INTRODUCTION

Yttria-stabilized tetragonal zirconia polycrystalline (Y-TZP) has become an indispensable ceramic material in dentistry during the last decade1,2). Y-TZP is clinically utilized as inlays, crowns, bridges, and dental implants because it is white and has sufficient fracture toughness. It is believed that Y-TZP is a bioinert material that is not capable of chemical bonding with bone tissue3). Therefore, the surfaces of Y-TZP are treated by various methods, such as alumina sandblasting and tribochemical silica coating4), to improve the adhesion to the surrounding tissue. On the other hand, Y-TZP implant shows 95% integration with bone after immediate loading into a dental single-piece implant 5). In addition, Y-TZP abutments without surface treatment easily attach to soft tissues6,7). Protein adsorption and cell adhesion may promote the adhesion of tissues to the Y-TZP because bone implants made of Y-TZP after coating with tissues containing collagen become compatible with human bodies8). Hydroxyl groups on the surface of an implant play an important role for protein adsorption. When hydroxyl groups are present on Y-TZP, they facilitate tissue attachment9).

As described above, there is a discrepancy between the bioinert and tissue adhesive properties of Y-TZP. To assist the elucidation of this mechanism, yttria-stabilized zirconia (YSZ) disks with crystalline planes of (100), (110), and (111) were immersed in ultrapure water and in Hanks’ solution. After immersion in ultrapure water for 60 days, the concentration of hydroxyl groups on the Y-TZP surface increased. In addition, only phosphate ions were incorporated into the surface during immersion in Hanks’ solution, while other ions did not react. On the other hand, the surface of Ti was also hydrated in ultrapure water; however, calcium phosphate formed on it during immersion in Hanks’ solution. Therefore, the reactivity of Y-TZP with electrolytes was lower than that of Ti. We conclude that the formation of the phosphate on the Y-TZP surface in physiological conditions possibly enhances the adhesion of soft and hard tissues to Y-TZP.

MATERIALS AND METHODS

Preparation of Y-TZP disks

Two types of commercial Y-TZP samples (KATANA HT12, Kuraray Noritake Dental, Tokyo, Japan) with 98.5 mm in diameter and 14.0 mm in thickness and ZR-SS colored Peach medium (Shofu, Kyoto, Japan) with 98.0 mm in diameter and 4.0 mm in thickness were purchased. The Y-TZP samples were ground to disks by a milling system (ZENOTEC mini, Wieland Dental, Pforzheim, Germany), followed by sintering in a furnace (ZENOTEC Fire, Wieland Dental) at 1,450°C for 2 h for KATANA and 1,500°C for 2 h for ZR-SS according to the manufacturers’ recommended sintering programs. Then, the disks were polished by the diamond slurry lapping.
The dimensions of resultant sintered Y-TZP disks were 10 mm in diameter and 2.5 mm in thickness; surface roughness $R_a$ was less than 0.5 mm measured by the optical profiler (CCI Sunstar, Taylor Hobson, Leicester, England, UK). Finally, the disks were ultrasonically cleaned in acetone and ethanol twice for 5 min. The disks are henceforth referred to as “Polished KATANA” and “Polished ZR-SS”, or collectively as “Polished Y-TZP.”

**Immersion in ultrapure water**

The Polished Y-TZPs were immersed in ultrapure water (Direct-Q UV 3 with Pump, Millipore, Burlington, MA, USA) at ambient temperature for 60 days. Immediately after immersion, the specimens were rinsed in fresh ultrapure water, and dried with nitrogen gas flow. They are henceforth referred to as “Water-treated Y-TZP”.

**Immersion in Hanks’ solution**

The Polished Y-TZPs were immersed in a Hanks’ solution without glucose at ambient temperature for 7 days. The composition of the Hanks’ solution is summarized in Table 1. Immediately after immersion, the specimens were rinsed in fresh ultrapure water and dried with nitrogen gas flow. They are henceforth referred to as “Hanks-treated Y-TZP”.

**X-ray diffractometry**

Crystalline phases of Polished Y-TZPs were analyzed using an X-ray diffractometer (D8 ADVANCE, Bruker, Billerica, MA, USA) with Cu Ka radiation at 40 kV and 40 mA in 20 range of 5°–140° with 0.08° steps. The detected peaks were identified with X’Pert HighScore Version 2.2.a. The analyses were carried out for different three specimens.

**X-ray fluorescence (XRF) spectroscopy**

Bulk chemical compositions of Polished Y-TZP were evaluated using an XRF spectroscopy (XGF-1000WR, HORIBA, Kyoto, Japan) with an X-ray voltage of 50 kV and a current of 280 µA. Fundamental parameter method was used for quantification of the elements. The analyses were carried out for different three specimens.

**XPS**

XPS was performed with an electron spectrometer (JPS-9010MC, JEOL, Tokyo, Japan). All binding energies given in this paper are relative to the Fermi level, and all spectra were excited with the monochromatized Mg Kα line (1253.6 eV). The detection angle of the photoelectron was 90° to the surface of the specimens. The spectrometer was calibrated against Au 4f7/2 (binding energy, 84.07 eV) and Au 4f5/2 (87.74 eV) of pure gold and Cu 2p3/2 (932.53 eV), Cu 2p1/2 (952.35 eV), and Cu Auger L3M5M4,5 line (kinetic energy, 918.65 eV) of pure copper. The energy values were based on published data19. The binding energies were calibrated with a C 1s energy region peak (285.0 eV) originated from a so-called contaminant. In order to estimate the photoelectron peak intensities, the background was subtracted from the measured spectrum according to Shirley’s method13. The composition was calculated with the exception of carbon as a contaminant according to a method described in previous reports14,15. In the case of Ti, the thickness of surface oxide film was also calculated. Empirical data16-18 and theoretically calculated data19 of the relative photoionization cross sections were used for quantification. The analyses were carried out for different three specimens.

**Preparation and characterization of the titanium**

Commercially pure titanium disks (grade 2) with 8.0 mm in diameter were metallographically polished and finally polished with 0.04 µm silica suspension. The specimens were ultrasonically cleaned in acetone and ethanol twice for 5 min before immersion into the ultrapure water or Hanks’ solution. They are henceforth referred to as “Polished Ti”. The Polished Ti was immersed in the ultrapure water for 60 days, henceforth referred to as “Water-treated Ti”. Another Polished Ti was immersed in the Hanks’ solution for 7 days, henceforth referred to as “Hanks-treated Ti”. The chemical states of specimens were evaluated in the same way as the Y-TZP specimens.

**RESULTS**

**Crystalline phases of Polished Y-TZP**

XRD patterns of Polished Y-TZPs are shown in Fig. 1. The peaks were detected at 30.19°, 34.66°, 35.06°, 50.19°, 50.55°, 59.29°, and 59.69° for KATANA and 30.19°, 34.70°, 35.22°, 50.23°, 50.63°, 59.33°, and 59.69° for ZR-SS, which were indexed as (101), (002), (110), (112), (200), (103) and (211) reflections, respectively (ICDD File No. 42 1164 Zirconium Oxide). It revealed that both Y-TZPs were tetragonal polycrystalline.

**Surface chemical states and bulk compositions of Polished Y-TZP**

Zirconium, yttrium, oxygen, and carbon as a contaminant carbon were detected from both Polished Y-TZPs using XPS. Figure 2 shows XPS spectra of the binding energy regions of Zr 3d, Y 3d, and O 1s electrons from the Polished KATANA. Zr and Y were detected as the Zr$^{4+}$ oxide state (182.5 eV and 184.9 eV, Fig. 2a).
and Y\(^{3+}\) oxidized state (157.4 eV and 159.4 eV, Fig. 2b), respectively. On the other hand, O 1s electron region peak was deconvoluted into three components: O\(^2−\) (530.3 eV), OH (532.0 eV), and H\(_2\)O (533.1 eV) (Fig. 2c). XPS spectra from the Polished ZR-SS revealed the same results as the Polished KATANA.

Relative concentrations of Zr, Y, and O and the proportions of O species in both Polished Y-TZPs are summarized in Table 2. The Table contains the bulk chemical compositions evaluated by XRF as a reference. Surface concentrations of Zr, Y, and O in Polished KATANA and ZR-SS determined by XPS were almost the same as bulk concentrations determined by XRF, respectively. Slight differences between surface and bulk concentrations are possibly generated by quantification error of XPS and XRF. Surface and bulk concentrations of Zr in KATANA was smaller than those in ZR-SS while Y in KATANA was larger than those in ZR-SS. On the other hand, O concentration and proportion of oxygen species were almost the same between KATANA and ZR-SS.

**Surface chemical states and composition of Water-treated Y-TZP**

Zr, Y, O, and C as a contaminant carbon were detected from both Water-treated Y-TZPs. Relative concentrations of Zr, Y, and O and the proportions of O species are

![XRD patterns of Polished KATANA and ZR-SS.](image)

**Fig. 1** XRD patterns of Polished KATANA and ZR-SS.

![XPS spectra of Polished KATANA: (a) Zr 3d, (b) Y 3d, and (c) O 1s electron binding energy regions.](image)

**Fig. 2** XPS spectra of Polished KATANA: (a) Zr 3d, (b) Y 3d, and (c) O 1s electron binding energy regions.

| Instrument | Relative concentration (at.%) | Proportion of O species | (\([OH^-]+[H_2O]\)/[O\(^2−\)]) |
|------------|------------------------------|-------------------------|--------------------------------|
|            | Zr  | Y   | O   | O\(^2−\) | OH | H\(_2\)O |
| XPS        | 32.0±0.2* | 2.7±0.0 | 65.3±0.2 | 0.79±0.02 | 0.15±0.02 | 0.06±0.01 | 0.27±0.04 |
| XRF        | 30.8±0.0 | 3.0±0.0 | 66.2±0.0 | —         | —     | —         | —         |

*Mean±SD, n=3

| Instrument | Relative concentration (at.%) | Proportion of O species | (\([OH^-]+[H_2O]\)/[O\(^2−\)]) |
|------------|------------------------------|-------------------------|--------------------------------|
|            | Zr  | Y   | O   | O\(^2−\) | OH | H\(_2\)O |
| XPS        | 32.8±0.2* | 2.1±0.0 | 65.1±0.1 | 0.81±0.01 | 0.13±0.00 | 0.06±0.01 | 0.23±0.01 |
| XRF        | 31.5±0.0 | 2.2±0.0 | 66.3±0.0 | —         | —     | —         | —         |

*Mean±SD, n=3

Table 2: Relative concentrations of elements and proportions of O species on Polished (a) KATANA and (b) ZR-SS surfaces determined using XPS and those determined using XRF
summarized in Table 3. Surface concentrations of Zr decreased by 0.9 and 2.2 at.% and those of Y decreased by 0.2 and 2.4 at.% in the Water-treated KATANA and ZR-SS compared with Polished TZPs, respectively. Surface concentrations of O increased by 1.1 and 2.6 at.% in the Water-treated KATANA and ZR-SS compared with Polished TZPs, respectively. The increase of O was caused by the hydration of the surface, because Y-TZP is completely oxidized already. However, the proportion of O species in Water-treated KATANA was almost the same as that of the Polished KATANA. On the other hand, the proportion of OH\(^-\) and H\(_2\)O in Water-treated ZR-SS increased by 0.06 and 0.02, respectively. This also supports the hydration of the surface of both Y-TZPs.

Surface chemical states and compositions of Hanks-treated Y-TZP

In the Hanks-treated Y-TZPs, phosphorus was detected as well as Zr, Y, O, and C. In addition, Fig. 3 shows the XPS spectra of the binding energy regions of P 2p electrons in the Hanks-treated KATANA. P in the Hanks-treated KATANA existed as PO\(_4\)^3- (133.6 eV) and H\(_2\)PO\(_4\)\(^-\) (135.9 eV), according to the P 2p binding energy\(^2\)\(^{20}\). P condition in the Hanks-treated ZR-SS is almost the same as that in the Hanks-treated KATANA. It was difficult to detect Ca in the Hanks-treated Y-TZP because the highest peak of Ca 2p (347–352 eV) is overlapped by the Zr 3p peak. However, the second highest peak of Ca 2s (440 eV) was not detected from the Hanks-treated Y-TZP. Therefore, Ca ions from Hanks’ solution were not incorporated to Y-TZP surface. In addition, other elements contained in Hanks’ solution were not detected in the Hanks-treated Y-TZPs. Therefore, only phosphate ions were incorporated into Y-TZP surface.

Relative concentrations of Zr, Y, O, and P and the proportions of O species in the Hanks-treated Y-TZP are summarized in Table 4. Concentrations of Zr and Y decreased and concentration of O increased in the Hanks-treated KATANA and ZR-SS. Incorporation of phosphate ions and hydration increased the concentration of O, while concentrations of Zr and Y relatively decreased.

![Fig. 3 XPS spectra of the P 2p electron binding energy region of KATANA immersed in Hanks’ solution for 7 days.](image)

Table 3  Relative concentrations of elements and proportions of O species on Water-treated (a)KATANA and (b) ZR-SS surfaces determined using XPS and change from Polished KATANA and ZR-SS

| (a) Water-treated KATANA | Relative concentration (at.%) | Proportion of O species | ([OH\(^-\)+H\(_2\)O])/[O\(^2\)^-] |
|--------------------------|-----------------------------|------------------------|----------------------------------|
| Zr | Y | O | O\(^2\) | OH\(^-\) | H\(_2\)O |
| Water-treated KATANA | 31.1±0.5* | 2.5±0.0 | 66.4±0.5 | 0.79±0.01 | 0.14±0.00 | 0.07±0.01 | 0.27±0.02 |
| Change from Polished KATANA | -0.9 | -0.2 | +1.1 | 0.00 | -0.01 | +0.01 | 0.00 |

*Mean±SD, n=3

| (b) Water-treated ZR-SS | Relative concentration (at.%) | Proportion of O species | ([OH\(^-\)+H\(_2\)O])/[O\(^2\)^-] |
|--------------------------|-----------------------------|------------------------|----------------------------------|
| Zr | Y | O | O\(^2\) | OH\(^-\) | H\(_2\)O |
| Water-treated ZR-SS | 30.6±0.8* | 1.7±0.1 | 67.7±0.8 | 0.73±0.03 | 0.19±0.01 | 0.08±0.02 | 0.37±0.07 |
| Change from Polished ZR-SS | -2.2 | -0.4 | +2.6 | -0.08 | +0.06 | +0.02 | +0.14 |

*Mean±SD, n=3
Valence band spectra
The XPS spectra of the valence band region (under 25 eV) from the Polished KATANA, Water-treated KATANA, and Hanks-treated KATANA are shown in Fig. 4. The valence band region spectra from all specimens are similar and broad consisting of several electron bands of hybrid orbitals of ZrO$_2$, Y$_2$O$_3$, and Al$_2$O$_3$. The valence band region spectra from the ZR-SS revealed the same results as the KATANA.

Surface changes of titanium in ultrapure water and Hanks’ solution
Ti, O, and C as a contaminant carbon were detected in Polished Ti as seen in Fig. 5a. Ti existed as all oxide states (Ti$^{4+}$, Ti$^{3+}$, and Ti$^{2+}$) and metal state (Ti$^{0}$) as shown in Fig. 5b, and O was originated from O$^{2-}$, OH$^-$, and H$_2$O (Fig. 5c). Therefore, a thin titanium oxide film existed on Ti substrate. The thickness of the oxide film was calculated as 6.1 nm. The Water-treated Ti showed the same results. In the case of the Hanks-treated Ti, Ca and P were detected in addition to Ti, O, and C as seen in Figs. 5d and e. Ca existed as a divalent calcium ion, and P existed as a phosphate ion. The binding energy of Ca 2p was 347.2 eV and that of P 2p was 133.1 eV. Therefore, Ca and P existed as calcium phosphate. The ratio [Ca]/[P]=0.85, which is much smaller than hydroxyapatite (1.67), enamel (1.62), and bone (1.65)$^{21}$. This ratio corresponds to that in a previous study (1.05)$^{22}$. The phosphate ion was initially adsorbed on Ti, and the [Ca]/[P] ratio was affected by coexisting molecules.

Relative concentrations of Ti, O, Ca, and P, the [Ca]/[P] ratios, and the proportions of Ti species ([Ti$^{4+}$]/([Ti$^{3+}$]+[Ti$^{2+}$]+[Ti$^{0}$]) ratios) and O species (([OH$^-$]+[H$_2$O])/[O$^{2-}$]) ratios of the Polished Ti, Water-treated Ti, and Hanks-treated Ti are summarized in Table 5. The relative concentration of O is larger than a stoichiometric concentration of TiO$_2$, so the surface oxide contains OH$^-$ and/or H$_2$O that is in accordance with Fig. 5c. The relative concentration of Ti decreased and that of O increased in the Water-treated Ti compared with the Polished Ti, indicating that the surface oxide film was more oxidized and/or hydrated. However, the ratio [Ti$^{4+}$]/([Ti$^{2+}$]+[Ti$^{3+}$]+[Ti$^{0}$]) was the same (0.82) in the Polished

![Fig. 4 XPS spectra of the valence band region of the Polished, Water-treated, and Hanks-treated KATANA.](image)

**Table 4** Relative concentrations of elements and proportions of O species on Hanks-treated (a)KATANA and (b) ZR-SS surfaces determined using XPS and change from Polished KATANA and ZR-SS

| (a) Hanks-treated KATANA | Relative concentration (at.%) | Proportion of O species | ([OH$^-$]+[H$_2$O])/[O$^{2-}$] |
|--------------------------|-----------------------------|-------------------------|-------------------------------|
| Zr | Y | O | P | O$^{2-}$ | OH$^-$ | H$_2$O | |
| Hanks-treated KATANA     | 28.7±0.3* | 2.4±0.0 | 66.5±0.2 | 2.4±0.3 | 0.72±0.02 | 0.19±0.01 | 0.09±0.02 | 0.39±0.03 |
| Change from polished KATANA | −3.3 | −0.3 | +1.2 | +2.4 | −0.07 | +0.04 | +0.03 | +0.12 |

*Mean±SD, n=3

| (b) Hanks-treated ZR-SS | Relative concentration (at.%) | Proportion of O species | ([OH$^-$]+[H$_2$O])/[O$^{2-}$] |
|--------------------------|-----------------------------|-------------------------|-------------------------------|
| Zr | Y | O | P | O$^{2-}$ | OH$^-$ | H$_2$O | |
| Hanks-treated ZR-SS      | 29.3±0.6 | 1.8±0.0 | 66.2±0.3 | 2.7±0.2 | 0.73±0.02 | 0.19±0.02 | 0.08±0.01 | 0.37±0.04 |
| Change from polished ZR-SS | −3.5 | −0.3 | +1.1 | +2.7 | −0.08 | +0.06 | +0.02 | +0.14 |

*Mean±SD, n=3
Fig. 5 XPS spectra of Polished Ti: (a) Wide scan, (b) Ti 2p, and (c) O 1s electron binding energy region and XPS spectra of Hanks treated Ti: (d) Ca 2p and (e) P 2p electron binding energy region.

Table 5 Relative concentrations of elements, [Ca]/[P] ratios, proportions of Ti species, [Ti<sup>4+</sup>]/([Ti<sup>2+</sup>]+[Ti<sup>3+</sup>]+[Ti<sup>4+</sup>]) ratios, and proportions of O species, ([OH<sup>-</sup>]+[H<sub>2</sub>O])/[O<sup>2-</sup>] ratios on Ti determined using XPS

| Specimen            | Relative concentration (at.%) | [Ca]/[P] | Thickness of surface oxide film (nm) |
|---------------------|-------------------------------|----------|-------------------------------------|
| Specimen            | Ti   | Ca   | O   | P   |       |          |
| Polished Ti         | 32.9±0.8* | 0.0±0.0 | 67.1±0.8 | 0.0±0.0 | —      | 6.1±0.2  |
| Water-treated Ti    | 17.7±2.6 | 0.0±0.0 | 82.3±2.6 | 0.0±0.0 | —      | 6.7±0.2  |
| Hanks-treated Ti    | 29.9±1.3 | 1.5±0.2 | 67.0±1.6 | 1.7±0.2 | 0.85±0.02 | 6.1±0.3  |

| Specimen            | Proportion of Ti species | [Ti<sup>4+</sup>]/([Ti<sup>2+</sup>]+[Ti<sup>3+</sup>]+[Ti<sup>4+</sup>]) |
|---------------------|--------------------------|---------------------------------|
| Specimen            | Ti   | Ti<sup>2+</sup>| Ti<sup>3+</sup>| Ti<sup>4+</sup> |       |
| Polished Ti         | 0.06±0.01 | 0.05±0.01 | 0.12±0.00 | 0.77±0.01 | 0.82±0.01 |
| Water-treated Ti    | 0.06±0.01 | 0.05±0.00 | 0.12±0.01 | 0.77±0.01 | 0.82±0.01 |
| Hanks-treated Ti    | 0.07±0.01 | 0.05±0.01 | 0.12±0.01 | 0.76±0.01 | 0.82±0.01 |

| Specimen            | Proportion of O species | ([OH<sup>-</sup>]+[H<sub>2</sub>O])/[O<sup>2-</sup>] |
|---------------------|-------------------------|---------------------------------|
| Specimen            | O<sup>2-</sup> | OH<sup>-</sup> | H<sub>2</sub>O |       |
| Polished Ti         | 0.76±0.02 | 0.13±0.02 | 0.11±0.01 | 0.31±0.04 |
| Water-treated Ti    | 0.35±0.09 | 0.32±0.07 | 0.33±0.02 | 1.99±0.79 |
| Hanks-treated Ti    | 0.74±0.05 | 0.13±0.00 | 0.13±0.05 | 0.35±0.09 |

*Mean±SD, n=3

Ti, Water-treated Ti, and Hanks-treated Ti. Therefore, the surface oxide was not further oxidized. On the other hand, the ratio ([OH<sup>-</sup>]+[H<sub>2</sub>O])/[O<sup>2-</sup>] increased from 0.31 to 1.99 for Water-treated Ti and to 0.35 for Hanks-treated Ti. Thus, the surface oxide was hydrated. Ca and P were detected in the Hanks-treated Ti as 1.5 and 1.7.
in the tissues may have reacted with the phosphate factor in protein reactions, some important proteins in vivo: as phosphate ions are well-known as an important site of bone formation on the Ti surface. The affinity of phosphate ions to Zr originates from the different amounts of Y composition as shown in Table 4. The difference of reactions may be difference of the sintering temperature may affect the attachment of tissue to Y-TZP is regulated by the reaction of the Y-TZP surfaces with the surrounding tissues and body fluids. In this study, we characterized the Y-TZP surfaces by immersing them into physiological solutions. KATANA was more stable in ultrapure water, compared to ZR-SS, as shown by the deviations from Polished Y-TZP in Table 3. On the other hand, KATANA and ZR-SS showed similar changes in Hanks’ solution as shown in Table 4. The difference of reactions may be originated from the different amounts of Y composition shown in Table 2. In addition, the grain size of Y-TZP by immersion in the ultrapure water or Hanks’ solution remained broad mixed by valence orbits of ZrO226,27). The obtained spectra of all the specimens were typical for the Y-TZP tetragonal phase and not the YSZ monoclinic phase25). This indicates that the transformation into the monoclinic phase does not occur in the early stages of the reaction, although it has been reported that 20% of the tetragonal phase of Y-TZP transforms into the monoclinic phase in 37°C water in 25 years28), and the amount of oxygen in Y-TZP changes the valence band26,29). In this study, we revealed that the crystalline phase of Y-TZP remains the same during the initial stage of reaction in a physiological environment, during which the hydration and phosphate incorporation occurred on the surface of Y-TZP. Hence, the reactivity of the Y-TZP surface may play an important role for tissue adhesion in human body. Such results were also demonstrated in single crystalline yttria-stabilized zirconia10). Based on the findings in Y-TZP reactivity to the water molecules and electrolytes in Hanks’ solution, further studies are required for cell activities.

**Difference between Y-TZP and Ti**
We compared the surface compositions and chemical states between Y-TZP and Ti. Regarding the relative concentrations of O, the Polished KATANA (65.3 at.%) and Polished ZR-SS (65.1 at.%) (Table 2) had slightly smaller concentration than the Polished Ti (67.1 at.%). In other words, Ti was more hydrated than Y-TZP. These results mean that the Y-TZP surfaces are less reactive to water molecules than Ti surface. OH− on Water-treated Y-TZP was decomposed from the O spectra, while that on Water-treated Ti was impossible to decompose because of the large amount of H2O. The ratios ([OH−]+[H2O])/[O2−] of Water-treated Y-TZPs (0.27 for KATANA, 0.37 for ZR-SS, shown in Table 3) were smaller than that of Water-treated Ti.
Another difference between Y-TZP and Ti was in the incorporation of Ca. Ca was not detected in the Hanks-treated Y-TZP using XPS, while it was detected in the Hanks-treated Ti. The surface oxide film on Ti is not completely oxidized and is relatively reactive. On the other hand, the surface oxide film on Zr is more passive and protective than that on Ti. Neither Ca nor phosphate stably exist alone on Ti; calcium phosphate is naturally formed on it. Calcium phosphate formed on Ti is stable and protective. On the other hand, Ca is never incorporated on Zr, while zirconium phosphate, which is stable and protective. On the other hand, Ca is never incorporated on Zr, while zirconium phosphate, which is easily formed on Zr, is highly stable and protective. Therefore, Y-TZP showed a similar property to metallic Zr. While there was no change in the valence band of Y-TZP, that of Ti changed as shown in Fig. 6, which also indicated the lower surface reactivity of Y-TZP to water and Hanks’ solution.

CONCLUSIONS

To elucidate the mechanism of adhesion of soft and hard tissues to Y-TZP in spite of its chemical inertness, two commercial Y-TZPs (KATANA and ZR-SS) were immersed in water and Hanks’ solution, and the surfaces were characterized using XPS. The reaction of Y-TZP with water molecules increased the hydroxyl groups on the surface. In addition, phosphate ions were incorporated into the Y-TZP surface through immersion in Hanks’ solution. The hydroxyl groups and phosphate ions possibly enhance the adsorption of protein on Y-TZP, which can promote reaction with the surrounding tissues. On the other hand, Ti was also hydrated in water; however, calcium phosphate formed on it. Therefore, the reactivity of Y-TZP with electrolytes was smaller than that of Ti.

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