# Surface Modification of Cobalt - Chromium Alloys Using Electrophoretic Deposition: A Comprehensive Review

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**ABSTRACT:** Cobalt–chromium alloys are widely used in human implants because of their high strength, good wear resistance, and corrosion stability, making them suitable for load-bearing applications such as hip and knee replacements. However, during long-term use in the human body, surface degradation and metal ion release can occur, which may cause biological complications. To improve their surface performance, electrophoretic deposition (EPD) has emerged as an effective and economical coating technique that enables uniform and well-controlled coatings without altering the bulk properties of the alloy. This review discusses recent progress in EPD-based coatings on Co–Cr alloys, focusing on their role in enhancing corrosion resistance, wear behavior, and biocompatibility. Existing challenges related to coating durability and long-term stability are also outlined, along with future research directions aimed at improving the safety and lifespan of Co–Cr implants.

**Keywords:** Cobalt–chromium alloys, electrophoretic deposition, surface coatings, corrosion resistance, wear behavior, biocompatibility, biomedical implants

## INTRODUCTION

Cobalt–chromium (Co–Cr) alloys are widely used in implants because of high strength, wear resistance, and good mechanical stability under physiological loading conditions. These properties make Co–Cr alloys suitable for long-term load-bearing applications such as hip joints, knee implants, and dental prostheses. However, despite their mechanical advantages, Co–Cr alloys are not inherently bioactive and may suffer from corrosion and metal ion release when exposed to the aggressive environment of the human body [1,2]. Such issues can lead to adverse biological responses, including inflammation and implant loosening, which limit the long-term performance of Co–Cr-based implants.

To address these limitations, surface modification of Co–Cr alloys has received significant attention over the past two decades. Among various surface engineering techniques, the deposition of bioactive ceramic coatings such as hydroxyapatite (HA) has been extensively explored due to its chemical similarity to natural bone mineral and its ability to promote bone bonding [3]. HA coatings act as a protective barrier against corrosion while simultaneously enhancing the biological response at the implant–tissue interface. However, the performance of HA coatings strongly depends on the deposition method, coating microstructure, adhesion strength, and processing parameters.

Electrophoretic deposition (EPD) has emerged as a promising coating technique for biomedical alloys, including Co–Cr systems, due to its simplicity, low cost, and ability to produce uniform coatings on complex-shaped substrates [4,5]. The EPD process allows fine control over coating thickness and composition by adjusting suspension chemistry, applied voltage, and deposition time. In addition, EPD enables the fabrication of composite and multilayer coatings, which has opened new possibilities for tailoring corrosion resistance, bioactivity, and additional functionalities such as antibacterial behavior [6].

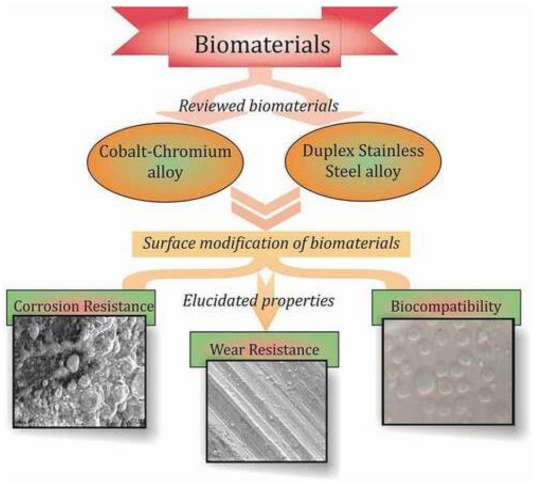


Fig 1 Overview of reviewed biomaterials, surface modification, and evaluated properties

In recent years, research on EPD-coated Co–Cr alloys has expanded beyond pure hydroxyapatite coatings to include polymer–ceramic composites, ceramic–ceramic nanocomposites, and multifunctional coatings incorporating biopolymers, bioactive glass, and carbon-based nanomaterials [7–9]. These advanced coatings aim to overcome the limitations of brittle ceramic layers while improving coating adhesion, mechanical stability, and biological performance. Despite this progress, a consolidated understanding of coating strategies, processing conditions, and resulting properties for EPD-based coatings on Co–Cr alloys is still needed.

Therefore, this review presents a comprehensive overview of electrophoretic and related electrochemical coating approaches applied specifically to cobalt–chromium alloys. The focus is placed on coating materials, deposition parameters, microstructural characteristics, corrosion behavior, and in vitro bioactivity reported in earlier studies. By summarizing and comparing key findings from the literature, this review aims to provide clear insight into current trends and future directions for surface modification of Co–Cr alloys for biomedical applications.

## THE ELECTROPHORETIC DEPOSITION (EPD)

Electrophoretic deposition (EPD) is a simple and flexible coating technique that has been widely used to deposit ceramic, polymer, and composite materials on conductive substrates [10,11]. EPD is particularly attractive for biomedical applications because it allows good control over coating thickness and composition, operates at room temperature, and can be applied to complex-shaped components such as orthopedic and dental implants [12]. For cobalt–chromium alloys, EPD has been extensively used to deposit hydroxyapatite and composite coatings to improve corrosion resistance and enhance bioactivity [13, 14]. By carefully adjusting suspension chemistry, applied voltage, and deposition time, coatings with tailored microstructures, improved adhesion, and better biological performance can be achieved [15].

| No. | Year | Coating / Composite | Substrate | Deposition method | Key outcomes | Ref. |
|---|---|---|---|---|---|---|
| 1 | 2002 | Hydroxyapatite (review & early EPD) | Co–Cr alloys | Review of EPD methods | Improved corrosion resistance and bioactivity | 16 |
| 2 | 2014 | Hydroxyapatite | CoCrMo alloy | Electrochemical deposition | Reduced metal ion release | 17 |
| 3 | 2017 | Hydroxyapatite (HA) coating (0.02–0.10 M) | Co–Cr–Mo alloy (ASTM F75) | Electrophoretic Deposition (EPD), 120 V, 30 min + sintering at 900°C | HA reduced corrosion rate compared to uncoated alloy. | 18 |
| 4 | 2016 | Hydroxyapatite | CoCrMo alloy | Optimized electrodeposition | Improved electrochemical stability | 19 |
| 5 | 2016 | Hydroxyapatite | CoCrMo–TiN alloy | EPD vs sol–gel | Better coating uniformity and corrosion resistance | 20 |

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|---|---|---|---|---|---|---|
| 6 | 2017 | Porous hydroxyapatite | Co–28Cr–5Mo alloy | EPD + sintering | Crack-free, porous and bioactive coating | 21 |
| 7 | 2023 | Multi-walled carbon nanotube (MWCNT) coating (functionalized & raw) | CoCrMo dental alloy | Ultrasonically assisted Electrophoretic Deposition (EPD), 20 V, 5 min | Functionalized MWCNT coating showed improved adhesion and significantly higher corrosion resistance in artificial saliva; increased charge transfer resistance and reduced corrosion current density | 22 |
| 8 | 2018 | PEEK–HA composite | Co–Cr alloy | Composite EPD | Dense coating with good barrier properties | 23 |
| 9 | 2019 | HA / $Al_2O_3$ multilayer | Co–Cr–Mo alloy | Layer-by-layer EPD | Improved coating integrity and bioactivity | 24 |
| 10 | 2020 | HA–$Fe_3O_4$–Chitosan | Co–Cr alloy | Composite EPD | Corrosion protection with antibacterial effect | 25 |
| 11 | 2022 | HA–Chitosan | Co–Cr alloy | Low-voltage EPD | Strong apatite formation and adhesion | 26 |
| 12 | 2023 | Carbon nanotube coating | CoCrMo dental alloy | Ultrasonic-assisted EPD | Uniform functional surface coating | 27 |

Table 1 presents an overview of reported studies on hydroxyapatite (HA) and HA-based composite coatings deposited on cobalt–chromium (Co–Cr) alloys using electrophoretic deposition (EPD) and related electrochemical techniques. The table summarizes key coating characteristics, including surface morphology, corrosion behavior, and in vitro bioactivity. A review of the listed studies clearly shows that parameters such as applied voltage, time, and suspension have a strong influence on coating. These parameters directly affect coating uniformity, porosity, adhesion, and protective performance against corrosion.

**The discussion related to Table 1 focuses on how variations in coating structure and composition influence corrosion resistance and bioactive response, highlighting the role of EPD as an effective method for tailoring HA-based coatings on Co–Cr alloys for biomedical application**

Sridhar et al. 2002 [16] reviewed early developments in electrophoretic deposition of hydroxyapatite coatings on metallic implant materials, including cobalt–chromium alloys. The authors discussed how factors such as suspension stability, applied electric field, and post-deposition heat treatment influence coating quality. They highlighted that properly deposited HA coatings can improve corrosion resistance and promote apatite formation, making EPD a suitable technique for biomedical surface modification.

Coşkun et al. 2014 [17] investigated electrochemical deposition of hydroxyapatite coatings on CoCrMo alloys to enhance their suitability for biomedical applications. The study focused on optimizing electrolyte composition to achieve dense and adherent coatings. Electrochemical results showed reduced metal ion release and improved corrosion resistance compared to uncoated alloys.

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Aminatun et al. (2017) [18] studied hydroxyapatite (HA) coating on cobalt alloy using the electrophoretic deposition (EPD) method for bone implant applications. They changed the HA suspension concentration (0.02–0.10 M) while keeping the voltage and time constant. The study examined coating thickness, adhesion strength, and corrosion behavior. Results showed that higher concentration increased coating thickness but reduced adhesion strength. The best result was obtained at 0.04 M, which gave suitable thickness, good corrosion resistance, and acceptable adhesion strength. The study highlights the importance of selecting proper EPD parameters for better implant performance.

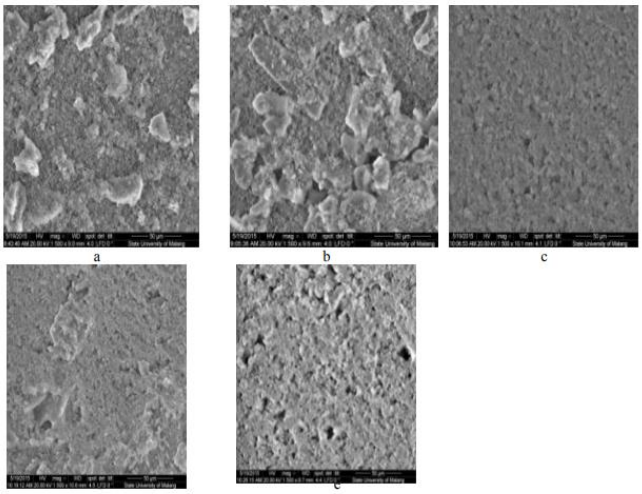

Fig 2 SEM surface morphology of HA-coated samples at 1500× magnification: (a) 0.02 M, (b) 0.04 M, (c) 0.06 M, (d) 0.08 M, and (e) 0.10 M suspension concentration.[18]

Coşkun et al. 2016 [19] further explored hydroxyapatite electrodeposition on CoCrMo biomedical alloys using both experimental and computational approaches. The coatings obtained were uniform and strongly adhered to the substrate surface. As a result, the coated alloys showed improved electrochemical stability compared to the bare alloy.

Charlena et al. 2016 [20] compared hydroxyapatite coatings deposited on CoCrMo–TiN alloys using electrophoretic deposition and sol–gel methods. The EPD coatings showed better homogeneity and corrosion resistance when appropriate surface preparation was applied. The study highlighted the importance of coating–substrate interaction in achieving reliable bioactive coatings.

Moskalewicz et al. 2017 [21] developed porous hydroxyapatite coatings on Co–28Cr–5Mo alloys using electrophoretic deposition followed by sintering. The coatings exhibited interconnected porosity without major cracks, which is favorable for bone tissue attachment. Electrochemical testing confirmed improved corrosion resistance in simulated physiological environments.

Łosiewicz et al. (2023) [22] studied the deposition of (MWCNT) coatings on dental alloy using the electrophoretic deposition (EPD) method. The nanotubes were chemically treated before coating to improve their properties. The results showed that the functionalized MWCNT coating had better adhesion and significantly higher corrosion resistance in artificial saliva compared to the uncoated alloy. The study concluded that ultrasonically assisted EPD is an effective and low-cost method to enhance the corrosion performance of dental alloys.

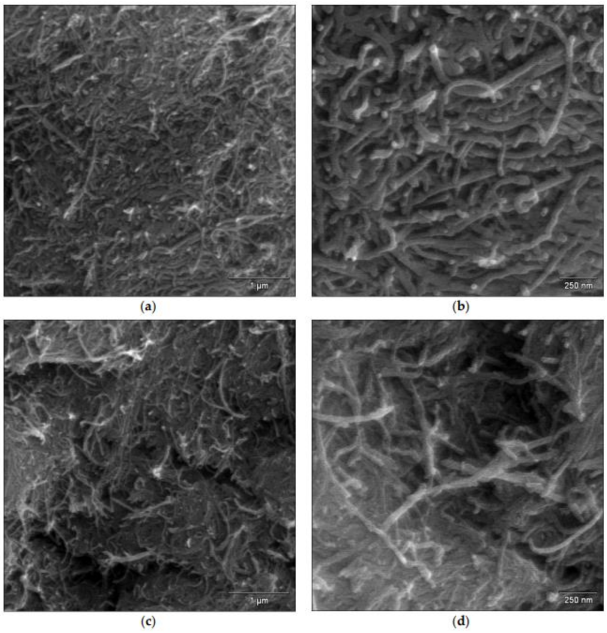


Fig 3 FE-SEM images of CoCrMo alloy after electrophoretic deposition at 20 V for 5 min from a colloidal suspension containing: (a,b) raw MWCNTs (MWCNTs-R); (c,d) functionalized MWCNTs (MWCNTs-F).[22]

Baştan et al. 2018 [23] reported EPD on PEEK and HA to form composite coatings on metallic substrates, including cobalt–chromium alloys. The resulting coatings were dense and acted as effective barriers against corrosive environments. The study suggested that polymer–ceramic coatings can improve mechanical stability while maintaining bioactivity.

Kim et al. 2019 [24] fabricated layered hydroxyapatite and alumina coatings on Co–Cr–Mo alloys using a layer-by-layer electrophoretic deposition technique. The multilayer coatings showed improved structural integrity and corrosion

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resistance. In vitro studies indicated enhanced apatite formation, demonstrating improved bioactivity.

Singh et al. 2020 [25] developed hydroxyapatite–$Fe_3O_4$–chitosan composite coatings on Co–Cr alloys using electrophoretic deposition. The composite coatings exhibited compact microstructures and significantly reduced corrosion rates. In addition, the presence of iron oxide imparted antibacterial properties, making the coatings suitable for multifunctional implant applications.

Gaafar et al. 2022 [26] studied hydroxyapatite–chitosan composite coatings deposited by low-voltage electrophoretic deposition on biomedical alloys, including cobalt–chromium systems. The addition of chitosan improved coating adhesion and flexibility, resulting in enhanced corrosion resistance. Strong apatite formation during in vitro testing confirmed good bioactivity.

Łosiewicz et al. 2023 [27] investigated ultrasonically assisted electrophoretic deposition of carbon nanotube coatings on CoCrMo dental alloys. Ultrasonic assistance improved coating uniformity and adhesion compared to conventional EPD. Although the focus was on surface functionalization rather than bioactive ceramics, the study demonstrated advanced EPD strategies applicable to Co–Cr alloys.

## CONCLUSION

This review highlights the effectiveness of electrophoretic deposition as a surface modification technique for hydroxyapatite-based and composite coatings on cobalt–chromium alloys. The literature shows that coating morphology, corrosion resistance, and bioactivity are strongly influenced by deposition parameters such as voltage, time, and suspension chemistry. While pure hydroxyapatite coatings improve corrosion resistance and bioactive response, composite coatings further enhance adhesion, stability, and functionality. Overall, electrophoretic deposition offers a promising approach for tailoring bioactive coatings on Co–Cr alloys, although further studies on long-term stability and in vivo performance are still required.

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