Introduction
This article describes what biofilms are and the important roles they appear to play in disrupting wound healing. In addition, it discusses potential interventions aimed at removing/reducing biofilms and preventing their reformation in wounds.

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Full author details can be found on page 5.

What are biofilms?
Biofilms are complex microbial communities containing bacteria and fungi. The microorganisms synthesize and secrete a protective matrix that attaches the biofilm firmly to a living or non-living surface.

Biofilms are dynamic heterogeneous communities that are continuously changing. They may consist of a single bacterial or fungal species, or more commonly, may be polymicrobial, i.e., contain multiple diverse species. At the most basic level, a biofilm can be described as bacteria embedded in a thick, slimy barrier of sugars and proteins. The biofilm barrier protects the microorganisms from external threats.

How are biofilms relevant to wounds?
Biofilms have long been known to form on surfaces of medical devices, such as urinary catheters, endotracheal and tympanostomy tubes, orthopaedic and breast implants, contact lenses, IUDs and sutures. They are a major contributor to diseases that are characterized by an underlying bacterial infection and chronic inflammation, e.g., periodontal disease, cystic fibrosis, chronic acne, and osteomyelitis.

Biofilms are also found in wounds and are suspected to delay healing in some. An analysis of biopsies from chronic wounds found that 60% of the specimens contained biofilm structures in comparison with only 6% of biopsies from acute wounds. Since biofilms are reported to be a major factor contributing to multiple chronic inflammatory diseases, it is likely that almost all chronic wounds have biofilm communities on at least part of the wound bed.

How do biofilms form?
Stage one: reversible surface attachment
Microorganisms are commonly perceived to be free-floating and solitary (i.e., planktonic). However, under natural conditions, most microorganisms tend to attach to surfaces and form biofilms. (Figure 1). The initial attachment is reversible.

Stage two: permanent surface attachment
As the bacteria multiply, they become more firmly attached (sessile) and change gene expression patterns. This is usually the result of a type of bacterial communication known as quorum sensing.

Stage three: slimy protective matrix/biofilm and multiplication
Once firmly attached, the bacteria begin to secrete a surrounding matrix known as extracellular polymeric substance (EPS). This is a protective matrix or ‘slime’. Microcolonies then form an initial biofilm.

The exact composition of EPS varies according to the microorganisms present, but generally consists of polysaccharides, proteins, glycolipids, and bacterial DNA. Bacterial DNA released by living or dead bacteria is thought to provide an important structural component for biofilm EPS matrix. Various secreted proteins and enzymes help the biofilm to become firmly attached to the wound bed.

Fully mature biofilms continuously shed planktonic bacteria and microcolonies, which can disperse and attach to other parts of the wound bed or to other wounds, forming new biofilm colonies.

Living in the mixed microbial communities typical of biofilms allows microorganisms to share their individual ‘skills and abilities’ for the survival of the group. This gives them many protective advantages.

How quickly do biofilms form?
Experimental laboratory studies have shown that planktonic bacteria, e.g., Staphylococci, Streptococci, Pseudomonas, and Escherichia coli, typically:
- attach within minutes
- form strongly attached microcolonies within 2–4 hours
- develop initial EPS and become increasingly tolerant to biocides, e.g., antibiotics, antiseptics, and disinfectants, within 6–12 hours
- evolve into fully mature biofilm colonies that are extremely resistant to biocides and shed planktonic bacteria within 2–4 days, depending on the species and growth conditions
- rapidly recover from mechanical disruption and reform mature biofilm within 24 hours.

This suggests that serial wound debridement or disruption could provide a window of opportunity, i.e., less than 24 hours, in which...
antimicrobial treatments are more effective in reducing both planktonic and biofilm microorganisms in wounds.

**Why have we just found out about biofilms in wounds?**

It is only relatively recently that biofilms have been generally accepted as a factor that can contribute to delay in healing in skin wounds. Chronic skin wounds often lack overt clinical signs of infection and often have low bacterial burdens as measured by standard clinical microbiology laboratory assays. However, standard clinical microbiology tests are optimised to culture planktonic bacteria, and do not adequately measure biofilm bacteria, which require special cultivation techniques. The term critical colonisation was developed in an attempt to acknowledge the concept that bacteria play a critical role in the failure of wounds that do not have obvious infection to heal. In reality, the concept of critical colonisation probably describes the presence of a biofilm in a chronic wound.

**Can we see biofilms?**

Biofilms are microscopic structures. However, when allowed to grow undisturbed for an extended period of time, biofilms can become thick enough to be seen with the naked eye. For example, tooth plaque can accumulate and become clearly visible within a day. Some microbial biofilms can be visually detected because of the production of pigments that are produced by bacteria only when growing in a biofilm state (e.g. green pyocyanin produced by *Pseudomonas*). Biofilms stimulate inflammation, which increases vascular permeability and production of wound exudate and the build up of fibrin slough. Therefore, slough may indicate that biofilm is present in the wound.

Currently, the most reliable method to confirm the presence of microbial biofilm is specialised microscopy, eg confocal laser scanning microscopy.

**How do mature biofilms ‘protect’ bacteria?**

Biofilms greatly enhance the tolerance of microorganisms embedded in the matrix to the immune system, antimicrobials and environmental stresses (e.g. nutritional or oxygen limitation). This tolerance may approach complete resistance to factors that would easily kill these same microbes when growing in an unprotected, planktonic state. BlockingOne simple way that EPS protects microbes is by preventing large molecules (e.g. antibodies) and inflammatory cells from penetrating deeply into the biofilm matrix. Mature biofilm may also act as a diffusion barrier even to small molecules like antimicrobial agents.

**Mutual protection**

Another unique property of polymicrobial biofilms is the cooperative protective effects that different species of bacteria can provide to each other. For example, antibiotic resistant bacteria may secrete protective enzymes or antibiotic binding proteins that can protect neighbouring non-antibiotic resistant bacteria in a biofilm, as well as transfer genes that confer antibiotic resistance, even between strains.

**Pseudomonas aeruginosa** biofilm on wounds appears milky pale green, translucent and viscous. Nevertheless, there is an important link between biofilms and slough. Biofilms stimulate inflammation, which increases vascular permeability and production of wound exudate and the build up of fibrin slough. Therefore, slough may indicate that biofilm is present in the wound.
different species. Studies have also shown that the specific characteristics of the EPS of biofilms established by one species can play a significant role in the ability of other species to attach and incorporate into an existing biofilm.

**Hibernation (quiescent bacteria)**

Another survival strategy that many bacteria in biofilms have developed is for a subpopulation to become metabolically quiescent, ie to hibernate. Bacteria need to be metabolically active for antibiotics to kill them. Therefore, hibernating bacteria in biofilms are unaffected by antibiotics that would normally kill active bacteria.

Research has shown that the minimal concentration required to kill or eliminate bacterial biofilm for many antibiotics actually exceeds the maximum prescription levels for the antibiotics. Thus, standard oral doses of those antibiotics, which effectively kill the normally susceptible bacteria when grown planktonically in a clinical laboratory, may have little or no antimicrobial effect on the same type of bacteria in biofilm form in the patient.

**How do biofilms delay wound healing?**

Biofilms stimulate a chronic inflammatory response in an attempt to rid the wound of the biofilm (Figure 2). This response results in abundant neutrophils and macrophages surrounding biofilms. The neutrophils and macrophages secrete high levels of reactive oxygen species (ROS) and proteases (matrix metalloproteinases (MMPs) and elastase). The proteases can help to break down the attachments between biofilms and the tissue, dislodging the biofilms from the wound. However, the ROS and proteases also damage normal and healing tissues, proteins and immune cells. These 'off target' damaging effects of the ROS and proteases impair healing.

The chronic inflammatory response is not always successful in removing the biofilm and it has been hypothesised that the response is in the interest of the biofilm. By inducing an ineffective inflammatory response, the biofilm protects the microorganisms it contains and increases exudate production, which provides a source of nutrition and helps to perpetuate the biofilm.

**Are there conditions that predispose a wound to develop a biofilm?**

General conditions that impair the immune system or reduce the effectiveness of antibiotic drugs favour the development of biofilms in wounds. These include tissue ischaemia or necrosis, poor nutrition and co-morbidities that impair immune function such as HIV, diabetes, major trauma, radiation treatment, or treatment with immune suppressing drugs.

**What are the principles of managing biofilms?**

Even when a wound is strongly suspected of containing a biofilm, there is no one-step solution for treatment. A proactive approach using a combination strategy based on elements of wound bed preparation may prove helpful (Figure 3) and aims to:

- reduce the biofilm burden
- prevent reconstitution of the biofilm.

This approach is sometimes called 'biofilm-based wound care'.

**How can biofilm burden be reduced?**

Evidence to date suggests that physical removal, ie debridement or vigorous physical cleansing, are the best methods for reducing biofilm burden.

Debridement involves the removal of necrotic and contaminated tissue and matter from a wound so that healing can occur. There are numerous methods of debridement, ranging from sharp debridement to techniques usually thought of as wound cleansing, eg wound irrigation. Choice of method of debridement or cleansing by a clinician will be heavily influenced by knowledge, training and competency, and must take into account safety and ethical considerations.

Research into the management of wound biofilms has so far used sharp debridement and ultrasonic debridement with the
aim of opening all tunnels and removing undermining, all devitalised tissue, slough and discoloured or soft bone. However, because of the difficulties of visualising biofilms, the impact of debridement and the best method of debridement for biofilm management is not yet clear.

**Frequency of debridement/cleansing**

No form of debridement or cleansing is likely to remove all of a biofilm, and so any remaining has the potential to regrow and form mature biofilm within a matter of days. As a result it is suggested that debridement in a wound suspected of containing biofilm needs to be performed regularly. As yet, the ideal frequency of debridement is not clear; in a study of patients with critical limb ischaemia, the wounds were debrided weekly.

Some products are suggested to have additional roles in wound cleansing by aiding removal of bacteria and debris, and disturbing biofilm. A promising technology, for example, lies in the surfactant properties of some polyhexamethylene biguanide (polyhexanide or PHMB) wound cleansing formulations (eg Prontosan®). The surfactant component (betaine) of the cleansing agent reduces surface tension and aids removal of debris and bacteria by irrigation.

If a wound is still not progressing following regular debridement with one method, it may be necessary to consider a more ‘aggressive’ form of debridement with specialist referral as appropriate.

**How can biofilm reconstitution be prevented?**

Biofilm may reconstitute in a wound by:
- spread of planktonic bacteria released from the remaining biofilm
- growth of biofilm by newly introduced microorganisms.

Principles involved in preventing reconstitution of the biofilm include prevention of further wound contamination (ie the use of dressings), and the use of antimicrobial agents to kill planktonic microorganisms.

The polymicrobial nature of many biofilms indicates that a topical broad spectrum antimicrobial that kills rather than inhibits microorganisms is the most appropriate. Details of the effects of antimicrobials on biofilm reformation are not yet known. However, the broad spectrum microbiidal antimicrobials most widely used in wound care are silver, iodine, honey and PHMB. These are available in a number of different formulations.

An emerging principle for the use of topical antimicrobials is changing to a different antimicrobial if there is lack of progress. As yet, there is no evidence to suggest which antimicrobial is preferable first line; choice will be dependent on how the antimicrobial will be used. For example, is it to be left in place for several days? If so, a sustained release formulation will be required to cover the period of use. Patient sensitivities/allergies must also be taken into account.

**How will I know when the biofilm has gone?**

The lack of definitive signs and readily available laboratory tests for biofilms means that it is not possible to state categorically when a wound has become biofilm free. The clearest clinical indicator is likely to be healing progression, along with a reduction in the production of exudate and slough.

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Until clear guidance becomes available, clinical judgement will be required to decide when and how to modify the management of wounds with suspected biofilm. For example, when healing is progressing well, it may be appropriate to change debridement method or reduce debridement frequency, and/or
Bacterial biofilms are known to contribute to numerous chronic inflammatory diseases and recent evidence suggests that biofilms also play important roles in impairing healing in chronic wounds. Biofilms have high levels of tolerance to antibodies, antibiotics, disinfectants and phagocytic inflammatory cells. Current understanding of biofilms suggests that management of suspected wound biofilm should involve frequent debridement along with interventions such as dressings and antimicrobials to prevent recontamination of the wound and suppress biofilm reformation.

**Glossary**

<table>
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<tr>
<th>Term</th>
<th>Description</th>
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<tr>
<td>Biofilm phenotype</td>
<td>Biofilm phenotype microorganisms express genes optimal for developing an attached community embedded in a protective self-secreted ‘slime’ matrix and surviving environmental stresses.</td>
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<tr>
<td>Commensal</td>
<td>A microorganism that lives on/in a tissue, usually without causing disease.</td>
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<tr>
<td>Extracellular polymeric substance (EPS)</td>
<td>The ‘slime’ produced by microorganisms in a biofilm comprising polysaccharides, proteins, glycolipids and bacterial DNA; it protects the microorganisms living in the biofilm from the host’s immune system and antimicrobial agents.</td>
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<tr>
<td>Phenotype</td>
<td>The characteristics of a microorganism that result from an interaction between the environment and the microorganism’s genes.</td>
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<td>Planktonic</td>
<td>Refers to free-floating microorganisms that are expressing genes optimal for single, unattached growth.</td>
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<tr>
<td>Quorum sensing</td>
<td>A mechanism used by microorganisms to communicate within and between bacterial species. It is used to detect and respond to changes in the environment (including the presence of other microbes or nutritional limitations). Quorum sensing induces changes in bacterial gene expression that aim to promote survival of the microorganisms.</td>
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<tr>
<td>Sessile</td>
<td>Microorganisms that are firmly attached to a surface by means of receptors and/or proteins called adhesins.</td>
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**Future developments**

There is a need to develop methods or devices to quickly detect the presence of biofilm before and after selected treatments. Initially, this would help guide researchers and healthcare providers to develop effective wound management strategies. Later, it would serve as a means to monitor the progress of treatment. Both currently available and novel antimicrobial agents and treatment methods are being scrutinised for their efficacy against biofilm, both as biofilm eliminators and biofilm inhibitors. For example, recent studies of the antimicrobial efficacy of various wound dressings against mature *Pseudomonas aeruginosa* biofilm cultured on porcine skin has revealed significant biofilm eliminating properties of cadexomer iodine4. However, the complex ever changing polymicrobial nature of biofilm, complicated by biofilm bacterial phenotypic heterogeneity means that antibiofilm efficacy of agents must be verified on a patient by patient basis.

**How do we explain biofilms to patients?**

Patients can be reassured that biofilms can be effectively treated by a combination of debridement and/or cleansing to remove the biofilms, application of dressings to block new bacteria from reaching the wound, and the use of antimicrobials to kill bacteria left in the wound bed. Patients should be told that treatment needs to be repeated and regular because biofilms can reform within a day and prevent wound healing.

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**Summary**

Bacterial biofilms are known to contribute to numerous chronic inflammatory diseases and recent evidence suggests that biofilms also play important roles in impairing healing in chronic wounds. Biofilms have high levels of tolerance to antibodies, antibiotics, disinfectants and phagocytic inflammatory cells. Current understanding of biofilms suggests that management of suspected wound biofilm should involve frequent debridement along with interventions such as dressings and antimicrobials to prevent recontamination of the wound and suppress biofilm reformation.

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References


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Further reading


