

One of the most common skin ailments for infants is diaper dermatitis [74]. Diaper rash and dermatitis are predisposing factors for wounds brought forth by bacterial and fungal infections caused by decreased skin integrity exuberated by dryness, scratching and scaling leading to enhanced microbial penetration [194]. Zeichner et al. [271] reported on the safe and effective treatment of moderate to severe hand dermatitis using a moisturizer containing 7% *P. amygdalus* carrier oil and 2% colloidal oatmeal. *Aloe vera* gel has been shown to slightly improve diaper rash [194]. Nourbakhsh et al. [178] conducted a trial of 64 children with diaper rash where the control group was treated with *C. officinalis* cream and the test group was treated with combined *C. officinalis* and 2% magnesium cream. The plain *C. officinalis* group had a mean recovery of 3.25 days and a significant increase in recovery rate was observed for the combination cream treatment within 1.5 days [178]. Another study, however, found the carrier oil to be less effective in treating diaper rash than the control [4]. The evidence for *C. officinalis* as a potential carrier treatment for diaper rash is inconclusive. It should also be noted that earlier reports of allergic reactions and sensitisation from *C. officinalis* have been found [99, 174]. A *S. chinensis* and clotrimazole emugel resulted in improved stability compared to commercial clotrimazole formulations such as Canestan® cream. An enhanced antifungal activity for *C. albicans* was also noted [229].

Fungal infections

Fungal infections can predispose the skin to secondary bacterial infections [16, 39, 92]. An essential oil combination (six oils) mixed in carrier oils of *P. amygdalis* and *C. nucifera* was investigated against clinical isolates of *Malassezia pachydermatis* isolated from dogs. Although no MIC value was reported for *C. nucifera* or *P. amygdalis* oils alone, the combination containing the essential oils and carrier oils displayed noteworthy activity (0.3%) [172]. A mixture of essential oils of *Thymus serpyllum* L. (Breckland thyme), *Origanum vulgare* L. (oregano) and *Rosmarinus officinalis* L. (rosemary) essential oils diluted in *P. amygdalus* carrier oil showed complete regression of *Trichophyton mentagrophytes* within two weeks with no observed side effects [167]. It must be noted that although these combinations have shown antimicrobial activity, the essential oils and the carrier oils were not investigated independently of the combination; thus, little is understood as to the influence that a carrier oil exerts over the overall therapeutic activity.

Carrier oils as a base for essential oils

As was shown in several studies, the majority of the carrier oils displayed moderate to poor antimicrobial activity [5, 117, 185, 218, 225, 232]; however, there was an enhanced rate of healing that was observed either due to anti-inflammatory or anti-oxidant properties and/or enhanced collagen formation. Thus, it would appear that the carrier oils do not necessarily contribute towards wound healing via antimicrobial activity, but rather as antioxidants, anti-inflammatory or tissue growth inducers. A combination of a carrier oil with poor antimicrobial activity combined with essential oils with noteworthy activity raises the question as to whether the weak antimicrobial activity is able to influence the overall antimicrobial activity of the essential oil. Although not incorporating carrier oils, several studies have demonstrated that the base used with an essential oil is able to influence the antimicrobial activity [73, 86, 183, 184, 263]. This raised the question as to the overall influence of the carrier oils themselves on essential oil activity. A recent study was found reporting a positive effect of carrier oils combined with essential oils where the antimicrobial activity was maintained, and in several instances enhanced, while decreasing the toxicity [185].

Overview of the influence of the chemistry

The chemistry of natural products contributes a key role in the overall biological activity involved in wound healing. The carrier oils are predominantly composed of free fatty acids and vitamins, which make their contribution in wound healing different from that of aromatic essential oils. Where essential oils have been identified as natural products with efficient antimicrobial activity, the majority of reports on carrier oil antimicrobial activity could only report weak to moderate antimicrobial activity [5, 117, 218, 225, 232]. However, despite the poor antimicrobial activity, accelerated wound healing has been emphasised. Thus, it would almost appear more that carrier oils influence wound healing via increasing certain inflammatory markers and decreasing others, and contributing anti-oxidant activity, rather than via antimicrobial activity. This thought is attributed to the general patterns of the compounds being free fatty acids (FFA). Further study on the FFA highlights how these molecules are able to contribute towards overall wound healing activity.

Free fatty acids (FFA)

Understanding the inflammatory cascade is necessary to understand the possible influence of FFA on healing. Figure 2 displays a brief demonstration of the FFA, which are precursors to the inflammatory mediators such as eicosapentaenoic (EPA) (20:5 ω-3), arachidonic acid (AA) (20:4 ω-6), and eicosatrienoic acids (ETA) (20:3 ω-9). The inflammatory mediators form part of the phospholipids cell membrane structures, serving as substrates for inflammatory mediators (eicosanoids) including prostaglandins, thromboxanes, prostacyclins (via cyclooxygenase), and leukotrienes (via lipooxygenase) [12, 36, 40, 84]. Arachidonic acid is one of the more potent pro-inflammatory inducers as it is responsible for the formation of prostaglandin E_2, thromboxane B_2, and leukotriene B_4. Eicosapentaenoic on the other hand induces anti-inflammatory markers prostaglandin E_3, thromboxane B_3, and leukotriene B_5. The three mentioned acids (EPA, AA and ETA), however, also require precursors, which include linolenic (18:3 ω-3), linoleic (18:2 ω-6), and oleic acid (18:1 ω-9) [12, 36, 40, 84]. Linoleic acid is a precursor of arachidonic acid [267].

Ribeiro Barros Cardoso et al. [213] found topically administered mono-unsaturated fatty acid (MUFA) oleic acid or the poly-unsaturated fatty acid (PUFA) linoleic acid to significantly increase the rate of wound healing in rat models, compared to rat models treated with PUFA linolenic acid. The increased wound healing was attributed to the pro-inflammatory activity exerted by these fatty acids during the healing process. The essential fatty acids are also able to influence the pH, which interferes with bacterial membrane

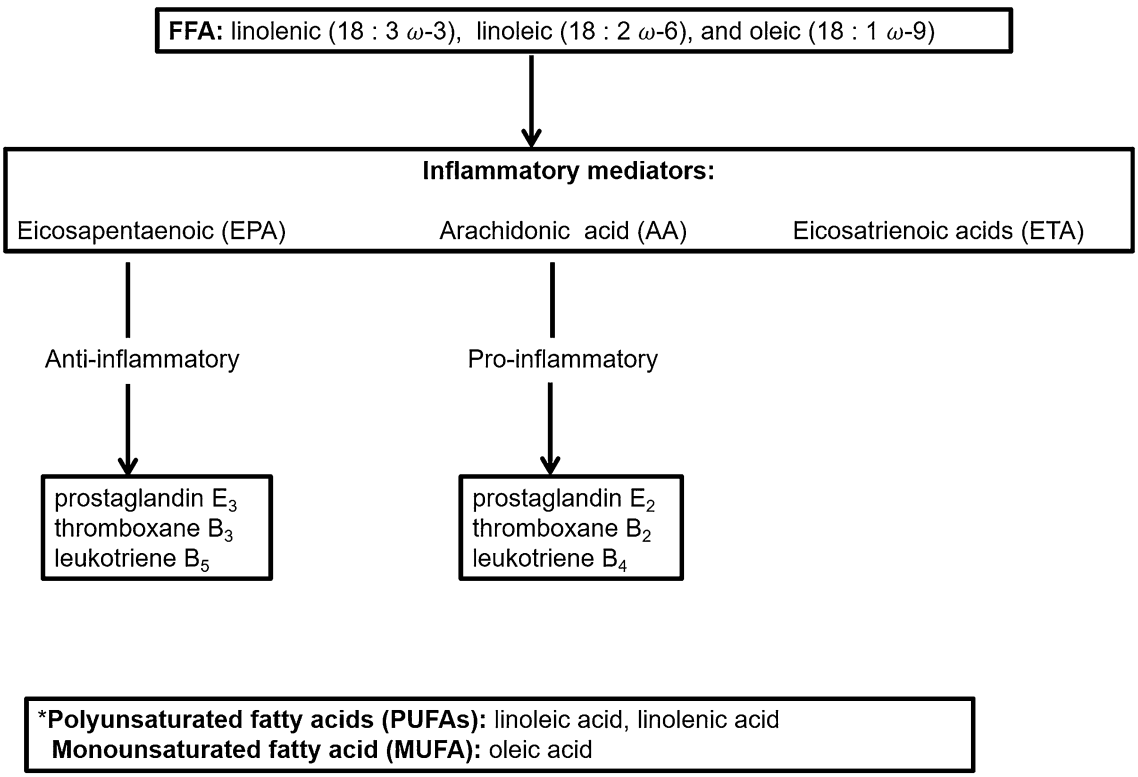

Fig. 2 FFA involvements in inflammatory cascade

permeability, resulting in antibacterial activity, an action that was observed by linoleic acid during successful treatment of infected venous ulcers [56]. However, ω-3 PUFAs previously exposed lipid oxidation may delay wound healing [55, 213]. Saturated fatty acids, such as linoleic fatty acid and oleic acids, alone and in combination, have displayed antimicrobial activity against *S. aureus* and MRSA at high concentrations [60, 103, 124]. The Gram-positive microorganisms appear to be more susceptible, with very poor to no activity reported against Gram-negative pathogens [60, 61, 123].

Overall it would appear that carrier oils would predominantly contribute towards the wound healing via stimulation of angiogenesis, as antioxidants, anti-inflammatories, and via stimulation of certain pro-inflammatory markers, rather than noteworthy antimicrobial activity. The additional presence of vitamins in carrier oils also contributes towards the healing mechanism, and enhancement of lipophilic drug solubility with the added effect of increasing pharmacological effects [203]. As shown, evidence of essential oils affected by the base is more prominent than the influence of the carrier oils on the overall essential oil activity.

Future recommendations and conclusions

Carrier oils are mainly made up of fatty acids [9, 35, 62, 196, 199, 234] that have potential in the management of dermatological conditions and wounds. One of their main functions is to act as the diluent/carrier for essential oils on the skin [43, 45, 68, 96], yet there is only one study that has reported the influence of carrier oils on essential oil antimicrobial activity [185]. It was noted from the few antimicrobial studies that carrier oils themselves hold little antimicrobial activity [5, 117, 218, 225, 232] and may rather contribute towards wound healing via angiogenesis, anti-inflammatory or antioxidant activity [19, 140, 180, 243, 244, 270].

Carrier oils are said to decrease the toxicity of essential oils, with one of the mechanisms being the ability to enhance the absorption of the essential oils [46, 132]. Despite this claim, reports on the lack of or low toxicity of these carriers exist [126, 205, 222], and only one report demonstrated the decrease of essential oil toxicity by carrier oils [185]. There are also inadequate reports on the ability of carrier oils to enhance permeation of medicines such as anti-inflammatories [78]. Thirdly, what is not yet considered is the influence on the overall biological activities. The lack of information on carrier oils is surprising considering the practical application of essential oils on the skin, which is rarely used without a carrier oil.

There is a need for carrier oils to be further investigated regarding their interactions with essential oils, especially considering that they contribute such a crucial role towards application in dermatology. Future studies could include:

- Determining the influence or carrier oils on essential oil
  - permeation,
  - anti-inflammatory activity,
  - and combined wound healing activities.
- Larger clinical trials, especially against wounds resistant to conventional treatment.
- Human studies on wound healing using essential oil diluted in carrier oils.

Of all the carriers, *A. vera* gel is the most studied, being one of the most popular natural products worldwide. This attention given to *A. vera* gel should be extended to the other carrier oils that are popular in the aroma-therapeutic literature for wounds. These include *A. vera* (macerate oil), *A. moluccana*, *C. officinalis*, *H. perforatum M. ternifolia*, *P. armeniaca*, *P. persica*, *S. chinensis*, *T. vulgare* and *V. vinifera*.

Furthermore, further research is encouraged where authors are specific about which form (whether an extract, fixed or macerate oil, essential oil, juice or gel) is studied as a critical evaluation of the data often led to difficulties in distinguishing if the carrier oil was the focus of the study. Future antimicrobial studies should make use of the broth micro-dilution assay and not include disc diffusion data. For combination studies, the individual and combined minimum inhibitory concentration for both the antimicrobial substance (e.g. essential oil) and the carrier (e.g. *S. chinensis*) should be included to determine the contribution by the carrier oil. Considering that the chemical composition of carrier oils can change according to geographic location, harvest time, climate, temperature and time [58, 242]; these data should also be reported.

Continued research into carrier oils is further encouraged, especially considering that without the carrier oils, there would be no effective use of essential oils for the dermatological treatment of wounds.

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