Bio-Ceramic Coatings

Applying a glass or ceramic coating onto the surface of a substrate allows us to have the best of both worlds. We have the bulk properties of the substrate and the surface properties of the coating. There are three main reasons for applying a coating:

1. Protect the substrate against corrosion

2. Make the implant biocompatible

3. Turn a nonbioactive surface into a bioactive one

There are four substrate-coating combinations:

1. Polycrystalline ceramic on ceramic

2. Glass on ceramic

3. Polycrystalline ceramic on metal

4. Glass on metal

Bioceramic coatings are often used on metallic substrates in which the fracture toughness of the metal is combined with the ability of the coating to present a bioactive surface to the surrounding tissue. The use of a bioceramic coating on a metal implant can lead to earlier stabilization of the implant in the surrounding bone and extend the functional life of the prosthesis. Under the proper conditions a cementless prosthesis should remain functional longer than a cemented device in which stability is threatened by fracture of the bone cement. The important ceramic coatings are HA and TCP.

Bioceramic as scaffold

In the past, most bone defects have been treated by bone grafts, which are extremely risky and complicated. As a result, scientists have been trying to find a suitable biomaterial (material that is compatible with human biology) to use as a scaffold, or template, for induced bone regrowth, which is a much safer procedure. An appropriate material must have the following properties:

- It must be porous, to allow nutrients and blood to get to bone cells
- It must be compatible with human biology so that it can be integrated with natural bone
- It must be biodegradable so that it will disintegrate when it is no longer needed
- It must have the mechanical properties of natural bone

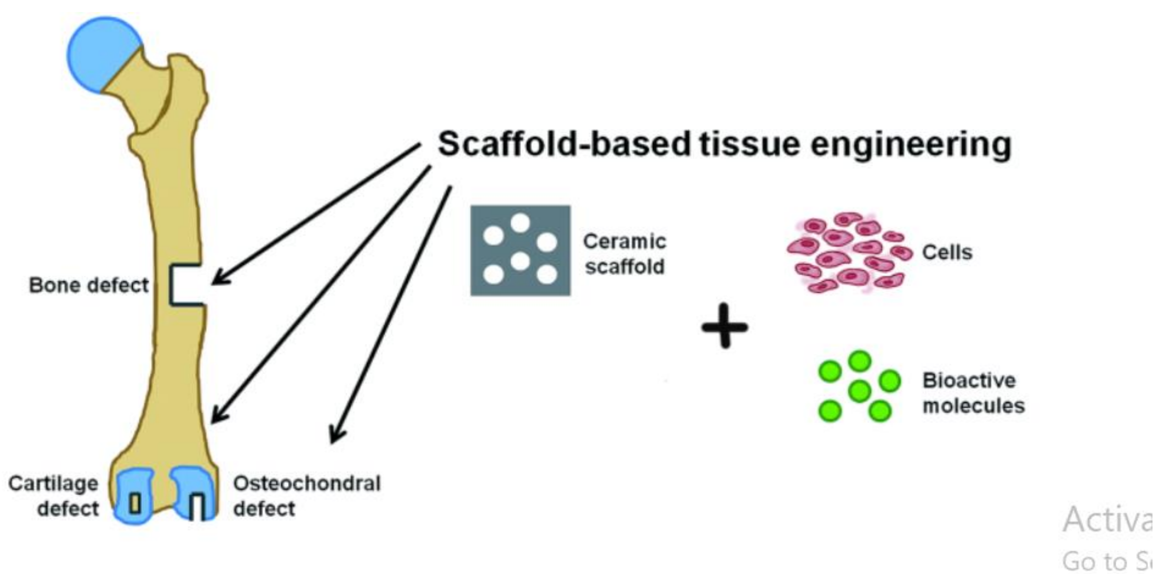

Figure B1: Function and mechanism of a bone scaffold

Using 3D printing methods, scientists have concluded that bioceramics are one of the best materials to use as scaffolds. There are four main types of ceramic materials: hydroxyapatite, beta-tricalcium phosphate, calcium phosphate cements, and bioactive glass-ceramics. Although each type is used in slightly different situations, they are all good choices because of some common traits they share.

First and foremost, they demonstrate high levels of biocompatibility—ceramics have a similar mineral structure to bone, so they integrate easily with existing bone in the body. This is important because the material needs to be able to facilitate natural cellular and molecular activity and ensure that growing bone cells will be able to stick to the scaffold.

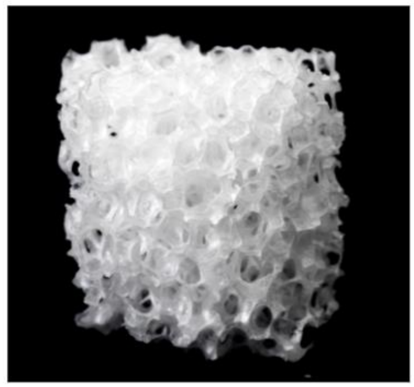

Figure B2: Structure of bioceramic

Next, they have natural microporosity, meaning that it is easy for blood capillaries to grow within the scaffold to deliver oxygen and nutrients to cells. The added benefit of using ceramics, unlike other materials, is that this porousness does not affect mechanical strength. The scaffold is still stiff enough to endure great amounts of compression force, and it has enough structural integrity to support itself.

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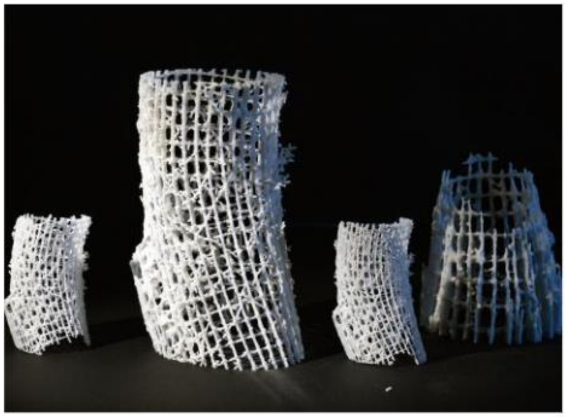

Figure B3: Different types of bone scaffolds

Finally, bioceramics have an optimal biodegradation rate. This means that they will remain structurally sound long enough for the bone to regenerate, and then disintegrate rapidly when they are no longer needed. Additionally, it is relatively easy to manipulate the molar ratios of the compounds in ceramic to change the degradation rate as needed, so scientists can quickly modify the scaffold to fit the needs of each patient.

Sterilization Methods

Sterilization is the killing or removal of all microorganisms, including bacterial spores, which are highly resistant. Sterilization refers to the antimicrobial process during which all microorganisms are killed or eliminated in or on a substance or substrate by applying different processes.

Sterilization procedures involve the use of heat, radiation, chemicals, or "physical removal" of microbes (Table. 1). The type of sterilization should always be chosen as required, by taking into consideration the quality of materials and tools used and the possible adverse effects of sterilization on them.

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Heat	Flaming Incineration Boiling Moist heat Dry heat
Radiation	UV Gamma rays Electron beam X-rays
Chemicals	Ethylene oxide Ozone
Plasma	Ionizing gas
Filtration	Membrane

Disinfection methods are different from sterilization as they kill many but not all microorganisms.

Sterilization by Heat

Heat is the most effective and rapid method of sterilization and disinfection. Excessive heat acts by coagulating cell proteins, whereas less heat interferes with metabolic reactions. Sterilization occurs by heating above 100°C, which ensures lolling of bacterial spores. Sterilization by hot air in a hot air oven (i.e., dry heat) and sterilization by autoclaving (i.e., moist heat) are the two most common methods used and will be described in the following. In particular, when sterilization occurs by heat, two types of techniques can be identified and will be briefly illustrated here:

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1. Sterilization by dry heat;
2. Sterilization by moist heat.

1. Dry Heat

The use of dry heat is based on the removal of the water content of microbes and subsequent oxidation, thus killing or removing all microorganisms, including bacterial spores. Dry heat sterilization technique requires longer exposure time (1.5–3 h) and higher temperatures than moist heat sterilization

Dry heat does most of the damage by oxidizing molecules. The essential cell constituents are destroyed and the organism dies. The temperature is maintained for almost an hour to kill the most resistant spores. Advantages and disadvantages of dry heat oven sterilization can be shown in (Table 2).

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Advantages	Disadvantages
A dry heat cabinet is easy to install and has relatively low operating costs	Time-consuming method because of slow rate of heat penetration and microbial killing
It penetrates materials	High temperatures are not suitable for most materials
It is nontoxic and does not harm the environment	
It is noncorrosive for metal and sharp instruments	

The most common time-temperature relationships for sterilization with hot air sterilizers are the following:

– 170°C for 30min;

– 160°C for 60min;

– 150°C for 150min or longer depending on the volume

2. Moist Heat (Autoclave)

Due to the fact that the heat conductivity of water is several times higher than that of the air, heat sterilizes more quickly and effectively in the presence of hot water or steam than dry heat. Moist heat acts by denaturation and coagulation of protein,

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breakage of DNA strands, and loss of functional integrity of cell membrane; in addition, the structural components for microorganism replication are destroyed.

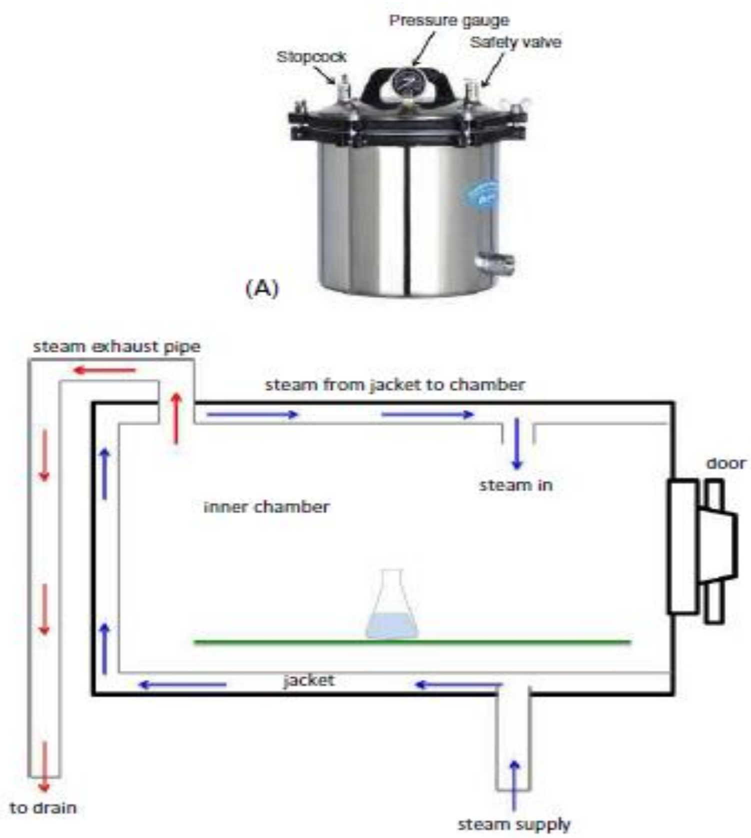
Sterilization by moist heat is one of the most used sterilization techniques because it is simple, low cost, and devoid of any risk for the operators. (Table 3) represent the advantages and disadvantages of autoclave sterilization

Advantages	Disadvantages
Nontoxic to patient, staff, environment	Deleterious for heat-sensitive or moist-sensitive instruments/materials
Cycle easy to control and monitor	Microsurgical instruments damaged by repeated exposure
Rapidly and efficacy microbicidal	May leave instruments wet, causing them to rust (in case of metallic devices)
Least affected by organic/inorganic soils among sterilization processes listed	Potential for burns
Rapid cycle time	
Penetrates medical packing, device lumens	

However, the time used for sterilization depends on the size and content of the load.

Autoclave is a metallic cylindrical vessel (Fig. 1); on the lid, there is a:

- Gauge for indicating the pressure,
- Safety valve, which can be set to blow off at any desired pressure,
- Stopcock to release the pressure. It is provided with a perforated diaphragm.



Water is placed below the diaphragm and heated by electricity, gas, or stove. Typical sterilization process is composed by three phases (Fig .2): heating phase, stationary phase (t=15–30min), and cooling phase.

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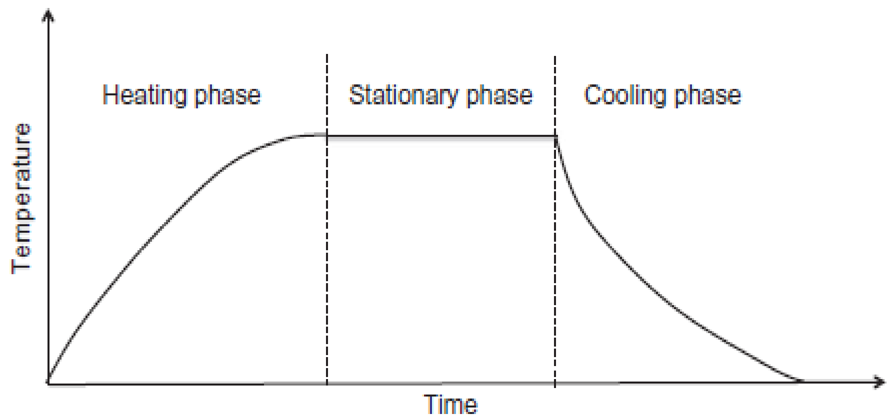

Sterilization by Ethylene Oxide

The materials used in chemical sterilization are liquids or gases. Liquid agents are used primarily for surface sterilization. Among sterilizing gases, those working at low temperature function by exposing the materials to be sterilized to high concentrations of very reactive gases (e.g., ethylene oxide (EtO), beta propiolactone, or formaldehyde).

Due to their alkylating effect, these compounds cause the death of microbes by damaging their proteins and nucleic acids. The chemical agents used for sterilization must be chemically compatible with the substances to be sterilized. The advantages and disadvantages of ethylene oxide sterilization represented in (Table 5).

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Advantages	Disadvantages
Low temperature	Excessively long cycle
Short aeration time	Safety concerns—carcinogenic to humans
High efficiency: it destroys microorganisms including resistant spores	Toxicity issues: toxic residues on surgical instruments and tubing
Large sterilizing volume/chamber capacity	EtO is flammable
Noncorrosive to: plastic, metal, and rubber materials	Requires special room conditions, safety equipment, and separate ventilation system

There are at least three stages in a typical EtO sterilization cycle (Fig. 3):

1. **Preconditioning:** This step prepares the chamber environment to meet the ideal conditions for temperature, pressure, and humidity. First, air is removed from the chamber to allow for gas penetration; then, steam is injected into the chamber, which humidifies the load as EtO is only effective in a humid environment. The chamber is heated by either steam or hot water, which is present in the jacket of the sterilizer.

2. **Sterilization:** This step is the actual sterilization process. The EtO enters the chamber via evaporation with a certain amount of steam to keep the humidity level up as well as to make sure the EtO is reaching all parts of the load.

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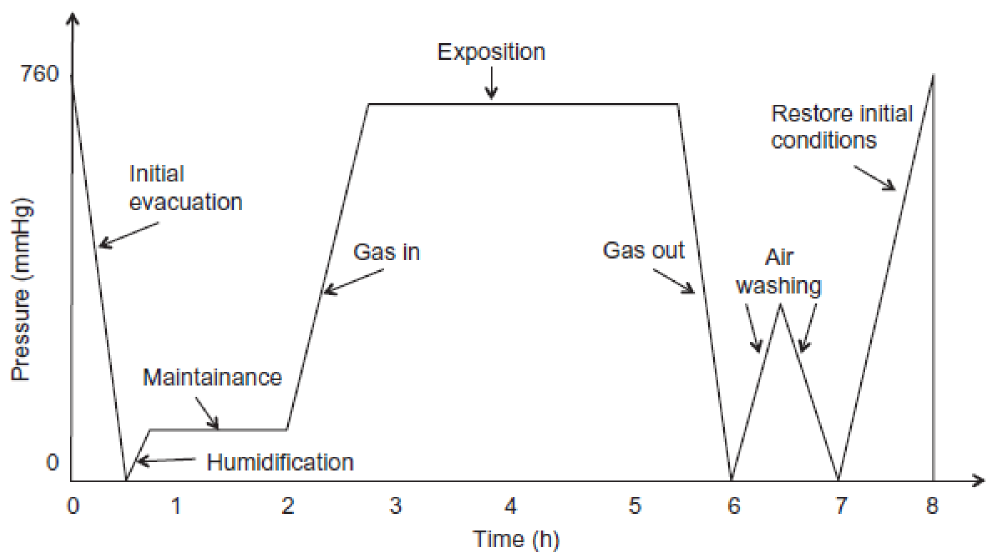
3. **Aeration (degassing):** It is the most important and longest part of the EtO sterilization cycle. In fact, materials such as plastics and rubbers absorb gas and, if applied to patients, the toxic gas could damage human body tissue. For this reason, it is very important to have an excessive aeration stage to remove any remaining EtO gas and to allow absorbed gas to evaporate again from the sterilized items.



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