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Review

Maggot Debridement Therapy: A Natural Solution for Wound Healing

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ABSTRACT

Maggots are soft-bodied grubs that are the larval stage of many dipterous flies. About half of fly species create maggot-like larvae, whereas others produce more specialized and different larvae. Whereas myiasis is described as the infestation of live vertebrates (people and/or animals) by dipterous larvae, medicinal maggots are sterile fly larvae that are introduced to the wound to effect debridement, disinfection, and, ultimately, wound healing. Maggots are also important in fish and poultry production due to their nutrition and antibacterial activities. Maggot wound therapy is the use of fly larvae, or 'maggots', to cure wounds. Maggot debridement therapy (MDT) is a type of therapeutic wound treatment in which sterile or disinfected larvae from specific blowfly species are employed to remove non-vitalized tissue, pus, slough, and metabolic wastes from the wound and facilitate healing. Furthermore, maggots ingest and digest many bacteria suspended in the liquid necrotic tissue, and their enzymatic excretions and secretions contain potent antimicrobials. Maggot meals, on the other hand, are healthier and more nutritious alternatives to fish meals due to their high nutritional value, particularly in protein, fat, and minerals. Insects are natural foods for fowl. So, maggot use is very important in veterinary treatment; however, their uses are limited. Thus, the purpose of this study is to highlight the significance of maggot use in wound treatment.

Keywords
Antibiotic resistance; Bioconversion; Debridement; Importance; Maggots; Wound.

INTRODUCTION

Maggots are soft-bodied grubs that are in the larval stage of many dipterous flies. About half of fly species create maggot-like larvae, whereas others produce more specialized and different larvae. The larval form of fly species with maggots remains throughout their life cycle.[1] Maggots or fly larvae (order diptera) are frequently highly specialized for life in wet environments, with very few adaptable to dry settings. A few species are internal parasites of animals or humans. Myiasis is the condition in which maggots infest animals, humans, or other vertebrates.[2,3]

Myiasis is the infestation of live vertebrates (humans and/or animals) by dipterous larvae. Dipterous larvae in animals (including humans) can feed on liquid bodily fluids, ingested food, or live or dead tissue, depending on where they are in the body and their relationship to their host. This can cause a variety of infestations.[4]

In medical therapy, sterile fly larvae, sometimes known as medicinal maggots, are introduced to the wound to aid in debridement, disinfection, and ultimately wound healing.[5] Alternatives to standard wound management are now available, allowing for faster wound healing with fewer complications. Maggot therapy is effective in treating chronic, long-standing infected wounds that have previously failed to respond to conventional treatment.[6]

Maggot therapy is a controlled clinical myiasis technique that employs newly hatched, sterile larvae of the common greenbottle fly, *Phoenicia* (*Lucilia*) *sericata*. Maggot therapy, on the other hand, is rarely used in veterinary clinical practice. Nonetheless, worries about antibiotic resistance, as well as an increase in demand for organic husbandry and residue-free meat and milk, suggest that it is a worthwhile choice.[7]

Maggot therapy, which involves treating wounds with live fly larvae, is becoming increasingly popular in many places throughout the world. Maggot therapy, also known as larval therapy (LT), maggot debridement therapy (MDT), or biosurgery, has several advantages, including its high success in removing (debriding) dead (necrotic) tissue, safety, and simplicity. These and other benefits have contributed to a recent renaissance in the use of maggot therapy.[8] The only negative effects noted are irritation, itching, and hypersensitivity at the wound site. It can also cause pain, irritation, and stink during the first dressing change.[9]

Maggot excretions and secretions contain allantoïn, sulfhydryl radicals, calcium, cysteine, glutathione, embryonic growth stimulating substance, growth stimulating factors for fibroblasts, carboxypeptidases A and B, leucine aminopeptidase, collagenase, and serine proteases (trypsin-like and chymotrypsin-like enzymes, metalloproteinase, and aspartyl protease).[10-12]

Given the growing problem of antibiotic resistance in the veterinary industry, any alternative treatment that could lead to less antibiotic use warrants further investigation. Larval therapy can minimize antibiotic use while also effectively disinfecting wounds that have already been infested with resistant bacteria. The fact that maggot secretory and excretory secretions are known to improve wound healing makes the therapy even more appealing. Furthermore, developing LT for use in dogs, cats, and horses will provide another treatment option for non-healing wounds before resorting to euthanasia.[13]

Maggot debridement therapy is rapidly gaining popularity as a quick and effective treatment for non-healing wounds. It has been demonstrated that adding sterile larvae to an infected non-healing wound results in necrotic tissue removal (debridement), disinfection, rapid elimination of harmful microorganisms, and stimulation of the healing process.[14]

Maggots have two uses: they are a waste bioconversion agent and a high-protein animal feed. Protein is a nutrient that cattle require. However, high-protein feed is relatively costly. Breeders are concerned about the rising cost of feed since it may result in a price mismatch between feed and crop. This maggot can later be utilized for poultry and fish feed.[15,16] There are several uses for maggots, but previous papers focused on or emphasized only a few of them; however, this assessment focuses on the multiple importance of maggot usage.

USES OF MAGGOT

Maggot Wound Therapy

Maggot wound therapy (MT) is the use of fly larvae, also known as maggots', to cure wounds. MT, as opposed to myiasis (wound infection by wild maggots), is the intentional clinical application of sterilized medicinal maggots raised in a controlled laboratory setting with strict quality control methods. The green bottle blowfly *Lucilia sericata* (Diptera: Calliphoridae) and the sheep blowfly *Lucilia cuprina* are the most commonly used fly species for MT.[17,18]

Maggot therapy outperforms traditional therapy and surgery approaches. It should be utilized to treat numerous disorders that are resistant to antibiotics and surgery.[19] Chronic ulcers were treated with antibiotics and surgery, and wounds were healed using maggot therapy. When it comes to debridement, maggot therapy is the best option, with outstanding outcomes. Surgery is harmful and frequently causes damage to healthy tissues, but maggot therapy just debrides dead tissues and does not harm good tissues; it only harms bacteria.[19]

Larval therapy is a treatment that involves using sterile fly larvae to heal superficial wounds in both people and animals. This approach has been used for many years to treat superficial wounds, such as war wounds.[20] Cutaneous wounds provide a substantial challenge in both human and equine medicine. The economic cost of treating skin wounds and accompanying problems in humans and horses is high, and certain types of chronic wounds in both species do not respond well to present treatments, causing suffering and morbidity.[21]

Larval treatment has been used to treat both diabetic ulcers and horse hoof lesions. Reports on the application of larval therapy to decrease tumor lesion effects have been encouraging.[20] A study on using larval therapy for horse sarcoid lesions found that four horses, diagnosed through exams and tests, were treated with this method. The larvae were placed on the lesion using the implantation approach in an artificial nest. Approximately ten larvae were employed per square centimeter. The treatment was successful in two cases of horses, and in one case, the lesion was mostly contained, but the skin began to regenerate. By the way, no favorable results were found in the other two cases, which was most likely related to the size of the lesion and the fragility of the larvae on it. According to the results, larval therapy appears to be beneficial in treating sarcoid necrotic lesions (Figure 1).[22]

Maggot Debridement Therapy

Wound debridement is the process of removing foreign material and dead, contaminated tissue from (or adjacent to) a traumatic or infected lesion to reveal healthy tissue. Foreign material embedded in the wound may also need to be removed.[11,23] MDT is a type of therapeutic wound treatment in which sterile or disinfected blowfly larvae are employed to remove non-vitalized tissue, pus, slough, and metabolic wastes from the wound and promote healing.[6,14] MDT is a safe, effective, and regulated approach for healing chronic wounds through debridement and disinfection.[6]

Therapeutic maggots (larvae) have the following benefits for wounds: tissue debridement, disinfection, wound stimulation, biofilm inhibition, and elimination.[24] *L. sericata* larvae do not enter tissues deeply because they require aerobic conditions to survive. Thus, the larvae disrupt wound surfaces by crawling about with hook-like mouthparts.[6] Four proteolytic enzymes produced by *P. sericata* larvae were recently reported to be active throughout a wide pH range. The enzymes consisted of two serine proteases, a metalloprotease, and an aspartyl protease. A chymotrypsin-like serine protease efficiently destroyed laminin, fibronectin, and collagen

Figure 1. *Evaluation of Maggot Therapy Effects on the Progression of Equine Sarcoid*

Adopted from: Ahmadnejad M[22]

Maggot therapy was used on one of the horses suffering from sarcoid lesions. A: Primary lesion. B) Wash the lesion. C: Rub the zinc oxide cream around the lesion. D: Place a tampon around the lesion. E: Tighten the tampon on the limb. F: Place the larvae on the lesion. G: The grid is attached to the construction. H: Apply a light layer of treatment to the artificial nest structure.

types I and III.[7,25]

The mechanical action of maggots and the production of proteolytic enzymes aid in the efficient debridement of tissues. Healthy tissue is not at risk since these enzymes are neutralized when they come into contact with intact tissue. This method removes cellular detritus, dead, tainted tissue, bacteria, and foreign substances. Maggots have two mandibles (hooks) that aid in locomotion and tissue attachment. Although probing and maceration of wound tissue with maggot mouth hooks may aid debridement, these hooks are used during feeding to rip membranes, allowing proteolytic enzymes to permeate.[7,26]

Maggot debridement therapy is a safe, effective, and regulated approach for healing chronic wounds through debridement and disinfection.[6] MDT is primarily used to treat a variety of wounds in horses and small animals. Although maggots are not often used in pets, some small animal veterinarians are already using MDT to treat difficult dog and cat wounds.[27] MDT helps treat a variety of wounds, including foot and leg wounds and horse wounds such as deep cuts, abscesses, and abdominal wounds.[28]

According to Lepage et al[29] treated cases (n=41) included horses with foot pathology (n=9), limb laceration (n=15), other soft tissue abscesses or wounds (n=6), fistulous withers (n=5), other musculoskeletal infections (n=2), and linea alba dehiscence (n=4). Five patients required a second maggot treatment to achieve the desired level of wound healing. In 38 cases, a satisfactory outcome was obtained in less than a week. Healing for one person with a sequestrum was unremarkable after it was removed. In two more horses, chronically infected wounds were infected with squamous cell carcinoma and melanoma, and complete healing was not possible due to underlying tumor recurrence. Seven patients experienced some discomfort between 24 and 72 hours of treatment. Maggot debridement therapy can be recommended in equids for debridement and improved healing due to its high antibacterial properties. Maggot debridement therapy is not suggested for tumor-infected wounds or when bone sequestration is suspected. Furthermore, MDT can be used to treat a variety of wounds, including foot and leg wounds and horse wounds such as serious cuts, abscesses, and stomach ulcers.

The other trial assessed the efficacy of MDT on a non-healing post-operatively infected wound spanning the abdomen and inguinal regions of a 3-year-old male cat. On the tenth day after laparotomy, sterile first- and second-stage larvae of *Lucilia sericata* were first put into the infected wound. The MDT method involved five larval applications. From the first to the final MDT application, the big, infected wound shrank and healed. Sterile *L. sericata* larvae were successfully employed to treat a chronic, infected wound that had not responded to antibiotics. According to Uğur et al[30] the use of MDT to promote healing in chronic necrotic and infected wounds is expected to expand because of its effectiveness, cost-efficiency, and ease of usage. Humans have utilized MDT to heal chronic wounds for generations. Recently, MDT has emerged as a powerful medical aid for animals. Although this therapy is currently limited to animals, there are few clinical investigations.

The study aimed to determine the effectiveness of MDT on a post-operatively infected wound. This was accomplished using Lucilia sericata's sterile first and second instar larvae. The first MDT administration took place six days after the amputation. The

second treatment was repeated after 24 hours, and the final two treatments were applied at intervals of 48 hours. Following the initial therapy, the amount of discharge in the wound gradually decreased, indicating that it was healing quickly. The wound was successfully treated using the wound-healing characteristics of sterile *L. sericata* larvae.[28]

Antimicrobial Effects

Maggots devour and digest a large number of bacteria suspended in liquefied necrotic tissue, and their enzymatic excretions and secretions include potent antibiotic chemicals. Finally, maggots have a scrambling eating behavior and constantly probe with their two mouth hooks. This disrupts and prevents microbial communities from developing biofilms, which impede wound healing and escape the immune system and antibiotic treatment. Maggot excretions and secretions also contain growth factors that promote blood vessel regeneration and granulation tissue growth, hence assisting with wound healing.[31,32]

The removal of necrotic tissue eliminates many of the accompanying germs and lowers wound odor. The ablation of necrotic tissue, which serves as a microbial substrate, may also minimize the risk of infection.[7] Antibacterial chemicals are constantly created in maggot saliva; after intake, bacteria are destroyed as they move through the digestive tract.

Allantoin, urea, phenylacetic acid, phenylacetaldehyde, calcium carbonate, proteolytic enzymes, and other secretions are thought to have broad-spectrum antibacterial properties. Maggots eat and break down bacteria that survive these secretions, effectively eliminating methicillin-resistant *Staphylococcus aureus* (MRSA), group A and B streptococci, as well as both gram-positive aerobic and anaerobic bacteria, along with pseudomonas.

Antimicrobial peptides play a crucial role in the innate immunity of many organisms because of their small size. They consist of multifunctional peptides primarily designed to combat pathogenic microorganisms, including Gram-positive and Gram-negative bacteria, fungi, and viruses. Antimicrobial peptides are classified into three types based on their amino acid sequence and biochemical properties: linear peptides that lack cysteine, peptides with a disulfide bridge-stabilized structure, and peptides with an amino acid overrepresentation.[33,34]

In insects, antimicrobial peptides and polypeptides are primarily synthesized in the fat body and released into the hemolymph, where they play an important role in the innate immune system and host defense mechanisms,[35] with broad-spectrum activity against both Gram-positive and Gram-negative bacteria and fungi.

A study was conducted to determine the antibacterial activity of water-soluble protein enzymatic hydrolysates and the ethanol (EtOH)-extracted fraction obtained from fly maggots (*Musca domestica*) against MRSA strains and vancomycin-resistant enterococci (VRE) 5117 strains. The water-soluble protein enzymatic hydrolysates were generated by incubating for 4 or 8 hours after combining with the water-soluble protein isolated from fly maggots plus thermolysin. After combining with fly maggots and pure EtOH at room temperature, the EtOH-extract A was homogenized. The EtOH-extracts B and C were produced by filtering after 24 hours of stationing at 4-20 ºC with the EtOH-extracts A. The growth inhibition curves for MRSA strain 3595 and VRE strain 5117 in water-soluble protein enzymatic hydrolysates were increased, and concentration-dependent inhibition was observed in the 8-hour hydrolysate compared to the 4-hour hydrolysate.[36]

Maggots as Fish Diets

The high cost of fish feed has hampered the growth of fish output. The rapid growth and success of commercial fish farming are heavily reliant on the supply of high-quality, low-cost feed. Using non-traditional feedstuffs and by-products for aqua feeds would lower the unit cost of fish production.[37,38]

Maggots are created from the semi-transparent larval stage of the housefly (*Musca domestica*) and are used to digest maggot meal. Fresh maggots were produced in a medium including fresh layer droppings, powdered milk, and sugar, and then dried in an oven at 550 ºC for 24 hours.[39]

Because of their high nutritional value, particularly protein, fat, and minerals, bug meals are a healthy and nutritious alternative to fish meals. Insect larval flours (maggots) have a crude protein, crude fat, and essential amino acid concentration comparable to fish meal. Maggots' crude protein content ranges from 40 to 64%.[40,41]

Housefly maggot (*Musca domestica*) meal contains a lot of B vitamins, trace minerals, and phosphorus. Housefly maggot meal can be used to substitute fish meal in fish diets, either partially or totally. Furthermore, by feeding the fish Housefly maggot meals, no physiological stress was induced. This indicates that the housefly maggot meal was well utilized by the fish, resulting in healthy fish development. Fish-fed maggot meal outperformed fish-fed fishmeal diets in terms of growth. This confirms maggot feed's high nutritional value and fish acceptance.[42] Maggots also have antibacterial and antifungal capabilities, making fish-consuming maggots resistant to bacterial and fungal illnesses (Figure 2).[43]

The fish feed industry relies on pricey fish meal (FM) to provide protein in feed formulations. A nutrient-rich and attractive insect meal-based fish feed was established by adding black soldier fly (BSF) (*Hermetia illucens*) prepupae meal (BSFPM) fed on organic waste, which added the benefit of waste bioremediation, resulting in a cost-effective diet. A feeding trial was conducted to evaluate the growth performance of mono-sex Nile tilapia (*Oreochromis niloticus*). The treatments were as follows: (1) dried BSF prepupae; (2) BSF prepupae and BSFPM-based feed in a 1:1 ratio; (3) BSFPM feed; and (4) FM control feed. BSFPM and control feed had no significant differences in survival, growth, feed efficiency, or hematological parameters.[16]

Figure 2. *Use of Black Soldier Fly (Hermetia illucens) Prepupae Reared on Organic Waste as Feed or as an Ingredient in a Pellet-feed Formulation for Nile Tilapia*

Adopted from: Panikkar et al [16]

A study was done to assess the effects of dietary black soldier fly larval meal (BSFLM) on juvenile striped catfish growth, digestive enzyme activity, hematological responses, and muscle growth-related gene expression. Juvenile-striped catfish fed diets containing BSFLM showed enhanced development and feed utilization. Dietary BSFLM supplementation increased the relative expression of muscle development genes. BSFLM is an effective alternative to fishmeal in striped catfish diets, with no negative effects on growth performance or physiological responses. According to Sudha et al[44] BSFLM can be used to replace up to 60% of fishmeal protein without compromising striped catfish growth or feed consumption.

Maggots as Poultry Feed

Poultry farming has emerged as a feasible choice in most African countries' development plans and poverty alleviation efforts due to its multiple advantages (e.g., short reproduction and production cycles, high return on investment). Poultry are fed specific protein-rich feed additives (such as fishmeal); nevertheless, these components are extremely expensive and unsustainable. Larvae offer a promising alternative protein source for chickens.[45]

Insects are natural foods for fowl. Chickens, for example, will pick worms and larvae off the topsoil and debris as they travel. Maggot meal has been used in broiler diets as a substitute for traditional protein sources, particularly fish meal. Most trials show that fish meal can be partially or completely replaced, although the optimal inclusion percentage is typically less than 10%. Higher rates have resulted in poorer intake and performance, possibly due to a decrease in palatability, as the darker hue of the meal is less appealing to chickens.[40] As a result, it influences the substitution of fishmeal by housefly larvae at varying rates and in different physical states in the diet of local chickens. There were no apparent impacts of substitution rate or the physical status of housefly larvae on growth performance. Thus, housefly larvae can be used as a 50% substitute for fishmeal in local chicken diets.[46]

A 30-day experimental study was conducted to assess the performance of finisher broiler hens fed maggot meal as a supplement in commercial diets. Feeding maggot meal to broiler chickens can lead to poor growth since these bug meals do not provide all of the nutrients needed for healthy broiler chicken growth. Maggot supplementation can eliminate 25% of the commercial ration provided to broiler chicks. However, due to its high protein content, maggot meal should only be used as a supplement to pricey fishmeal in broiler feed formulations.[47]

One major problem is the transition to more sustainable protein sources in poultry feed. In this approach, insects represent the unseen rising stars. Insects like the black soldier fly (*Hermetia illucens*) and the house fly (*Musca domestica*) has been recommended as multifunctional mini-livestock for feed production. These flies' larvae are capable of converting low-quality organic waste streams into valuable body mass rich in high-quality protein and fat. Furthermore, due to bioactive compounds and poultry's natural interest in them, larvae have been shown to improve health and well-being.[48,49]

The study on the effects of increasing levels of whole Black Soldier Fly (*Hermetia illucens*) larvae in broiler rations on broiler acceptance, nutrient and energy intakes and utilization, and growth performance concludes that after a brief learning period, chickens can consume up to 30% of their voluntary FI in a matter of minutes. Broiler larvae's eating habits and rates show a strong preference for black soldier fly larvae (BSFL) over a standard diet. Despite its high-fat content, whole BSFL can be included in broiler rations up to 20% without affecting growth performance or nutrient conversion efficiency; however, higher levels are associated with decreased protein utilization efficiency, most likely due to lower overall energy intake.[50]

CONCLUSION

Maggots are the larvae of several fly species. Maggot use has many benefits, including wound maggot therapy, wound debridement therapy, antibacterial properties, and feed-in chicken and fish production. Maggot therapy outperforms traditional therapy and surgery. Surgery is damaging and can sometimes cause damage to healthy tissues, whereas maggot therapy simply debrides dead tissues and does not harm healthy ones but is toxic to bacteria. However, the crawling of maggots causes tickling and irritating sensations. Because of their high nutritional value, particularly protein, fat, and minerals, maggot meals are healthy and nutritious alternatives to fish meals, and larvae provide a possible alternate protein source for chickens. The use of maggots is extremely important, yet there has been very little research into it until recently. Thus, further investigations on maggot roles to compensate for feed scarcity and therapy possibilities, as well as recommended doses per species of animal, are encouraged.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

Not applicable.

CONSENT FOR PUBLICATION

Not applicable.

AVAILABILITY OF DATA AND MATERIALS

This manuscript includes all the datasets generated or analyzed during this study.

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AUTHORS' CONTRIBUTIONS

GD contributed to data collection, references search, manuscript draft, and writing; IAK and HFG contributed to the conception of the study idea, study design, manuscript editing, and revisions. All authors have approved the submission of the final manuscript.

CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

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