Corrosion Behavior and In Vitro Cytotoxicity of Ni–Ti and Stainless Steel Arch Wires Exposed to Lysozyme, Ovalbumin, and Bovine Serum Albumin

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ABSTRACT: In this study, the tendency and mechanisms by which protein and mechanical loads contribute to corrosion were determined by exposing Ni–Ti and stainless steel arch wires under varying mechanical loads to artificial saliva containing different types of protein (lysozyme, ovalbumin, and bovine serum albumin). The corrosion behavior and in vitro cytotoxicity results show that exposure to both protein and mechanical stress significantly decreased the corrosion resistance of stainless steel and increased the release of toxic corrosion products. Adding protein inhibited the corrosion of Ni–Ti, but the mechanical loads counteracted this effect. Even proteins containing the same types of amino acids had different effects on the corrosion resistance of the same alloy. The effect of protein or stress, or their combination, should be considered in the application of metal medical materials.

INTRODUCTION

The development of materials science and engineering has led to the applications of Ni–Ti (Ni–Ti) shape memory alloys and stainless steel (SS) alloys in biomedicine. Ni–Ti alloy has been widely used in biomedical applications because of its unique shape memory effect and superelasticity.1,2 SS has been used as ureteral stents, orthopedic devices, orthodontic brackets, and wires because of its superior mechanical properties.3,4 Although SS provides excellent biomechanical properties compared to other alloys, the reduced corrosion resistance and biocompatibility of SS restrict its clinical application. The physiological environment is a complicated electrochemical system, and the in vitro or in vivo biological response to Ni–Ti and SS alloys correlates to elemental release, which is the result of corrosion. Nickel is one of the main toxic elements that can be released by Ni–Ti and SS alloys during the corrosion process.5 Research has shown that nickel or its compounds could cause hypersensitivity, dermatitis, or asthma, so there exists the possibility that corrosion products of nickel released from orthodontic arch wires or brackets might elicit side reactions.6,7

The physiological environment is a complicated system that contains not only inorganic species but also organic molecules, such as proteins. The underlying presupposition is that proteins and other components would not significantly increase the corrosion susceptibility of medical devices in contact with the blood or body fluid. Proteins were previously found to have an effect on the elemental release and cytotoxicity of alloys.8 The physicochemical characteristics and surface quality of alloys and the consequent toxic ion release may generate undesired biological reactions. Unfortunately, little work has been done on the influence of proteins in saliva, which may be important to dental clinical applications, especially when electrochemical, microtopography, and cytotoxicity tests are combined. However, to improve the performance of biomaterials, some studies have focused on materials design, composition, and surface modification. Surface modification designed to prepare a protein-resistant surface is considered as a promising core technology in biomaterials development.9,10 To design a biomaterial whose surface is resistant to biofouling via surface modification, it is necessary to understand how protein adsorption affects the biomaterial surface.11,12 Therefore, more systematic studies are needed to further unveil the interaction between proteins and materials, especially the subsequent corrosion process.

A cationic alkaline protein, lysozyme is a glycoside hydrolase composed of 130 amino acids, with a relative molecular weight of 14.4 kDa.13 It largely exists in many kinds of secretions, such as saliva, mucus, and tears. It is also the primary line of oral immunization defense14 and is related to the prevalence of dental caries and occurrence of periodontal disease.15 There-
fore, it is necessary to study the effect of lysozyme on the corrosion process of dental alloys.

Ovalbumin is the main protein found in egg white and is composed of 385 amino acids, with a relative molecular weight of 45 kDa. It could chelate heavy metals and trap them within sulphydryl bonds and could reduce the absorption of metal ions into the digestive system and stop poisoning. Surfaces that have been coated with albumin could lead to low bacterial adhesion. Ovalbumin used in this study could serve as a representative protein ingredient in food.

Bovine serum albumin (BSA) is the main protein in bovine serum and has similar effects as that of human albumin. The role of BSA is to maintain blood volume and perfusion pressure. The full-length BSA precursor protein is composed of 607 amino acids, and its relative molecular weight is 66 kDa. BSA is an essential component of a cell culture medium and is commonly used in detecting the biocompatibility of metallic materials. It is necessary to study the interaction between BSA and materials and provide a basis for the accurate detection of biocompatibility.

Biometal materials, such as vascular stents, orthodontic arch wires, or oral implantations, need to bear considerable applied stress to exercise therapeutic function, except for the wires, or oral implantations, need to bear considerable applied stress. The full-length BSA precursor protein is composed of 607 amino acids, and its relative molecular weight is 66 kDa. BSA is an essential component of a cell culture medium and is commonly used in detecting the biocompatibility of metallic materials.

It is necessary to study the combined effect of proteins and mechanical stress on the corrosion resistance of Ni–Ti and SS alloys in the oral application environment. Lysozymes, ovalbumin, and BSA are medium-weight proteins that are widely distributed in organisms. In this study, the relationship of these proteins with the corrosion process and mechanisms of Ni–Ti and SS was studied. The impetus for comparing the effects of different proteins on corrosion was to evaluate and predict corrosion behavior in oral saliva with a deep insight into electrochemistry, topography, and cytotoxicity. This study will provide an experimental basis for Ni–Ti and SS arch wires used in dentistry and a reference for improving two biological materials and optimizing biofunctionalization strategies for surface modification.

**Materials and Experiments**

**Materials and Sample Preparation.** The base metals were a Ti–44.73 wt % Ni–Ti SMA wire (Smart Co., Beijing, China) and Fe–18Cr–8Ni SS (Grikin Advanced Materials Co., Ltd.). The size of the orthodontic arch wires was 60 mm (length) × 0.64 mm (width) × 0.48 mm (thickness). The specimens were ground step by step by silicon carbide papers until the oxide layer was removed.

**Test Solution Preparation, Immersion Tests, and Stress Condition Implementation.** The artificial saliva (AS) was prepared as previously described, and 40 mg/L lysozyme, ovalbumin, and BSA (Sigma, US) were respectively added to prepare different test solutions. The samples were ground and cleaned in 95% alcohol and double-distilled water. A fixture made of a glass sheet was used for applying a continuous three-point bending force, as shown in Figure 1. The two ends of the arch wire were fixed on the glass fixture, and different strains were applied by cylinders with different diameters onto the arch wire. The device could apply displacements of 2.0, 3.0, and 4.0 mm to mimic stress application. The no-stress-application samples were placed in the same device without stress application (deflection: 0 mm).

Each experiment included 12 groups [3 types of protein (lysozyme, ovalbumin, and BSA) × 4 loading stress (bending deflection of 0, 2.0, 3.0, and 4.0 mm)], and there were five replicates each group. The wires were immersed in the test solutions and maintained at 37 °C for 60 days.

After 60 days, the samples were weighed (Precision electronic balance, M2-P, Sartorius, Gottingen, Germany), and the weight loss of corrosion was calculated. The immersed solutions were analyzed for Ni (ICP-OES, Optima 3300DV, Perkin Elmer, Boston, MA, USA) and used for in vitro cell cytotoxicity tests. The internal standard solution was employed for a Ni ion test, and the detection limit was 0.01 ppm.

**Electrochemical Tests.** A CHI 760E electrochemical workstation (CH Instruments, Shanghai, China) was used to complete the electrochemical experiment. The counter electrode and the reference electrode were a platinum plate and saturated calomel electrode (SCE), respectively. The specimens were preground to achieve homogeneous roughness and closed partly by cold-curing epoxy resin. The exposed area for the test was 20 × 0.64 mm2. The electrochemical cell was immersed in a water bath to maintain the temperature at 37 ± 0.5 °C.

Bubbling argon gas was used to deaerate the solution for 30 min. An initial delay of 1 h before scanning was necessary to reach a steady state. The scan started from −1 V/SCE with the sweep rate of 1 mV/s. The scope of potentiodynamic polarization was between −1000 and +1000 mV. The electrochemical parameters were set up according to the ASTM standard in cyclic polarization. The potential versus current density curves could be drawn under the control of a cyber-potentiostat, from which the data of cyclic polarization could be calculated.

**Surface Morphology by Scanning Electron Microscopy (SEM) Observation.** After the immersion corrosion, the surface morphology of samples in different solutions and stress dislocation groups was observed by environmental SEM (Zeiss EVO18, Jena, Germany). The topographical characterization of the specimens in each group was randomly recorded by atomic force microscopy (AFM) (Seiko Instruments, Inc., Japan). The spring constant of the silicon microcantilever was 0.99–1.99 N/m in tapping mode, and the scanning frequency was 70 kHz (Olympus Co., Japan). The scan was completed by an etched conical tip, and the scope and format of the scan were 10 × 10 μm and 256 × 256, respectively.

**In Vitro Cytotoxicity Test.** The mouse fibroblast L-929 cell line was cultured at 37 °C and 5% CO2 to evaluate the cytotoxicity of corrosion products. The culture medium was Dulbecco’s modified Eagle’s medium (DMEM) with 10% fetal bovine serum (FBS), 100 μU ml−1 penicillin, and 100 μg ml−1 streptomycin. After the immersion test, the solutions containing corrosive products from different proteins or stress

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**Figure 1.** Fixture device used to apply three-point bending forces to Ni–Ti and SS arch wire samples.
dislocation tests were sterilized by UV irradiation for 1 h as extraction of Ni–Ti and SS. The cells were seeded and incubated in 96-well cell culture plates at 5 × 10³ cells/100 μL medium per well for 24 h. Then, a part of the medium was replaced with 20 μL of corrosive solution. Simple DMEM without Ni–Ti or SS extraction media was used as a negative control, and dimethyl sulfoxide (DMSO) was used as a positive control. After incubation for 48 h, the cells were observed under an optical microscope. The activity of cell proliferation was evaluated by the cell counting kit-8 (CCK-8) test according to the manufacturers' instructions (Dojindo Molecular Technologies, Japan). The spectrophotometric absorbance of the specimens was measured at 490 nm by a microplate reader ( Molecular Device, USA). The viabilities of cells are calculated as the mean ± standard deviation with n = 5 per group. The error bars are the standard deviations calculated over five measurements.

## RESULTS

### Electrochemical Measurements

Figure 2 shows the effects of different proteins on the polarization behavior of Ni–Ti and SS arch wires. Table 1 contains the calculated electrochemical parameters. Before the pitting potential, both the Ni–Ti and SS arch wires experienced a passive course in the anodic polarization section. The corrosion potentials \(E_{corr}\) of Ni–Ti in the protein groups were increased compared to those in simple AS, whereas the \(E_{corr}\) of SS was decreased in all protein groups. For the Ni–Ti samples, \(E_{corr}\) in the BSA AS was the highest among the protein groups and that in the lysozyme AS was slightly higher than that in the ovalbumin AS. \(E_{corr}\) for SS in all three protein AS was quite similar. The differences between the breaking potential \(E_b\) and corrosion potential \(E_{corr}\) for different protein solutions are calculated in Table 1. \(E_b−E_{corr}\) for Ni–Ti in the protein AS was almost the same but much lower than that in the simple AS. Similarly, the constant current densities for both arch wires increased rapidly after cathodic polarization. In protein groups, the \(i_{corr}\) value of Ni–Ti alloy was smaller, while the \(i_{corr}\) of SS was larger than that in simple AS.

The cyclic polarization behavior for Ni–Ti and SS in different solutions presented hysteresis as in Figure 2. However, the corrosion behaviors of the alloys were influenced by different types of protein. The difference values between the \(E_b\) and the repassivation potential \(E_{prot}\) for each protein are listed in Table 1. \(E_b−E_{prot}\) for both alloys in the ovalbumin AS was larger, and that in the BSA AS was relatively smaller. The value of \(E_b−E_{prot}\) in the lysozyme AS of Ni–Ti was quite small, but it was the largest in the SS group.

### Weight Loss, Elemental Release, and Surface Morphology in Immersion Corrosion

Representative SEM images of the specimen surface morphology after immersion in different AS and stresses are shown in Figures 3 and 4. Corrosion pits were generated regardless of the type of solution or stress application. The Ni–Ti arch wires in the protein groups showed small and circumscribed corrosion pits, while the corrosion locus of the SS samples was similar to that in the simple AS samples. The corrosion morphology of both stressed Ni–Ti and SS samples exhibited more irregular morphology than that of unstressed ones in the same type of

| Material and Solution | \(E_b−E_{corr}\) (mV/SCE) | \(E_b−E_{prot}\) (mV/SCE) | \(i_{corr}\) (μA/cm²) |
|-----------------------|--------------------------|--------------------------|---------------------|
| SS in simple AS       | 82 (±6)                  | 1008 (±8)                | 0.30 (±0.03)        |
| SS in lysozyme        | 41 (±2)                  | 952 (±6)                 | 0.56 (±0.03)        |
| SS in ovalbumin       | 68 (±3)                  | 354 (±5)                 | 0.94 (±0.06)        |
| SS in BSA             | 132 (±7)                 | -                        | 0.43 (±0.05)        |
| Ni–Ti in simple AS    | 69 (±3)                  | 450 (±4)                 | 0.22 (±0.03)        |
| Ni–Ti in lysozyme     | 60 (±5)                  | 1020 (±3)                | 0.26 (±0.08)        |
| Ni–Ti in ovalbumin    | 170 (±4)                 | 179 (±5)                 | 0.39 (±0.04)        |

*Data are presented as the mean ± standard deviation.*
solution. As the bending dislocation increased, the corrosion loci became larger, deeper, and rougher. The surface morphology of Ni\textsuperscript{−}Ti seemed slightly shallow in the BSA groups at the same mechanical dislocation. The ion release and weight loss of the specimens were calculated, as shown in Figure 5, and the results are calculated relative to the exposed surface area. In the same protein solution, both the ion release of nickel and the weight loss of the same material increased as the applied stress dislocation increased. The ion release of Ni\textsuperscript{−}Ti in the protein solution was slightly lower than that of the control group. The metal release of Ni in the lysozyme and ovalbumin groups was similar, and the Ni release in the BSA group was the slowest.

The AFM images in Figure 6 show the different morphologies of the sediments deposited on the surfaces of specimens in the three proteins groups. The height of the sediments in the lysozyme AS is the smallest, forming a small needle-like surface accompanied by deep corrosion pits. The sediments in the ovalbumin AS are the most striking, and the particles are rough and easy to aggregate. There were also deep corrosion pits between the sediments in the ovalbumin AS. The surface sediments of the BSA AS were uniform in particle size and relatively shallow in the corrosion sites. In general, in the same protein group, the surface roughness and depth of the dress pit of Ni\textsuperscript{−}Ti are small and shallow, while the corrosion pit of SS is deep.

**In Vitro Cytotoxicity of the CAW Extract.** The in vitro cytotoxicity of Ni\textsuperscript{−}Ti and SS corrosion products in different protein solutions and bending stress groups was evaluated by exposure to L-929 cells (Figure 7). The relative cell viability is presented as a percentage value after calculation, and the viability of the control group was considered to be 100%. The vitality of the cells decreased gradually as the applied dislocation increased. Under the same external stress, the viability of cells cultured with different Ni\textsuperscript{−}Ti protein extraction media was lower than that in simple DMEM (negative control) but higher than that of cells cultured in simple AS. However, the viability of cells cultured with SS protein extraction media was similar to that of cells cultured in simple AS. The viability of cells cultured in both Ni\textsuperscript{−}Ti and SS protein extraction media remained greater than 60% over 48 h of culture.

**DISCUSSION**

Nickel is considered the main toxic element in Ni\textsuperscript{−}Ti and SS, and nickel leached from alloys into surrounding tissues could inhibit cell proliferation and differentiation by changing the expression of related genes. The potential adverse reactions caused by toxic ions restrict the application of metallic materials in the human body.\textsuperscript{24} From another perspective, materials prepared with specific proteins would have numerous
applications in biomedicine. However, it remains unclear how surface chemistry and topography affect protein adsorption.\textsuperscript{25}

For potentiodynamic polarization, a part of the cathodic polarization process is controlled purely by activation, whereas a part of the anodic polarization process is controlled by the diffusion of dissolved metals and the subsequent formation of a passive film. For Ni–Ti alloy, the higher $E_{\text{corr}}$ in the protein groups suggested that the corrosion resistance was increased in the participation of protein. The value of $E_{\text{corr}}$ in the BSA AS was the highest among the protein groups, indicating the good stability of the passive layer. During electrochemical corrosion of Ni–Ti alloy, oxygen dissolved in the electrolyte could adsorb onto the surface and form a protective film that was mainly made up of Ti oxide to inhibit the ions from being even more conductive.\textsuperscript{26} The anodic dissolution current could not be stable until the formation and dissolution of the oxide film leveled off. The smaller $i_{\text{corr}}$ for Ni–Ti alloy in the protein groups illustrated that the corrosion current density was decreased by adding protein. The passive region of SS was relatively longer and more typical. The lower $E_{\text{corr}}$ of SS in the protein groups suggested that adding protein decreased the stability of the oxide layer and might accelerate the process of corrosion. These data indicated that the participation of protein decreased the corrosion resistance of SS and that the effects of different proteins were similar.

$E_b$ was considered to be the value where the potential–current density plot shows an abrupt increase in current density. This value represents the potential where the passivation film is ruptured and where the corrosion process accelerates. $E_b - E_{\text{corr}}$ is one of the parameters for evaluating the susceptibility to pitting corrosion. The $E_b$ of SS in all groups was more obvious than that of Ni–Ti.\textsuperscript{27} $E_b - E_{\text{corr}}$ for

Figure 6. 2D and 3D AFM scans showing the morphologies of Ni–Ti and SS samples immersed in protein solutions: (a) Ni–Ti in lysosome AS, (b) SS in lysosome AS, (c) Ni–Ti in ovalbumin AS, (d) SS in ovalbumin AS, (e) Ni–Ti in BSA AS, and (f) SS in BSA AS.

Figure 7. Relative viability of L-929 cells compared to that of the negative control (DMEM only) after 48 h of culture in Ni–Ti and SS extraction media.
both alloys in the three protein AS was similar, which demonstrates that the three types of protein have little influence on the pitting stability of alloys. The constantly increased current densities for both alloys indicate that the protective film was damaged.\textsuperscript{28} For Ni–Ti alloy, \( i_{\text{corr}} \) in the protein groups was smaller than that in the simple AS, whereas \( i_{\text{corr}} \) of SS in protein was larger. This result illustrates that the addition of protein might inhibit the progress of Ni–Ti corrosion but accelerate that of SS corrosion.

In this study, using cyclic anodic polarization, we assessed the corrosion resistance of a surface and its ability to repassivate. The passive layer could be broken down until repassivation occurred. The ability to repassivate in two arch wires was assessed by recording the difference of \( E_b - E_{\text{prot}} \).\textsuperscript{29} \( E_{\text{prot}} \) was the potential where the current density returned to the passive current density during the reverse polarization.\textsuperscript{30} \( E_b - E_{\text{prot}} \) is related to the reactions occurring at the surface during repassivation. There is breakdown of the passive layer for Ni–Ti and SS arch wires, as well as presentation of hysteresis, indicating the ability of the alloys to repassivate in the participation of proteins. \( E_b - E_{\text{prot}} \) for both Ni–Ti and SS in the ovalbumin AS was larger, and that in the BSA AS was relatively smaller. This suggests that ovalbumin decreases the repair capacity of the passivation film, whereas BSA has the opposite effect. The value of \( E_b - E_{\text{prot}} \) of Ni–Ti was quite small, but that of the SS group was relatively larger. Therefore, the same type of protein has different effects on the repair of the passive film on different materials.\textsuperscript{31} BSA not only improved the stability of the passive layer but also enhanced the repair ability of the alloys.

According to the results, we try to elucidate how proteins in an oral environment might interact with the repassivation process and influence the properties of the passive layer. The charge transfer in the double layer is due to \( \text{H}^+ \) and \( \text{O}^- \) ions and protein molecules outside the metal surface depending on if the state of passivation is up to or beyond removal.\textsuperscript{32} The complex of metal/hydroxylated compounds gradually formed and deposited on the surface. When the metal oxide of Ni–Ti or SS is stable, the surface of the alloy acts as a cathode; when the surface is passivated, it acts as an anode.\textsuperscript{33} When added, negative proteins act synergistically with oxygen and combine with metal ions to accelerate dissolution. However, as time goes on, increasingly more proteins would adsorb and accumulate onto the alloy surface. Protein molecules, as a part of a surface passive membrane, could inhibit the further invasion of oxygen.\textsuperscript{34,35} Furthermore, in the aggressive environments of this study, the passive films were readily broken down, whereas the repair process of the passive films could be difficult and slow, exposing the underlying metal to the corrosive environment until repassivation occurred.\textsuperscript{36} Repassivation also contains the effect of protein in the corrosive solution and form a similar corrosion process since a loop is formed. Therefore, the role of protein in the process of alloy corrosion has several aspects, and we evaluated the reason for both electrochemical corrosion and immersion corrosion. The participation of proteins in solution would break the equilibrium, take part in the loop of passive film “metabolism”, and influence the corrosion resistance of alloys.\textsuperscript{37} Although the metal–protein bond would be weaker than the metal–oxygen bond, the addition of protein would disrupt the original balance and participate in the creation of a new one.\textsuperscript{38,39}

After the immersion tests, we examined the alloy surfaces to identify sites of corrosion attack. Corrosion pits were generated in both the protein and simple AS groups. For both the Ni–Ti and SS stressed wires, the corrosion was aggravated, and the ion release accumulated as the stress dislocation increased. This finding verified that mechanical stress accumulates the process of corrosion. The rough corrosion morphology and high ion release of SS in the protein group illustrated that protein could decrease the corrosion resistance of the SS alloy. However, the slightly low metal release and small and circumscribed corrosion morphology of Ni–Ti in the protein AS showed that protein may inhibit the corrosion process of the Ni–Ti arch wire,\textsuperscript{40} especially in the BSA AS. The corrosion morphology was aggravated by both protein and stress, which indicates that the corrosion resistance was decreased under the combined effect of protein and stress. This observation agrees with a previous study on SS with passive chromium-rich surface oxides.\textsuperscript{41} For both alloys, the weight loss in the protein groups was similar to that in the simple AS because the adsorption of protein offsets the dissolution of metal. The morphologies of the sediments deposited on the surface of different protein groups were different in the AFM images. Changes in the surface topography reflect differences in the organization of the adsorbed films. The uniform deposit and shallow corrosion sites of the BSA AS proved that the passive layer was more protective and that the corrosion was milder.

The results of ion precipitation, surface corrosion morphology, and cytotoxicity of corrosion products further demonstrate that proteins have different effects on the corrosion of different alloys. The nature of the surface will affect not only the initial fouling layer but also the amount of deposit that subsequently accumulates. It is believed that the supramolecular organization of the adsorbed protein layer is controlled by surface chemistry and topography. The surface characteristic was influenced by wettability and polar surface energy, which were different between the SS and Ni–Ti arch wires.\textsuperscript{42} The adsorption of proteins complied with the Langmuir adsorption isotherm in corrosive solution and was considered ligand adsorption, which complexed with a surface oxide/hydroxide metal atom and could detach from the surface oxide.\textsuperscript{43} The dynamic equilibrium of adsorption and detachment leads to corrosion. In addition, the surface charge is a significant factor in the adsorption of proteins because another driving force for protein adsorption on alloys is electrostatic interactions. The \( \zeta \) potential of massive SS and Ni–Ti alloy is commonly reported to be negative at neutral pH, similar to this study, and the isoelectric point is identified between pH 3 and 7. Due to the different isoelectric points, the electrostatic adsorption capacity of the two alloys is different, so the interaction between the surface and protein is different.\textsuperscript{44} This phenomenon explains why three types of protein have different effects on the corrosion process.\textsuperscript{45} However, the specific mechanisms underlying constitution and surface conditions require further study.

Studies on cell binding with bio-alloy might help to analyze corrosion products and subsequent systemic responses in vivo.\textsuperscript{46} Therefore, we studied the cytotoxicity of corrosion products in the Ni–Ti and SS immersion extracts. Under the same external stress, the higher viability of cells cultured with the Ni–Ti protein extraction media and the lower viability of cells cultured with the SS protein extraction media showed that the addition of protein inhibited the release of toxic corrosion products in the Ni–Ti arch wire but aggravated that in the SS.
proteins containing the same types of amino acids have different effects on the corrosion resistance of the same alloy. Therefore, the effects of protein on the corrosion process of alloys may be due to the amino acid sequence, spatial conformation, conformational stability, or flexibility under changing ionic conditions. These factors illustrate the complexity in the process of protein interactions with alloy.

Moreover, albumin is the most abundant protein in the serum and interstitial fluid, and the binding complex between albumin and metal ions could cause the latter to enter the circulation and induce side effects. However, the pre-adhesion of albumin on the surfaces of alloys might inhibit the adsorption of plasma proteins and subsequent cell interactions, even leading to a decrease in bacterial adhesion. Thus, proteins with low conformational stability may adhere to hydrophobic or hydrophilic surfaces of alloys for modification. Therefore, further results should focus not only on the prevention of protein adsorption but also on the application of interactions between proteins and alloys.

CONCLUSIONS
The presence of lysozyme, ovalbumin, and BSA does not lead to the fracture of the Ni−Ti or SS arch wire or the excessive release of toxic Ni ions. The effects of protein on the corrosion process differ according to different types of proteins and alloys. The presence of protein could accelerate the corrosion process of SS but increase the corrosion resistance of Ni−Ti alloy. The application of bending stress accelerated the corrosion process and production of toxicants. The combined effect of protein and stress dislocation would reduce the corrosion resistance of Ni−Ti and SS. BSA could enhance the stability of the passive layer and the repair ability of alloys, whereas ovalbumin could not. Even proteins containing the same types of amino acids could have different effects on the corrosion resistance of the same alloy. The results of this study provide a reference for the surface modification of metal biomaterials to enhance biocompatibility.

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Notes
The authors declare no competing financial interest.

ACKNOWLEDGMENTS
This work funded by the National Natural Science Foundation of China (81801007), Postdoctoral Science Foundation of China (2019 M659280), National Natural Science Foundation of Guangdong Province (2018A030310442), and Science and Cultivation Foundation of Stomatological Hospital of Southern Medical University (FY2018027).

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