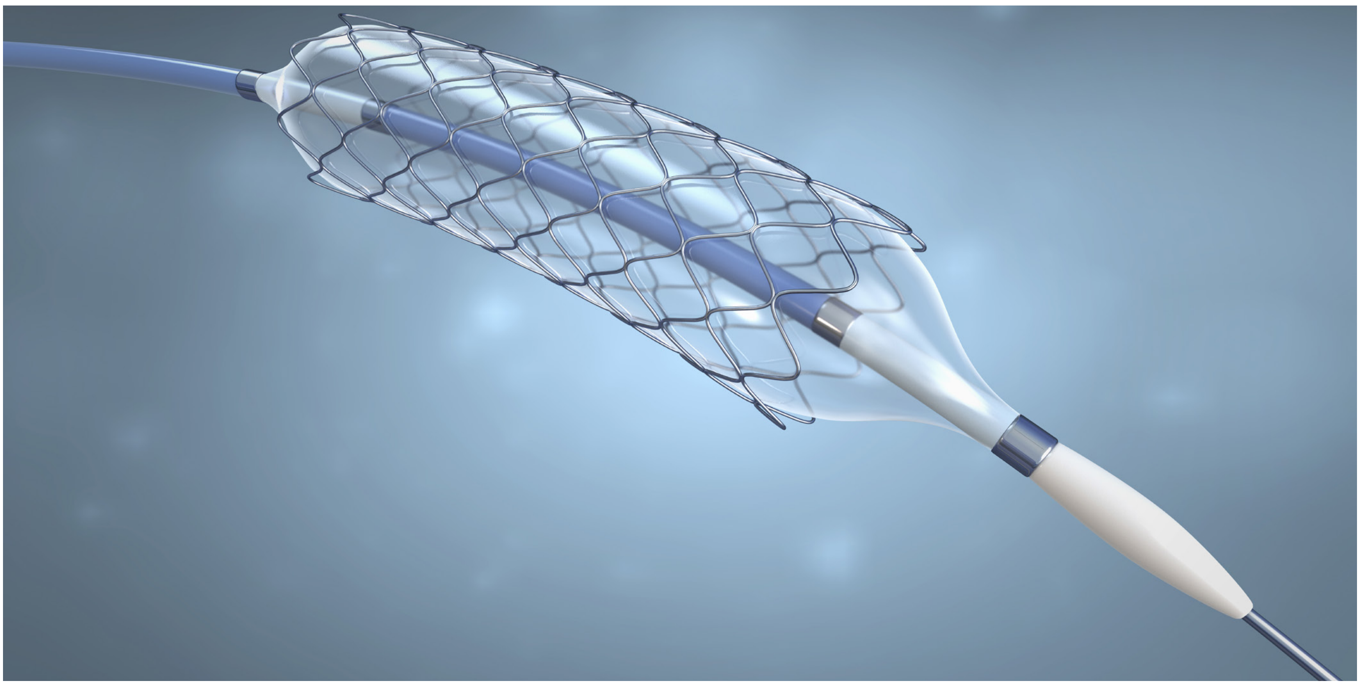
Overview

Effect of Wettability in Biomedical Applications



Various types of artificial materials are being utilized in medical devices. The surface properties of the material determine its interactions with the surrounding environment. Physicochemical properties of the surface, like wettability, surface chemistry of the exposed atoms, surface energy, and surface topography, are of prime importance when biocompatibility of the material is determined. The biocompatibility of the material is nowadays often defined as "the ability of a material to perform with an appropriate host response in a specific application" [1].

In addition to biocompatibility, wettability is also important in medical device manufacturing. Different types of coatings are often used to improve the surface properties of these devices. The success of biomedical coating depends on its proper and adequate adhesion on target substrate, which is influence by the surface properties of the substrates [2].

What is wettability?

Wettability is the preference of a liquid to be in contact with a solid surrounded by another fluid which can be liquid or gas.

Surface wettability is influenced by three forces; the surface tension of a liquid, the surface tension of a solid (i.e. surface free energy) and the interfacial tension between the solid and the liquid. Surface free energy is the property of the solid similarly as surface tension is a property of a liquid.

Wettability is affected by both surface chemistry and surface roughness. Wettability of the material is evaluated through contact angle measurements. In a contact angle measurement, a drop of liquid, most typically water, is placed on a sample and an image of the drop is taken. The contact angle is then defined as the angle the droplet forms with the solid surface as shown in figure 1.

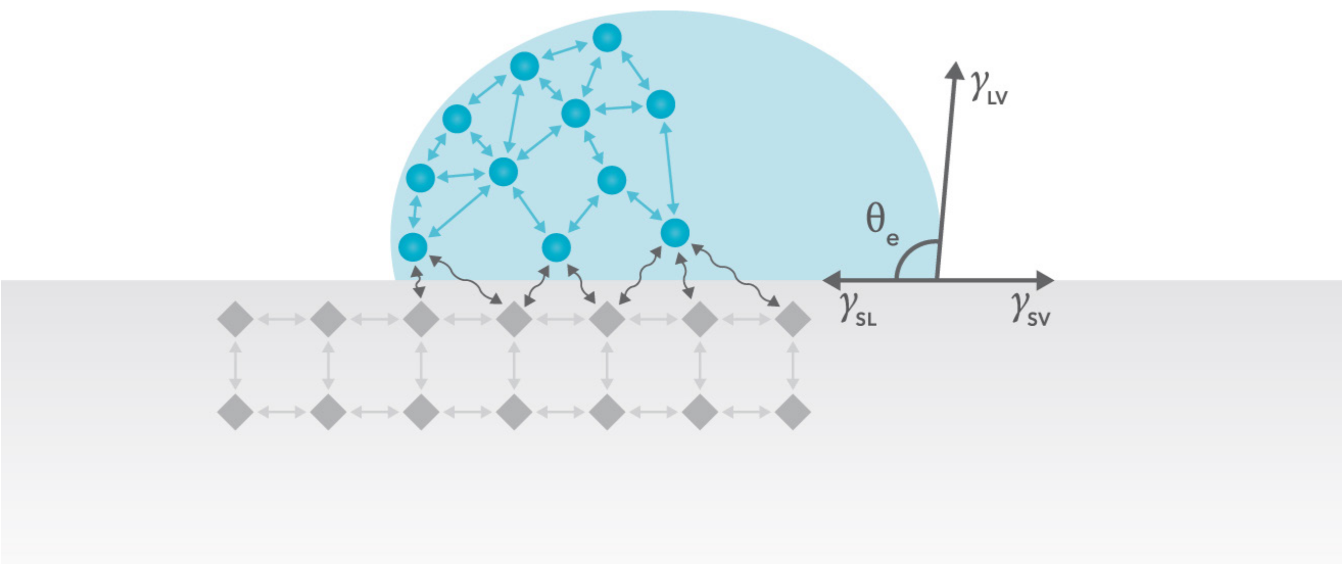


Figure 1. Forces acting an a three-phase contact point where solid, liquid, and gas (or another liquid) meet.

Hydrophilic vs. hydrophobic surfaces

Based on the water contact angle measurements, the materials can be classified as hydrophilic or hydrophobic. A water contact angle at 90° is used as a threshold value. Surfaces with water contact angle less than 90° is termed hydrophilic and above 90° hydrophobic. Hydrophilic surfaces are generally considered low fouling surfaces and be enough to limit cell adhesion or blood platelet activation which would then appear to enhance biocompatibility. Reduced protein fouling is likely to reduce both bacterial and mammalian cell adhesion [3]. This can be an advantage especially in short term implant surfaces but in applications where a cell adhesive surface is desired this presents a challenge. There are several proposed solutions to overcome these challenges but overall, the material properties are always balanced between the promotion of cell adhesion and infection and eventually biofilm formation prevention.

Hydrophilicity also seems to be an important property of temporary medical devices, such as catheters. Hydrophilicity is related to lubricity which is connected to the ease with which catheter can be inserted and removed. Friction between the material and mucosa can cause damage and discomfort to the patient [4]. In order to add hydrophilic coatings on plastic polymer tube (which are inherently hydrophobic), surface treatments are typically applied to improve coating adhesion.

Based on water contact angle surfaces can be either hydrophilic or hydrophobic.

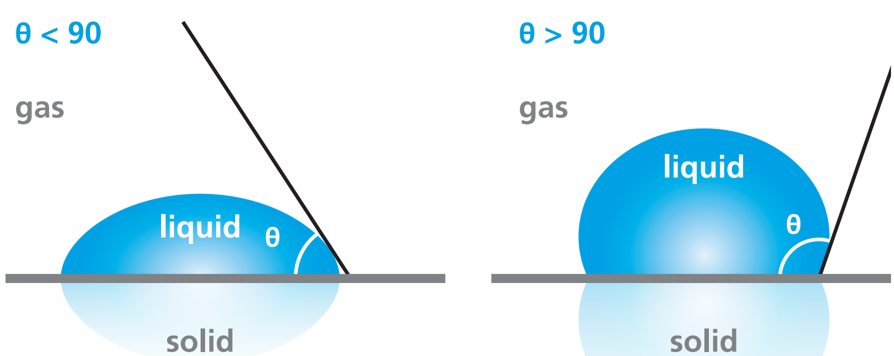


Figure 2. (left) Hydrophilic sample (right) hydrophobic sample.

APPLICATIONS	What is studied?
Biocompatibility of permanent implants	Contact angle as an early indicator for cell adhesion and biocompatibility
Contact lens	Optimizing contact lens comfort and visual performance
Biomedical coating optimization for permanent implants (e.g. dental and other bone-connecting)	To improve cell adhesion and integration of selected cell types
Hydrophilic biomedical coatings	To improve lubricity of the coatings
Plasma treatment to improve adhesion of biomedical coating	Plasma treatment parameters can be determined and the efficiency evaluated with contact angle measurements.

Table 1. Biomedical applications and wettability measurements.

The optimum surface energy range for minimizing the degree of surface fouling is predicted to lie between 20 to 30 mN/m and then again above 70 mN/m.

Effect of surface free energy on biomaterial performance

The majority of the substrates used in medical devices are polymers and can be considered hydrophobic. The surface energies range between 20 mN/m (fluoropolymers) to 42 mN/m (Nylons and polyvinyl chloride). Metals are an exception as the surface oxide layer can lead to a high surface free energy (SFE) along with glasses and ceramics which can have SFE values as high as 110 mN/m and above.

The optimum surface energy range for minimizing the degree of surface fouling is predicted to lie between 20 to 30 mN/m and then again above 70 mN/m [5]. The surface polarity has also been shown to correlate with cell adhesion strength [6].

Surface free energies can be determined by the contact angle measurements. Contact angle measurements with pure probe liquids are used to determine the polar and dispersive parts of the surface free energy of the material [7].

Surface roughness influences the wettability and biocompatibility

In addition to surface chemistry, surface roughness also influences the wettability and biocompatibility. At the cellular level, biological responses, such as the orientation and migration of cells as well as their ability to produce organized cytoskeletal arrangements are directly influenced by the surface topography [8]. There is also evidences that suitable surface roughness, at the nano- and micrometer level, can lead to successful osseointegration of titanium implants, which is important for dental and other bone-connecting implants [9]. Due to this, porous titanium coatings have also gained a lot of interest, but increased surface roughness also enhances bacterial adhesion increasing the infection risks [10].

In addition, surface roughness also affects wettability as the wettability of the surface is further enhanced by the surface roughness. Simply put, if the contact angle is below 90 °, adding roughness to the surface will decrease the contact angle even further. Then on the other hand, if the contact angle is above 90 °, adding roughness will increase the contact angle even more [11]. As both surface roughness and wettability affects how proteins and cell interact with the material, it is important to separate the effect of the two from each other.

Conclusions

Wettability of the biomaterial is important both in device manufacturing as well as for overall performance of the device in human body. In device manufacturing, a hydrophilic Wettability affects the biocompatibility. As the optimum cell-biomaterial interaction depends on how the implant or medical devices is used, it is not possible to determine the best wettability or surface topography that would apply to all situations. Contact angle measurement (and surface free energy determination) offer the first indications on the suitability of the material for a specific application.

Hydrophilicity of the surface is also important in applications like cathether. To coat the polymer cathethers, the material surface needs to be treated for proper adhesion of the coating. Good wettability is required for good adhesion which makes wettability measurements important also in medical device manufacturing.

References

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