# DIAMOND-LIKE CARBON – A VERSATILE BIOCOMPATIBLE COATING

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**Abstract: Diamond-like carbon (DLC) coatings protect against wear and corrosion, reduce friction, thereby prolonging the life of mechanical components such as prosthetic implants. The coatings are chemically inert and when exposed to cells cause no adverse reactions. The coatings have been applied to prostheses (knee replacements) in patients allergic to metallic implants, with the additional advantage that the coating acts as a barrier preventing metal from the implant entering the surrounding tissue. A further advantageous property is the anti-thrombogenic behaviour of the coating. DLC is deposited without external heating and can therefore be coated on plastics such as silicone catheters rendering the catheters lubricious and reducing colonisation and encrustation. DLC can also be coated on collagen, which is used as a tissue replacement incorporated as a permanent graft, but must not come into contact with flowing blood, as it is thrombogenic. Replacement bypass vessels could be constructed from collagen and coated with DLC to prevent clotting. DLC coating can prevent degradation of collagen patch graft in gastro-intestinal system due to acidic and alkaline chemistry from the stomach and associated conduits. The coatings are durable because DLC forms chemical bonds with the substrate material.**

## Introduction

Medical implants need to be biocompatible and chemically inert to avoid adverse reactions in the patient. Depending on application, it may be important for the implant to possess in addition one or more of the following properties: wear resistance, low friction surface, low fibrin adhesive (anti-thrombogenic) surface. The material of the implant may not satisfy all of these requirements, however coatings may be provided on exposed surfaces of the implant, allowing the implant to function while protecting the biological environment from adverse effects.

Diamond-like carbon (DLC) coatings can provide protection on a wide range of implants. DLC coatings are:

Biocompatible - no inflammatory reaction
Haemocompatible - reduce thrombus deposition
Wear resistant - hard but flexible
Lubricious - friction coefficient 0.1
Impervious - implant material confined
Durable - insoluble, chemically bonded

DLC coatings are deposited at low temperature allowing temperature sensitive materials to be coated as well as metals and ceramics (1,2).

## Biomedical tests for DLC

*Biocompatible coating*

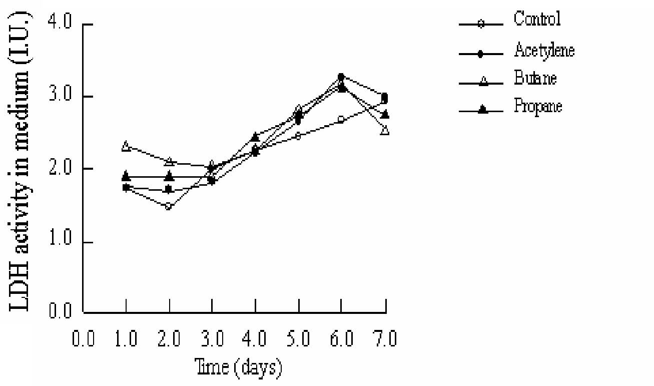


Figure 1: Release of lactate dehydrogenase

Following exposure of mouse fibroblasts to DLC coatings produced from three hydrocarbon precursor gases, there was no significant release of lactate dehydrogenase between coatings and control o (fig 1), hence no toxic or inflammatory response. Morphological examination confirmed there was no cellular damage.

*Haemocompatible coating*

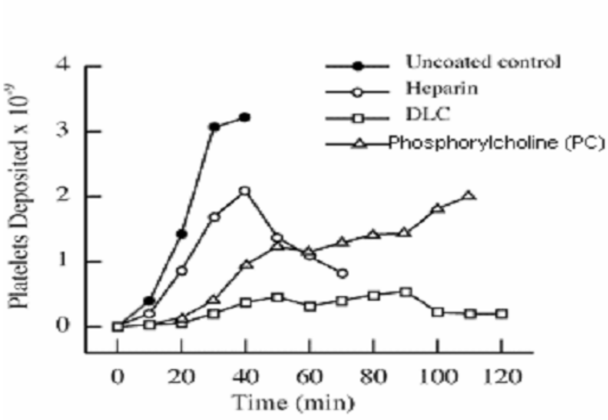


Figure 2: Platelet deposition on blood flow accelerator


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Medical devices that are in direct and continuous contact with blood such as vascular stents will be subject to thrombogenic response.
To inhibit thrombus formation, coatings have been applied to implants,. The effect of such coatings compared with an uncoated device (flow accelerator) implanted in an artery is shown in fig 2. Platelet deposition with the DLC coating was much reduced compared with other anti-thrombogenic coatings. A flow accelerator coated with DLC was inserted in the centre of an artery for eight weeks. The artery remained thrombus free (fig 3) in contrast to the thrombus formation in an artery coated with phophoryl choline (fig 4).

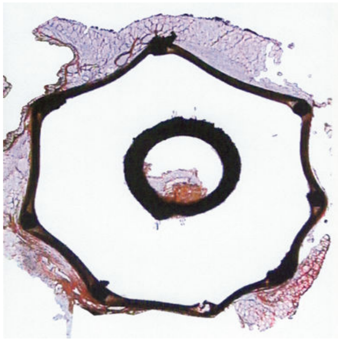

Figure 3: DLC coated flow accelerator in centre of artery showing clear thrombus free cross-section for blood eight weeks after implant

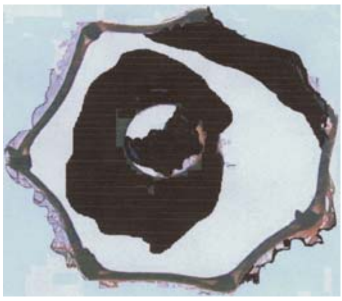

Figure 4: Accelerator coated with phosphorylcholine. Dark areas indicate significant thrombus deposit, both on accelerator device and on artery walls.

*Wear resistance*

Titanium used in massive prostheses is damaged by wear against soft tissue. In an 1100 hour test with tissue sliding in serum against a titanium cylinder at 110mm/sec with a load of 2.5 kg both the titanium and the tissue were damaged (figs 6 and 7). Under the same conditions there was little damage to a DLC coated cylinder (fig 8) or to soft tissue (fig 9).

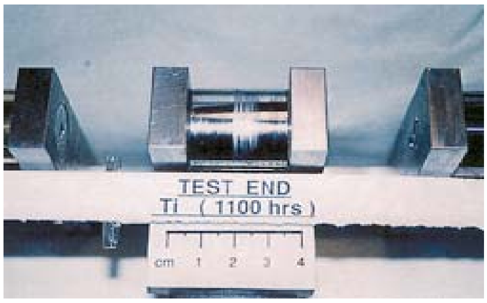


Figure 6: Uncoated titanium after wear test


Figure 7: Soft tissue against titanium


Figure 8: DLC coated titanium after wear test


Figure 9: Soft tissue against DLC coated titanium


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**The coating process**

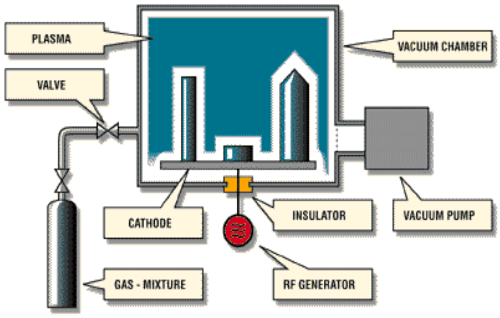


Figure 10: Schematic of the coating system

Diamond-like carbon is produced when carbon is deposited under energetic conditions. Carbon is then strongly bonded in all directions as in diamond, but as an amorphous structure.

A method of producing the strongly bonded structure is by plasma assisted chemical vapour deposition (PACVD). Components to be coated are placed on an electrode, which is capacitively coupled to a radio frequency source. A carbon containing gas such as acetylene is ionised by the field and the positive carbon ions bombard the components forming the strongly bonded coating. In contrast to diamond, no external heating is applied, therefore temperature sensitive materials such as plastics and collagen can be coated as well as a wide range of metals and ceramics.

**Application examples**

*Metal implants*

Massive metal implants such as hip, shoulder and knee prostheses (fig 11) can cause adverse responses in the body due predominantly to metal ion release into surrounding tissue. Because of its dense structure, a DLC coating acts as a barrier preventing diffusion of the metal from the implant. Further advantages of DLC for these applications are that the coatings are wear resistant and lubricious.

Figure 11: Components of knee replacement DLC coated for Royal National Orthopaedic Hospital

Metal implants in contact with blood such as stents, are thrombogenic. DLC coatings can reduce blood coagulation. On transcutaneous prostheses, in which the implant protrudes outside the body, the coating inhibits microbial colonisation on the exposed section.

*Metal tools: dental, surgical*

To repair dental cavities, epoxy filings have generally replaced mercury as the filling material because of possible toxic effects of mercury. However, during the filling procedure, epoxy tends to adhere to the metal instrument tips, which is prevented with DLC coated tips (fig 12).

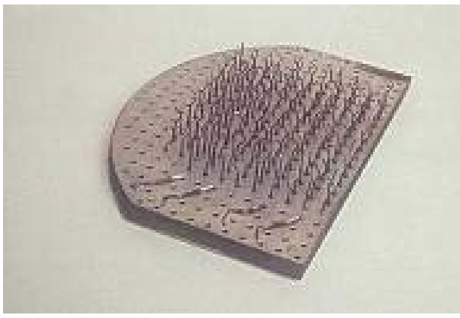

Figure 12: DLC coated instrument tips to prevent epoxy adhesion

Surgical instruments are coated with DLC to improve wear resistance and lubricity (fig 13)

Figure 13: Intext drill coated with DLC, biocompatible, wear resistant, lubricious

*Metal wear*

Metal parts, such as those containing nickel alloys, in contact with skin may cause allergic reactions. Such reactions are prevented with DLC coatings, which may incidentally also improve the appearance of the part (fig 14).

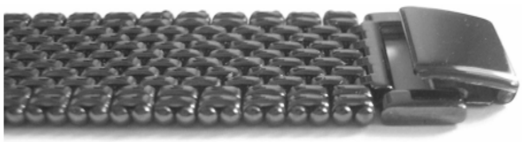

Figure 14: DLC coated watch strap



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*Temperature sensitive materials*

DLC coatings can be applied without external heating, temperature sensitive materials can therefore be coated Plastic instruments, such as catheters (fig 15) are coated with DLC to increase lubricity, prevent microbial colonisation and in the case of urinary catheters to inhibit encrustation.

Figure 15: Catheter biocompatible, lubricious

DLC has been applied to fibrous dermal collagen (FDC) in its hydrated state. Collagen incorporates in the body as a permanent graft but is thrombogenic and porous. Advantages of a DLC coating are that a collagen vessel can be exposed to blood and in repair operations, the coating prevents degradation of the patch graft due to acidic or alkaline chemistry from the stomach and associated conduits.

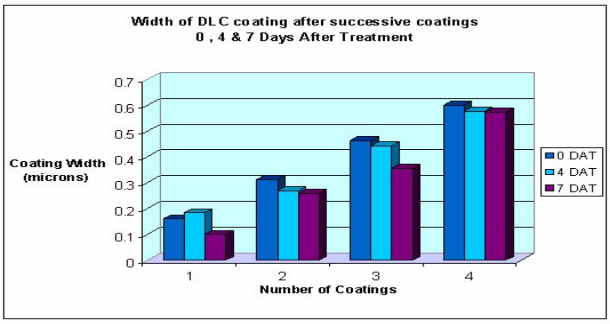


Figure 16: DLC-collagen composites are durable

Projected applications of the DLC-collagen composite: tissue repair kits for bone cartilage, tendons, ligaments; vascular replacements

## Conclusion

Diamond-like carbon enhances the effectiveness of present implants because the durable coating is biocompatible, anti-thrombogenic, wear resistant, lubricious and impervious, protecting the implant and its environment. As a low temperature process, the coating can be applied to plastics and further to hydrated collagen, potentially with wide ranging biomedical applications.

## References

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