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Future Prospects of Zr-14nb Alloy as a Next-Generation Dental Prosthesis Material

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Various materials such as metals, ceramics, and polymers have been used for dental prosthesis. Although metals cannot replicate the color of teeth, they are widely used in metal-ceramic restorations because of their elasticity and fracture toughness, particularly in implant-supported fixed prosthesis and long-span bridges [1-3]. Recently, noble alloys have gradually been replaced by base metal alloys such as Ti and Co-Cr alloys owing to the increasing price of gold and palladium [4-7]. However, when these base alloys are placed in the mouth, they often inhibit the diagnosis of magnetic resonance imaging (MRI) because of their high magnetic susceptibility [8-12].

MRI is widely used as an important diagnostic tool because it has remarkable diagnostic advantages in high degrees of image resolution without invasive X-ray irradiation [13]. However, metals with high magnetic susceptibility become magnetized when exposed to the high static magnetic field of an MRI machine, which induced field inhomogeneity, causing an artifact that distorts the images around metal devices [8-10]. In addition, there has been a growing interest in the use of high field strengths (3 T and higher) in MRI to increase the diagnostic yield. Consequently, there is a possibility that artifact problems may become more serious, as MRI artifacts increase on increasing the magnetic field strength [14-15]. Therefore, we are anticipating the development of new materials that meet the criteria for being a biomaterial, in terms of mechanical properties, biocompatibility, and low magnetic susceptibility.

The Zr-Nb alloy has attracted much attention as a surgical implant in orthopedics [16-19]. Zr belongs to the same group as Ti. It exhibits high biocompatibility and excellent mechanical properties, almost the same as those of Ti [20-21]. Nb is also nontoxic, biocompatible, and a major alloying element for Zr [22]. The mechanical properties of Zr-Nb alloys, their biocompatibility, and their magnetic susceptibility vary depending on their Nb concentration, and the Zr-14Nb alloy, which is an example of a Zr-Nb alloy, exhibits an optimum balance between mechanical properties and magnetic susceptibility [23-25]. We evaluated the possibility of Zr-14Nb being used as a dental prosthesis alloy and reported that the 0.2% proof strength and ultimate tensile strength of the Zr-14Nb alloy are comparable to those of the Co-Cr alloy with an elongation greater than that of a Co-Cr alloy. Moreover, the castability of the Zr-14Nb alloy is comparable to that of the Ti-alloy, and the magnetic susceptibility of the Zr-14Nb alloy is about one-fifth that of the Co-Cr alloy and half of that of Ti and Ti alloys [23-26].

In our latest study [27], we focus on using the Zr-14Nb alloy in metal-ceramic fixed partial dentures and evaluate the shear bond strength between the Zr-14Nb alloy and porcelain. In general, the presence of an oxide layer on the surface of alloys has been considered crucial to achieving a considerably strong metal-ceramic bond. However, the Zr-14Nb alloy reportedly has a high reactivity with oxygen, and forms a very thick oxide layer upon reaction [25,26]. Thus, in order to clarify the optimum preheat treatment condition, four different pre-heat treatments were performed at 700 C° (control, heating for 5 min, 10 min, and 20 min). Then, porcelain was veneered on the specimens, and then their shear bond strengths were evaluated. The results showed that the oxide layer of the specimen heated for 20 min was brittle and easily delaminated from the Zr-14Nb alloy substrate, making its shear bond strength insufficient for clinical use. However, the shear bond strengths of the specimens heated for 5 and 10 min were significantly higher than that of Ti, which is conventionally used as a dental material for implant-supported fixed prosthesis. The specimens subjected to 5 and 10 min of pre-heat treatment promote Nb diffusion to the porcelain side, which may contribute to chemical bonding. In addition, the oxide layer has a rough surface, which may contribute to mechanical interlocking. However, the oxidation kinetics of the Zr–Nb alloy followed a parabolic trend at high temperatures; the early stages of the heat treatment – i.e., within the first 5 min – strongly affect oxidation [28]. As it is possible to obtain more appropriate pre-oxidation conditions in the first 5 min of the treatment process, further investigations are required to determine the optimal oxidation settings.

The difference in the coefficients of thermal expansion (CTE) of metal and porcelain is very important factor, and the alloy should have a higher CTE than porcelain (but the difference should be less than 1×10^{-6}/°C) in order to produce an effective compressive stress in porcelain [29,30]. The commercially used dental alloys have porcelain that has a suitable CTE; however, the CTE of the Zr-14Nb alloy is lower than that of commercial dental alloys [27]. Thus, no porcelain is compatible with the Zr-14Nb alloy. If new dental porcelain is developed, which has an optimized CTE that provides a better compatibility with Zr-14Nb, the shear bond strength between Zr-14Nb and porcelain will possibly improve further.

Further evaluations, such as the precision of fit and grindability, are still necessary in order to use the Zr-14Nb alloy in dental prosthesis materials in the future. However, the Zr-14Nb alloys exhibit remarkable properties because of their excellent biocompatibility, mechanical properties, and low magnetic susceptibility. Thus, the alloy has good prospects of being a next-generation dental prosthesis material.

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