

4 PVC-P as a biomaterial

4.1 Introduction

Semi-rigid poly(vinyl chloride) (PVC) or PVC-rubber blended materials have been used to make medical disposables, such as containers, connectors, trays, blister packaging and drip chambers. Flexible, soft plasticised PVC (PVC-P) is the most widely applied biomaterial for medical applications. The earliest medical application of PVC-P was to replace the traditional metal and glass materials for the packaging of pharmaceutical products, such as blood components, sterilised sugars and electrolytes for intravenous infusion and peritoneal dialysis during World War II. As the increasing need for flexible, disposable, biocompatible plastics for medical devices evolved over 50 years, PVC-P became by far the most commonly used polymer in the medical plastics industry. In 1990, its estimated market share was around 25% of all the polymeric materials used in medical devices [1]. By 1995, it was estimated that PVC represented 37% of all medical plastics used in the USA, with worldwide percentages believed to be even higher [2]. In 2004, about 40,000 t of plasticised PVC was used in the medical field in Europe and there is an annual growth rate of 4.3% [3].

According to Webster's New Collegiate Dictionary, a biomaterial is defined as '*a material used for or suitable for use in prostheses that come in direct contact with living tissues*'. Briefly, a biomaterial can be defined as a nonviable material used in a medical device intended to interact with a biological system [4]. In more detail, a biomaterial is a substance, which is used in prostheses or in medical devices designed for contact with the living body for the intended method of application and for the intended period [5].

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Synthetic polymers form the most diverse class of biomaterials. As an ideal biomaterial, a synthetic polymer needs to meet the following criteria [6]:

- The polymer should be one that can be reproducibly obtained as a pure material,
- The polymer should be one that can be fabricated into the desired form without being degraded or adversely changed,
- The polymer should possess the required chemical, physical and mechanical properties for performing its function,
- The polymer should be biocompatible.

The following sections discuss how PVC-P meets these basic requirements as a biomaterial and where its drawbacks are.

4.2 Advantages of PVC-P

PVC-P-based film, sheet and tubing are used in numerous medical products. The typical requirements for tubing as the intravenous (IV) set, for example, include clarity, flexibility, kink resistance, toughness, scratch resistance, ease of bonding with common solvents or adhesives and suitability for gamma, ethylene oxide (EO) or electron-beam sterilisation. As a biomaterial, PVC-P has achieved its prominent role in the medical plastics industry by virtue of a unique combination of desirable properties.

PVC can be used to produce a variety of medical products, ranging from rigid components to flexible sheeting. The type and amount of plasticiser used determine the compound's glass transition temperature (T_g), which in turn defines its flexibility and low-temperature properties, and thereby establishes its versatility. Flexible or rigid PVC can be easily processed to shaped end products. They can be readily assembled by solvent bonding or sealed using heat or radio frequency. As a biomaterial for medical products, PVC-P

can be sterilised by most commonly employed sterilisation methods, such as steam, ethylene oxide or gamma radiation. PVC-P can have a T_g as low as $-40\text{ }^\circ\text{C}$ and still be suitable for steam sterilisation at $121\text{ }^\circ\text{C}$. PVC-P has excellent biocompatibility, very low toxicity and chemical stability. Additional characteristics that make PVC attractive include its low cost, high transparency, wide range of gas permeability, thermoplastic elastomer-like material properties, fire resistance and good insulation properties. Medical products made from PVC have passed many critical toxicological, biological and physiological tests according to national or international standards. In summary, PVC-P is one of the best medical materials in terms of cost and function. No other single material has such broad advantages (**Figure 4.1**).

In terms of life management of medical PVC, the environmental advantages of PVC use in medical devices are (www.ecvm.org):

- Comparatively low energy and resource use in production and conversion,
- Medical-grade PVC products are durable,
- Medical-grade PVC can be safely incinerated, allowing energy recovery, or safely disposed of in landfill.

4.3 Disadvantages

According to the criteria that an ideal biomaterial should meet, as previously considered, a polymer should be sufficiently pure without any influence of biocompatibility due to any unintentional additives, such as monomer residues, low molecular weight polymers and other reaction residues, and intentional additives, such as plasticisers, stabilisers, lubricants and fillers. For PVC-P, however, it is the additives that make PVC versatile and useful, while at the same time they are continuously receiving criticism [7].

The most commonly cited shortcomings involve toxic effluents such as vinyl chloride monomer (VCM) produced during manufacture

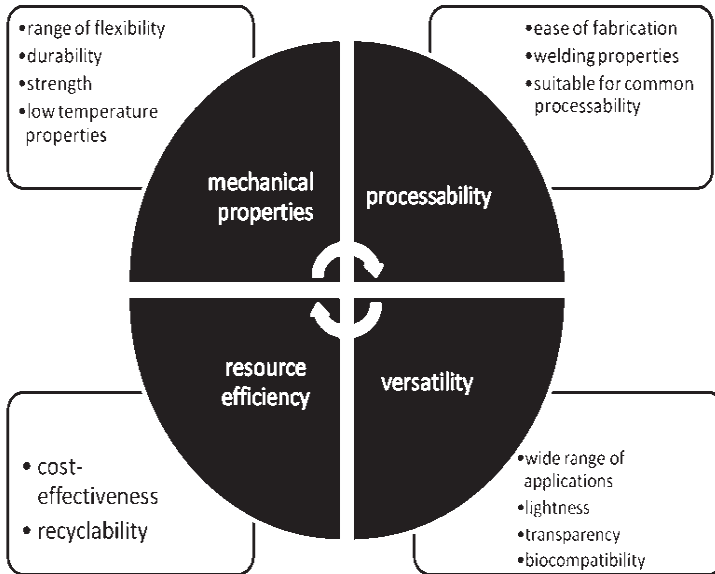


Figure 4.1 Advantages of PVC-P in medical applications

and the generation of hydrogen chloride (HCl) during incineration. Other concerns related to PVC-P depend largely on the type and amount of plasticisers used.

Plasticisers have been found to leach into medical solutions [8], the human body during long-term dialysis [9, 10], stored human blood [11] and foodstuffs [12]. PVC-P pharmaceutical packaging bags have been found to cause drug loss during storage periods. For example, drugs such as diazepam, isosorbide dinitrate, nitroglycerin and warfarin sodium can be adsorbed by PVC-P with 55%, 23%, 51% and 24% loss, respectively, during a 24 h study period [13]. Kowaluk and co-workers [14] have studied the interaction between 46 injectable drugs and PVC-P infusion bags. They found that the drug loss is due to a diffusion-controlled sorption process.

With regard to the leaching of the plasticiser di-2-ethylhexyl

phthalate (DEHP), the most commonly applied plasticiser for medical applications, however, there are many divided opinions. It appears that no proof has been found that DEHP is toxic or is a carcinogenic initiator, while its beneficial effect on red blood cell survival is a valued property.

4.4 PVC-P as a blood-contacting biomaterial

The advantages of PVC-P have led to the wide application of PVC-P in single-use, presterilised and disposable blood-contacting devices. Generally, blood-contacting devices are categorised in the ISO10993-4 standard into ‘external communicating devices’ and ‘implant devices’ [15]. For PVC-P, the major applications are in the first area as external communicating devices, as shown in **Figure 4.2**.

The blood products collected and packaged using PVC-P include whole blood, red blood cells and platelet concentrates. PVC-DEHP is currently the most widely used packaging material for the storage of whole blood, while for red blood cells and platelets, PVC- butyryl tri-*n*-hexyl citrate (BTHC) has been shown to be capable of maintaining them under optimum conditions [16].

Blood tubing made of PVC-P is widely used in blood extracorporeal circulating devices, such as haemodialysis equipment and lung-heart bypass sets. Medical tubing made of polyurethane and silicone have been utilised, but both are relatively expensive. CellTran developed a ‘living bandage’ using plasticised PVC as a base to carry cells for treatment of chronic wounds.

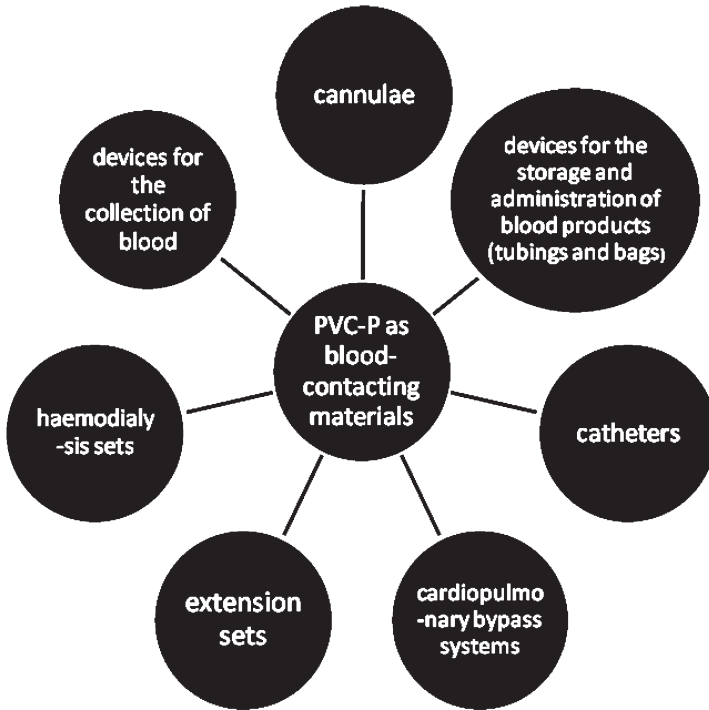


Figure 4.2 Applications of PVC-P as a blood-contacting biomaterial

4.5 Other applications of PVC-P as a biomaterial

The applications of PVC-P as a biomaterial other than for blood-contacting use are summarised in **Table 4.1**.

Table 4.1 Applications of PVC-P as a non-blood-contacting biomaterial	
Pharmaceutical solution packaging or delivery sets	Intravenous solution pack, IV sets Peritoneal dialysis solution packs Endotracheal tubes Connectors
Medical disposables	Gloves, syringes Drainage tubing or bags Urinary bags and tubing Other surgical products
Medical building products	Waterproof mattress sheets Wall-coverings, floor-coverings Electrical systems Appliances and furnishings Oxygen tents
Tissue-contacting biomaterials	Burn dressings [17] Artificial skin [18] Other surgical dressings [19, 20]
Biosensor or enzyme electrodes	Glucose biosensors [21] Protamine-sensitive polymer membrane electrode [22] Ion-sensors [23]
Drug-delivery system	Prostaglandin-releasing polymers [24] Fungicidal and bactericidal additive-releasing PVC [25]

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