The Inhibitory Capability of Decorative Plated Coatings for the Growth of Bacteria

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The antibacterial activity of various electroplated coatings (cobalt, zinc, copper, and cobalt-containing alloys of nickel, zinc, chromium) was determined by a "Drop-method" antibacterial experiment against pathogenic bacteria (gram-positive bacterial *S. aureus*, MRSA, and gram-negative bacteria *E. coli*, *P. aeruginosa*). It was found that all of them possessed a higher antibacterial activity than stainless steel. The ralationship between the inhibitory capability for the growth of bacteria and the rest potential of the electroplated coatings was also investigated. A significant antibacterial activity of the coatings was apparently displayed by a rest-potential shift to more negative values. It was suggested that all of the tested bacteria fell closely within the lethal range when the rest potentials were lower than −543 mV. However, some amount of metal ions dissolved from various from various electroplated coatings was measured; accordingly, the inhibitory capability of the simulated dissolution concentrations of metal ions the growth of bacteria is discussed.

Cobalt,[1,2] silver,[3] copper,[3] and other metal ions[4] as well as their complexes or metal ions have an inhibitory capability for the growth of bacteria, fungi and other microorganisms. This property has been extensively applied to zeolites,[5,6] textiles, and various fields. Recently, a methicillin-resistant *Staphylococcusaureus* (MRSA), which has resistance to many species of antibiotics, has been found in Japan.[7] Therefore, we are interested in searching for new antibacterial materials having a broad activity spectra that can control resistant strains of pathogenic diseases which are usually difficult to cure. It is proposed that decorative coatings of plating with bactericidal action be used to prevent contamination by bacteria in hospital facilities and conventional equipment.

In a previous publication,[8] various electroplated coatings containing cobalt, zinc, copper, cobalt-containing alloys of nickel, zinc, chromium, and electroless plated coatings of silver, with or without antibacterial activity, were evaluated; also, the inhibitory capability of coatings for the growth of bacteria had been defined to be related to their rest potential using the antibacterial experimental "Halo-test". Halo-test[28] was normalized in the field of worldwide microorganisms in 1950. This method has been approved by JIS Z 2991 in Japan since 1976. Halo-test, as one of the fundamental antibacterial experiment methods, is used to measure the inhibitory capability of antibacterial activity materials for the growth of microorganisms. In our experiments,[8] a tested plated coating sample was lightly put at the center of a Petri-dish containing solidifying agar that had been mixed with the bacteria medium. After the Petri-dishes were incubated, on the basis of the width of the inhibitory zone around the sample, the relative intensity of the inhibitory capability of the sample was evaluated. Nevertheless, the Halo-test is an important method for estimating the inhibitory capability of coatings which easily undergo corrosion or diffusion under general conditions, because it is based on the corrosion and diffusion principle of antibacterial materials. In practice, however, we genuinely desire to accurately determine the inhibitory capability of antibacterial materials for the growth of bacteria which possess corrosion resistance and a low rate of diffusion of their corrosion species. Therefore, this paper describes an evaluation of the inhibitory capability of corrosion-resistant or corrodible materials, as well as low-diffusion-rate electroplated coatings using the "Drop-method". In addition, possible mechanisms of the antibacterial activity of coatings are also discussed.

Materials and Methods

Electroplated Coatings. Electroplated coatings of cobalt, zinc, copper, silver, nickel, chromium, and cobalt-containing alloys of nickel (19 wt%), zinc(96 wt%), chromium(12 wt%) were deposited to a thickness of 20—25 μm on a copper substrate. Gold was deposited to an approximate thickness of 10 μm on cobalt-plated samples. Chromium was deposited on cobalt and nickel. A zinc-plated coating was immersed in a chromate conversion coating medium. All of the samples used with the same area of 3 cm×4 cm plated coatings were sterilized by a treatment system at 60 °C for 24 h before being tested.

Measurements of the Rest Potential of the Electroplated Coatings. A beaker-type cell of 100 mL volume containing

a phosphate buffer solution electrolyte was used for batch experiments. Electroplated coatings with part of a center area of 1 cm^2 were continuously immersed in the buffer solution, and their rest potentials were measured exactly against a saturated calomel electrode (SCE) for 24 h at 25 °C. Buffered saline containing NaCl (0.68%), potassium dihydrogenphosphate (0.455%) and sodium hydroxide was used for the electrolyte. The pH of the solution was adjusted to 7.00.

Dissolved Metal Ion Measurements. A small amount of various metal ions was obtained from the electroplated coatings of 3 cm×4 cm area immersed in a phosphate buffer solution of 80 mL for 24 h at 25 °C. A slight amount of precipitates was formed in the buffer solution due to the generation of insoluble compounds due to a chemical reaction between some metal ions and the phosphate buffer solution. To achieve a sufficient generation of metal ions, an appropriate concentration of nitric acid was added to the container. This solution, diluted with deionized water, was dispensed into 25-mL flasks. Immediately afterwards, the metal-ion concentrations were exactly determined with an atomic-absorption spectrophotometer.

Bacterial Culture. The gram-positive bacteria used in the experiments were *Staphylococcus aureus* (*S. aureus*) IFO 12732 and methicillin-resistant *Staphylococcus aureus* (MRSA). MRSA (MIC value to methicillin, 200 μg mL^{-1}) was isolated from Ehime University Hospital. The gram-negative bacteria used were *Escherichia coli* (*E. coli*) IFO 3806 and *Pseudomonas aeruginosa* (*P. aeruginosa*) IFO 13275. Microorganisms were cultured in SCD (Soybean-Casein Digest Broth) medium (Nihon Pharm. Co., Ltd.) at 37 °C for 18—24 h. During this time, bacteria which were thought to be in the late logarithmic phase of their growth were grown to reach approximately 10^9 colony-forming units per tube (CFU/tube). A portion of the culture medium containing the bacteria in a phosphate buffer solution was diluted to 10^4 CFU/tube bacteria for the "Drop-method" antibacterial experiments.

Drop-Method Antibacterial Experiment. As described above concerning bacterial culture, 1 mL of 10^4 CFU/tube test bacteria was homogeneously added dropwise by a dispenser onto the surface of each electroplated coating of 3 cm×4 cm area, which had been horizontally placed into sterilized bottles. The samples were incubated at 25 °C for 24 h. Immediately after incubation, the incubated solution was sufficiently mixed after the addition of 9 mL of a SCDLP (Soybean-Casein Digest Broth with Lecithin & Polysorbate 80) medium (Nihon Pharm. Co., Ltd.) into an incubated solution bottle containing the electroplated coating. In order to measure exactly the colony-forming-units, a portion of the culture medium containing the bacteria was diluted to 10^{-1}, 10^{-2}, 10^{-3} CFU/tube bacteria in the SCD medium. Each concentration of the bacterial medium was added into a 9-cm diameter Petri-dish, followed by the addition of approximately 20 mL of standard agar which solidified after being sufficiently mixed with the bacterial medium. The number of surviving bacteria and the bacteria survival rates on the Petri-dishes were measured after incubation for 2 d at 37 °C.

Examination of the Inhibitory Capability of the Simulated Dissolution Concentration for the Growth of Pathogenic Bacteria. Cobalt and nickel ions were tested as cobalt chloride and nickel chloride; zinc, copper, and silver ions as zinc nitrate, cooper nitrate, and silver nitrate; and chromium ion as potassium chromate. All of the metal-ion solutions were diluted by a fresh sterilized phosphate buffer solution to simulated dissolution concentrations for the antibacterial experiments. As stated above concerning the bacterial culture, 1 mL of approximately a 10^4 CFU/tube tested bacterial solution was added into each 30 mL sterilized bottle containing 1 mL of different metal-ion solutions, respectively. After properly mixing, they were incubated at 25 °C for 24 h. After incubation, as described above concerning the Drop-method antibacterial experiment, the number of surviving bacteria and the bacterial survival rates were measured.

Measurement of H_2O_2. The concentrations of H_2O_2 eluded from the electroplated coatings were measured based on the super Oritector Model 5 (Oriental Electric Co., Ltd.). A H_2O_2 solution of 31% was diluted to 1 ppm by a phosphate buffer solution which had been deoxidized for over 1 h under a cold condition. The next 2 mL of a 1 ppm H_2O_2 solution was put into a cell thermostated at 30 °C after the solution in the cell had been sufficiently deoxidized, followed by the addition of 20 μL catalyze. The concentration of the H_2O_2 solution, as a calibration, was measured. After the measurement, the cell was washed 4—5 times. A measurement showed that the concentration of H_2O_2 was eluded from each sample in which the electroplated coating was immersed in an 80 mL phosphate buffer solution for 24 h at 25 °C, respectively.

Results and Discussion

Measurements of the Inhibitory Capabilities of Electroplated Coatings for the Growth of Pathogenic Bacteria with Drop-Method Antibacterial Experiments. With the Drop-method, because the bacterial solution was homogeneously added dropwise onto the surface of a plated coating, more detailed data concerning the inhibitory capability of the electroplated coatings for the growth of bacteria can be obtained than from the Halo-test results, by which the width of the inhibitory zone around a sample was measured.[8] The bacterial survival rates are summarized in Table 1. The results demonstrate that all of the electroplated coatings used in our experiments show a more significant inhibitory capability for the growth of gram-positive and gram-negative bacteria than stainless steel (SUS 304).

A number of electroplated coatings showed the survival rates of gram-positive bacteria MRSA to be less than 1%, except for silver and cobalt–nickel alloy. Regarding *S. aureus*, the bacterial survival rates on various coatings were close to zero, except for copper and chromium.

Cobalt, zinc, silver, and cobalt-containing alloys of nickel, and zinc electroplated coatings also showed survival rates of gram-negative bacteria *E. coli* to be less than 1%.

However, in the Halo-test[8] the antibacterial experimental results with copper and chromated zinc coatings were the same as those with nickel, chromium, chromium on the nickel and cobalt-electroplated coatings, which did not show any inhibitory zone. However, in the Drop-method the inhibitory capability of the copper and chromated zinc coatings for the growth of *E. coli* was evidently stronger than the nickel, chromium and chromium on the nickel and cobalt-electroplated coatings. In addition, a decreased number of surviving bacteria on a copper coating, at least 10-times or more compared to the surviving bacterial number of the nickel, chromium coatings, was achieved in our Drop-method antibacterial experiments.

The significant inhibitory capabilities of cobalt, zinc, and cobalt alloy electroplated coatings for the growth of gram-negative bacteria *P. aeruginosa* were definitely achieved in

the Drop-method. As pointed out in Table 1, the number of surviving *P. aeruginosa* bacteria on the surface of a copper coating was approximately zero.

In the Drop-method the inhibitory capability of the copper coating proved to be more significant than in the Halo-test. Thus, one explanation concerning the bacteria solution which was directly placed on the surface of the copper coating in the Drop-method is that the copper ions dissolved from the copper coating can come into contact with bacteria. This is because at the place where bacteria were directly exposed to the presence of copper ions they can be taken up by the bacteria.[9] The copper ions is adsorbed by the bacteria where they can bind mercaptol moieties of cellular proteins, DNA and enzymes.[10] These enzymes are unable to function properly[11] when the mercaptol moieties are bound, resulting in an inhibition of the normal proliferation of bacteria and initial damage to the bacteria. However, since the copper ion is not well-diffused, there was somewhat or no inhibitory zone displayed next to the copper coating in the Halo-test.

In contrast to the antibacterial activity of coatings, the number of all surviving bacteria has not been found to decrease on the surface of stainless steel (SUS 304), but to increase. One of the reasons is considered to be because some trace-amount of metal ions is frequently an important component of the bacterial cell wall fabric, such as iron ions. The metal ions dissolved from SUS 304 as nutrition are attributable to a more significant growth of bacteria on the surface of SUS 304 than a control.

On the basis of the Drop-method experiment results, a physical explanation for the mechanisms by which all of the coatings show an inhibitory capability for the growth of bacteria is that bacteria can display an adhesive behavior due to attractive forces, which presumably include electrostatic forces[27] and electrodynamics (Van der Waals') forces,[12] all of which can act over distances greatly in excess of the chemical bond lengths. The attachment of bacteria to the coating surfaces strongly influences the normal proliferation of bacteria. According to a previous study theory,[13,14] numerous factors affect the attachment of bacteria to the surfaces of a coating. For example, in the chromium coating case, the number of surviving bacteria decreased in the "Drop-method" for all tested bacteria; nevertheless, there was no apparent inhibitory zone next to the chromium coating in the previous Halo-test.[8] The first reason is due to the chromium coating, which has very good corrosion resistance, so that its inhibitory capability is difficult to accurately measure by the Halo-test antibacterial experiment. The second reason for the above observations is expected to be that the bacteria come into contact with the surface of a chromium coating due to attractive interactions between the bacteria and the surface of the coating, which causes a diminished proliferation of the bacteria.

On the other hand, chemical explanations for the mechanisms will be described on the basis of the following results of the antibacterial experiment.

Relationship between the Rest Potential and Inhibitory Capability of Electroplated Coatings for the Growth of Bacteria. Using the Drop-method, the relationship between the rest potential and the inhibitory capability of various coatings was accurately investigated. The results are given in Fig. 1. The larger decrease that the bacterial survival rates show, the more negative are the rest-potential shifts. Namely, when the rest potential is lower than −543 mV, the survival rates of all tested bacteria are almost close to zero.

Table 1. Results of the Inhibitory Capability of Electroplated Coatings for the Growth of Bacteria Using Drop-Method[a]

Materials	Gram-negative bacteria		Gram-positive bacteria	
	E. coli IFO 3806	*P. aeruginosa* IFO 13275	*S. aureus* IFO 12732	MRSA MIC to Methicillin 200 μg mL^{-1}
	Bacterial survival rates %[c]	Bacterial survival rates %[c]	Bacterial survival rates %[c]	Bacterial survival rates %[c]
Control CFU/tube[b]	3.5×10^4	3.2×10^3	1.2×10^4	1.3×10^3
SUS304	>100	>100	≧100	>100
Ag	0.086±0.0062	28±0.86	0	3.8±0.54
Co	0.19±0.0084	0	0	0
Cr	6.3±0.54	22±1.2	26±1.3	0
Cu	0.34±0.046	0	10±1.1	0
Ni	10±1.2	0	0	0
Zn	0.071±0.0086	0.31±0.063	0	0
Co–Ni	0.10±0.046	0	0	22±1.2
Co–Zn	0	0	0	0.3±0.077
Au on Co	0.23±0.033	0	0	0
Chromating on Zn	0.13±0.0082	0.16±0.038	0.042±0.068	0
Cr on Ni	14±1.4	0.47±0.052	0	0
Cr on Co	3.4±0.12	≧100	0	0

a) Incubation in pH 7.0 phosphate buffer solution for 24 h at 25 °C. b) Colony forming units per tube. c) Divide bacterial number of control by the surviving bacterial number, the bacteria are proliferation when the value is bigger than 100%, the mean value and standard deviation of bacterial survival rates.

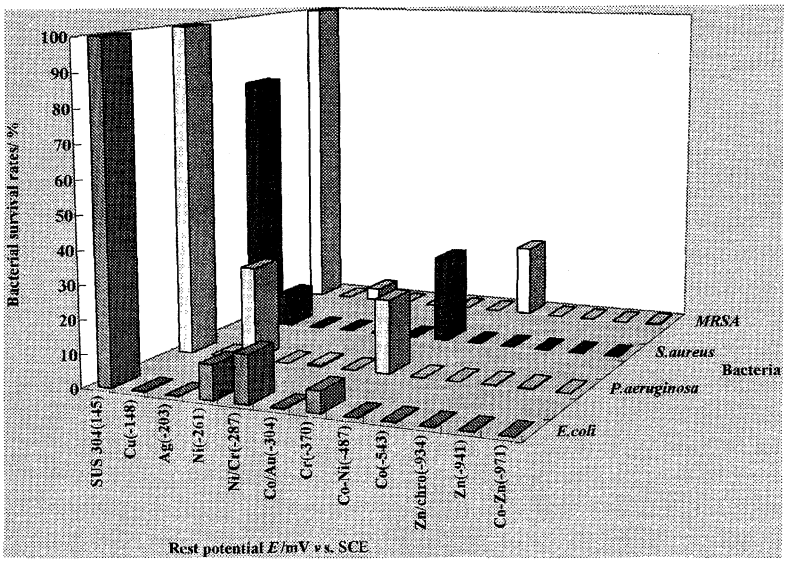

Fig. 1. Relationship between the rest potential and the inhibitory capability of plated coatings for the growth of bacteria with Drop-method. Incubation at 25 °C for 24 h.

As is well-known, due to various metals on the surface of electroplated coatings, which are made to readily react with a constant concentration of dissolved molecular oxygen in solutions, they are oxidized at a different rate. Electroplated coatings therefore possess different rest potentials. The more the rest potential shifts to negative potentials, the more violent dose the redox reaction become, and more antibacterial chemical intermediates and compounds are produced. The reaction is responsible for the formation of H_2O_2 through the reduction of active molecular oxygen, which is produced by electrons released on the surface of the coatings.[15,18] The potential for generating H_2O_2 is 430 mV versus that of a standard calomel electrode (SCE) in near-neutral electrolyte.[17] When the rest potentials are lower than −430 mV, generation of H_2O_2 on the surface of the coatings is considered to be feasible. Our experimental results proved this theory, as shown in Table 4. The elution concentrations of H_2O_2 from cobalt, chromating on zinc, zinc and zinc-cobalt alloy coatings were apparently higher than that of other coatings. This result is compatible with the date of Fig. 1, where their rest potentials were below −543 mV. Due to the operation of H_2O_2 on the microorganisms, all of the tested bacteria come close to the lethal range as the rest potential becomes lower than −543 mV. However, in cases where it is hypothesized that the volume of H_2O_2 is generated from the coatings in a heterogeneous diffusion layer, it is necessary that the H_2O_2 be sufficient for a lethal concentration.[16,18,19] As shown in Fig. 2, the lethal concentration of H_2O_2 is approximately 10^{-7} mol dm^{-3} to *P. aeruginosa*, *S. aureus*, and MRSA. Against *E. coli*, the lethal concentration of H_2O_2 is about one order higher; 10^{-6} mol dm^{-3}, than the former. It is apparent that all bacteria are sensitive to H_2O_2 to some degree. Thus, the bacteria which are partly oxidized by the H_2O_2 must be rapidly destroyed. Therefore, as the rest po-

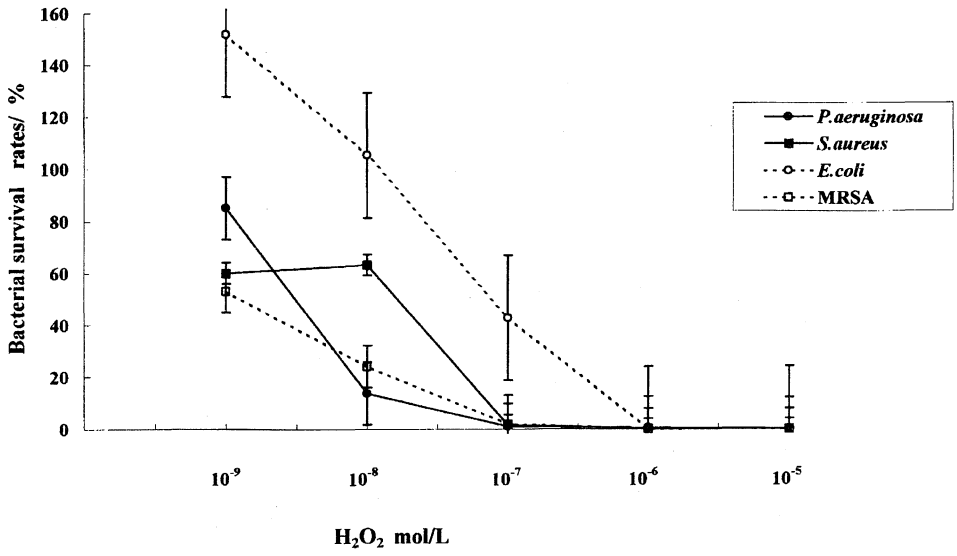

Fig. 2. Effect of H_2O_2 concentrations on the bacterial survival rates. Incubation at 25 °C for 24 h.

Table 2. The Metal Ion Amounts Dissolved from the Electroplated Coatings[a)]

Metal ions		Amount of metal ions $\mu g/cm^2$		
Control (Buffer)	Zn	5.00×10^{-5}	Cr	3.00×10^{-5}
SUS304	Ni	7.08×10^{-5}	Cr	1.88×10^{-5}
Ag	Ag	4.04×10^{-5}		—
Co	Co	3.41×10^{-3}		—
Cr	Cr	9.58×10^{-4}		—
Cu	Cu	2.01×10^{-2}		—
Ni	Ni	7.54×10^{-4}		—
Zn	Zn	1.92×10^{-1}		—
Co–Ni	Co	2.35×10^{-3}	Ni	3.94×10^{-4}
Co–Zn	Zn	2.00×10^{-1}	Co	3.38×10^{-4}
Au on Co	Co	2.11×10^{-3}		—
Chromating on Zn	Zn	2.08×10^{-2}		—
Cr on Co	Co	3.45×10^{-3}	Cr	5.44×10^{-4}
Cr on Ni	Ni	1.55×10^{-3}	Cr	6.67×10^{-5}

a) Immersion in pH 7.0 phosphate buffer solution for 24 h at 25 °C.

tential shifts to more negative values, one of the reasons that a lethal region for bacteria apparently exists is that H_2O_2 plays an essential role in the bactericidal effect of the coatings. At the same time, other antibacterial factors are not negligible, such as the dominant nature of the dissolved metal ions and their appropriate concentrations, which are generated from a corrosion reaction on the surface of the coatings. This makes it possible to inhibit bacterial proliferation when the coatings have more negative rest potential values.

However, when the rest potential is higher than zero, such as that on the surface of SUS 304, the bacterial survival rates do not appear to be satisfactorily diminished. Due to the fact that corrosion of the metal is difficult to cause on the surface of SUS 304, fewer electrochemical species having antibacterial activity are generated than on the other coatings. According to the above experimental results, it is considered that the rest potential of the coatings in a suitable negative range is an advantageous and necessary conditions for the inhibitory capability of bacterial growth.

The Effect of the Amount of Metal Ions Dissolved from Electroplated Coatings on Their Inhibitory Capability for the Growth of Bacteria. It is considered that as one of the mechanisms for the antibacterial activity on plated coatings is the metal ions and their concentrations. Thus, the metal-ion amount dissolved from various coatings was measured. The results are summarized in Table 2. One of the lowest dissolved metal-ion amounts was silver at about 10^{-5} $\mu g\,cm^{-2}$ (comprising 10^{-5} wt% of the total amount of silver plated on a square centimeter surface of a copper substrate) from a silver coating. The amount of chromium (comprises 10^{-4} wt%) dissolved at about the same level as silver from a chromium coating or from chromium on cobalt and nickel. The largest dissolved amount was zinc at 10^{-1} $\mu g\,cm^{-2}$ (comprises 10^{-1} wt%) from zinc and zinc-cobalt alloy coatings. The dissolved amount of zinc decreased by one order to 10^{-2} $\mu g\,cm^{-2}$ (comprises 10^{-2} wt%) when chromating of the zinc was carried out. On a level with this is the amount of copper (comprises 10^{-2} wt%) dissolved from a copper coating. Additionally, the dissolved amount of cobalt was approximately 10^{-3} $\mu g\,cm^{-2}$ (comprises 10^{-3} wt%) from the surface of cobalt and cobalt-containing alloy electroplated coatings. The amount of dissolved nickel (comprises 10^{-4} wt%) from the surface of nickel and nickel-containing alloy coatings was approximately one order less than that of the cobalt coating. Another of the lowest dissolved amount was nickel and iron at 10^{-5} $\mu g\,cm^{-2}$ from stainless steel. The amount of chromium dissolved from SUS 304 was at the same level as that in the control buffer

Table 3. The Inhibitory Capability of the Metal Ion Amounts Dissolved from the Electroplated Coatings for the Growth of Bacteria[a)]

			Gram-negative bacteria		Gram-positive bacteria	
			E. coli IFO 3806	*S. aeruginosa* IFO 13275	*S. aureus* IFO 12732	MRSA MIC to Methicillin 200 $\mu g\,mL^{-1}$
Ions	Compounds	Concentrations (PPM)	Bacterial survival rates %[c)]	Bacterial survival rates %[c)]	Bacterial survival rates %[c)]	Bacterial survival rates %[c)]
	Initial bacteria CFU/tube[b)]		3.5×10^4	3.2×10^4	3.2×10^4	1.3×10^4
	Control		1.3×10^3	4.2×10^4	5.7×10^3	6.1×10^3
Ag^{1+}	$AgNO_3$	1.0×10^{-5}	21±0.14	≧100	≧100	≧100
Co^{2+}	$CoCl_2$	1.0×10^{-4}	98±3.0	≧100	≧100	≧100
Cr^{6+}	$K_2Cr_2O_7$	1.0×10^{-5}	≧100	≧100	≧100	≧100
Cu^{2+}	$Cu(NO_3)_2$	1.0×10^{-3}	41±2.1	72±2.2	96±2.1	97±2.3
Ni^{2+}	$NiCl_2$	1.0×10^{-4}	≧100	63±1.5	82±1.5	79±2.0
Zn^{2+}	$Zn(NO_3)_2$	1.0×10^{-2}	73±1.5	79±1.6	23±1.4	53±2.1

a) Incubation in pH 7.0 phosphate buffer solution for 24 h at 25 °C. b) Colony forming units per tube. c) Divide bacterial number of control by the surviving bacterial number, the bacteria are proliferation when the value is bigger than 100%, the mean value and standard deviation of bacterial survival rates.

Table 4. The Amount of H_2O_2 Eluded from the Electroplated Coatings[a)]

Metal ions	Amount of H_2O_2 mmol cm^{-2}
Control (Buffer)	0
SUS304	0
Ag	5.9×10^{-7}
Co	1.6×10^{-5}
Cr	7.8×10^{-7}
Cu	1.2×10^{-6}
Ni	1.1×10^{-6}
Zn	3.4×10^{-5}
Co–Ni	6.3×10^{-6}
Co–Zn	3.1×10^{-5}
Au on Co	9.8×10^{-7}
Chromating on Zn	4.0×10^{-5}
Cr on Co	2.0×10^{-6}
Cr on Ni	9.8×10^{-7}

a) Immersion in pH 7.0 phosphate buffer solution for 24 h at 25 °C.

solution (10^{-5} μg cm^{-2}). According to these experimental results, because the chromium coating has corrosion-resistant, it shows the least dissolved chromium-ion amount in all of that of the coatings. Nevertheless, as are described in Table 1, its inhibitory capability is slightly weaker than other coatings. However, for strengthening the resistance to corrosion, chromium is plated on a cobalt and nickel coating.

The inhibitory capability of simulated dissolution concentrations of metal ions from various coatings for the growth of the tested bacteria was examined. As Table 3 shows, the dominant concentrations of dissolved metal ions are outside of the bacterial lethal range. Due to such as small quantity of metal ions, adequate nutrition exists for the growth of the bacteria; therefore the survival rates of parts of the *E. coli*, *P. aeruginosa*, *S. aureus*, and MRSA are much greater than 100%. In other words, the bacterial population is increased more in metal-ion solutions than when no metal ions are added to the buffer solution. The experimental results also indicate that the dissolved concentrations of chromium do not provide an inhibitory capability for the growth of all tested bacteria. Thus, due to the existence of trace amounts of metal ions, a marked change in the morphology of bacteria for a long time is not possible.[10)]

However, the concentrations of dissolved copper, nickel and zinc show a slightly inhibiting capability for the growth of *S. aureus*, *P. aeruginosa*, and MRSA. The experimental results also suggest that the dissolved concentrations of some metal ions show some an inhibitory capability for the growth of *E. coli*. Because silver and copper ions have mercaptol binding properties,[22,25)] biologically available silver is able to disrupt membranes, disable proteins,[20)] inhibit enzymes,[23)] and cleave nucleic acids[21,24,26)] in bacteria.

In conclusion, electroplated coatings possess a significant inhibitory capability for the growth of pathogenic bacteria. Namely, it has been found that the antibacterial activity of coatings can be associated with their rest potential and dissolved metal ions.

As one of the mechanisms for the inhibitory capability of coatings for the growth of bacteria, metal ions and their concentrations are not a negligible factor. Therefore, the antibacterial activity of metal ions and the minimum inhibitory concentrations (MIC) of various metal ions against all tested bacteria will be investigated in further work.

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