valuation of orrosion ehaviors and urface Profiles of Platinum- oated lectrodes lectrochemistr and omplementar Microscop : iomedical Implications for nticancer Therap

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1. Introduction

Electrochemical treatment (ECT) is one of the most effective therapies for a variety of tumors in clinical trials (Chou et al., 1997; Griffin et al., 1994; Nilsson et al., 1999). ECT is useful especially for patients who are unsuited for operation and chemotherapy due to old age, and who suffer from general weakness or insufficiency of vital organs (Xin, 1994). Electric direct current ranging from 10 to 180 mA is applied to retard the growth of malignant tumor cells via electrodes inserted into the proliferating tumor tissues. As the electric current flows into electrodes, electrochemical reactions occur on the surface of electrodes. The main reaction at the anode is the decomposition of water to oxygen and oxidation of chloride ions to chlorine; concomitantly hydrogen ions are produced. At the cathode the hydrogen evolution reaction leads to the formation of hydroxide ions. During these reactions, pH values were pushed down to as low as 1.0 in the tissues adjacent to the anode, whereas 13.0 near the cathode (Von Euler et al., 2001). However, there is still a lack of knowledge about the mechanisms by which ECT inhibits tumor growth. Tang et al (2005) proposed that the antitumor effect is correlated with the degree of ionization and alteration in pH state, and G_1 cell cycle arrest. Meanwhile, a recent work (Zhao et al., 2006) also revealed the mechanism of wound healing by electrical signals employing molecular genetic approaches.

During ECT, electrode materials such as iron, tungsten, their alloys and others, are prone to corrode in contact with the acidic body fluids containing chloride ion. Currently, the most commonly used electrodes in clinical trials are either pure platinum (Pt) or its alloys in order to avoid corrosion problems (Chou et al., 1997; Lee et al., 2004). As a transition metal, Pt is biocompatible and almost immune to corrosion in the body fluid environment. However, the high ductility of pure Pt electrodes makes it difficult to use them for human tissues, especially tumor tissues that are harder than normal tissues. To overcome such a physical problem, some electrodes have been made of alloys such as Pt-iridium alloy (David et al., 1985) and Pt-coating on appropriate metals (Daniele et al., 2001). In case of alloys, the manufacturing cost is high due to the relatively high melting points of alloying metals. Meanwhile, the corrosion properties of Pt-coated electrodes are dependent on coating methods and substrate metals. This increases the need to monitor and evaluate the corrosion behaviors of Pt-coated electrodes resistant to corrosion reactions under the condition of high applied potentials (<20 V) and electric current (<180 mA). For analysis of surface profiles, atomic force microscopy (AFM) can be suitable for this purpose, since it can provide quantitative information on the change of surface topography with emphasis on the shape and lateral distribution of the corrosion products (Kleber et al., 2002). The topographic data obtained by AFM contain the entire x, y, z-coordinates of the specimen, which allows line or region profiles from specific features to be quantitatively analyzed and measurements of statistical surface parameters including height, volume, and so on (Kim, 2006). In this study, we prepared four types of Pt-coated needle electrodes (Pt/titanium, Pt/tungsten, Pt/brass, and Pt/stainless steel) by unbalanced magnetron sputtering (UBM) (Lee et al., 2004) aiming at applications in clinical trials of anticancer therapy. To investigate corrosion resistance of the electrodes, we used a potentiodynamic polarization method and analyzed surface profiles of the electrodes by AFM before and after the electrochemical test.

2. Materials and methods

2.1 **lectrode preparation:** Four types of needle electrodes (0.6 mm in diameter and 150 mm in length) were used in this study: (i) titanium (Ti), (ii) tungsten (W), (iii) brass (Cu-40Zn), and (iv) stainless steel (SUS304). Each type of electrode was coated with a thin layer (approximately less than 300 nm in thickness) of pure (99.99%) Pt by UBM under an argon atmosphere of 2 10^{-3} Torr at room temperature (20 to 24). The electrode coating by UBM was performed as described previously (Lee et al., 2004).

2.2 **Potentiod namic ehavior:** To determine the corrosion potential and rate for assessment of the corrosion resistance of electrodes, an anodic potentiodynamic polarization test was employed in this study. The electrochemical cell consisted of a saturated calomel reference electrode (SCE), pure Pt counter electrode, and a working electrode. The working electrode was encapsulated with silicon sealant and exposed in 15 to 30 mm length from the electrode end into deaerated 0.9% sodium chloride solution.

2.3 **FM imaging and surface anal sis:** Electrodes were directly mounted on a steel disc (18 mm in diameter) using two-sided adhesive tape. The steel disc was then magnetically fixed to the piezoscanner (maximum x, y-scan range of 5 μm) of AFM (AutoProbe-CP; Park Scientific Instruments, Sunny Valley, CA, USA; transferred to Veeco Instruments, NY, USA). Non-contact AFM was performed to acquire topographic images under ambient conditions using standard V-shaped silicon cantilevers (Ultralevers; Park Scientific Instruments) with a specified spring constant of 3.2 N/m. To quantify surface profiles of the acquired topographic images, the conventional statistical parameters of the surface profiles, such as mean height and volume, were analyzed and processed using a software package (ProScan version 1.51b; Park Scientific Instruments, Sunny Valley, CA) provided with the microscope.

3. Results and Discussion

3.1 **Potentiod namic ehavior:** The potentiodynamic polarization tests of the Pt-coated electrodes revealed the different responses of each electrode in the deaerated 0.9% sodium chloride solution (Fig. 1). The corrosion potential of the Pt-coated electrodes ranged from -242 to 228 mV_{SCE} with the highest for the Pt/Ti electrode and the lowest for the Pt/Cu-40Zn electrode (Table 1).

3.2 **FM imaging and surface anal sis:** AFM revealed topographic images of the Pt-coated electrodes before and after the polarization test over scan areas of 5.0 5.0 μm^2. It appeared that the surfaces of the electrodes became rough and irregular after the polarization test except Pt/Ti electrodes that remained relatively smooth even after the polarization test. Meanwhile, the other electrodes overall exhibited spherical or granular morphology and deep valleys throughout the scan areas. Subtle differences in height fluctuation caused by corrosion could be separated by quantifying surface profiles of the acquired topographic images. Results from the numerical analysis of surface parameters were consistent with those from topographic images of the electrodes. The mean heights of the scan surface of the four electrodes were overall similar to each other before the polarization test (0.09 to 0.11 μm). After the polarization test, the mean height increased by different degrees depending on the substrate materials. Pt/Ti electrodes showed the least change of mean height, followed by Pt/W, Pt/SUS304, and Pt/Cu-40Zn electrodes. Also, the results from volume measurement were in agreement with those of mean height analysis, revealing the smallest volume change of Pt/Ti electrodes after the polarization test. It was evident that the mean height and volume change of electrodes after the electrochemical test was in accordance with evaluated corrosion resistance as described above. The electrodes with higher corrosion resistance undergo less deformation by the electrochemical test because they suffer slower dissolution of substrate and consequently has less cavities and/or corrosion products. In this way, the AFM results confirmed the relative corrosion resistance evaluated by the potentiodynamic polarization behaviors. We suggest, therefore, that Pt/Ti electrodes can be the most appropriate material among the four types of Pt-electrodes for possible tumor treatment.

4. onclusion

In conclusion, this study demonstrated that Pt/Ti electrodes had the highest corrosion resistance among electrodes tested in this study. The excellent corrosion resistance of Pt/Ti electrodes appears to be mainly attributed to the fact that Ti is closer to Pt in the galvanic series and hence Pt/Ti electrodes are barely affected by the galvanic corrosion. The surface imaging and morphological analysis by reflected light microscopy and AFM confirmed the behavior of corrosion resistance evaluated by the potentiodynamic polarization test, i.e. that the electrodes with higher corrosion resistance underwent less roughening by the electrochemical test, for they suffered slower dissolution of substrate and consequently had less cavities and/or corrosion products. These results suggest that either Pt/Ti or Pt/W electrodes for solid tumors are suitable to be used in ECT of anticancer therapy performed in the corrosive environment of tumor tissues in the body fluid environment. As electric stimulation is used in tumor therapy, it hardly causes negative side effects and can be readily available for tumor treatment. It remains to be done to validate the control efficacy of ECT by either Pt/Ti or Pt/W electrodes on diverse body parts and tumor types including hemangioma to confirm its broad-spectrum characteristics and establish optimal electrochemotherapy regimen in further studies.

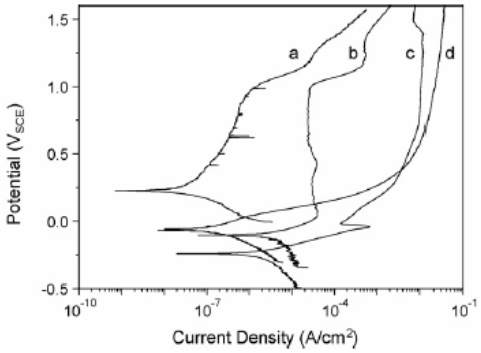

Fig. 1 Potentiodynamic polarization curves of the Pt-coated electrodes in deaerated 0.9% sodium chloride solution at room temperature, measured at a scan rate of 0.5 mV/s. (a) Pt/Ti, (b) Pt/W, (c) Pt/Cu–40Zn, and (d) Pt/SUS304.

Electrode	Corrosion potential, E_{corr} (mV_{SCE})	Corrosion rate, I_{corr} ($\mu A/cm^2$)
Pt/Ti	228	0.10
Pt/W	−101	19.84
Pt/Cu–40Zn	−242	3.65
Pt/SUS304	−53	0.09

Table. 1 Comparison of the electrochemical parameters of the Pt-coated electrodes determined from the polarization curves in Fig. 1

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