Review

Boron and orthopedic implants: A review of the literature

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ABSTRACT

A material created to interact with biological systems to enhance, treat or modify a tissue, organ, or body function is called a biomaterial. Sutures, dental fillings, needles, catheters, bone plates, and orthopedic implants are the most commonly used medical biomaterials. With the increasing use of orthopedic implants worldwide, there remains significant interest in developing new technologies to improve the effective clinical performance of contemporary treatment modalities and devices. Biomaterials used in orthopedics often require revision due to problems such as wear, corrosion, and infection. These revisions have become a significant burden for the patient and the healthcare system. Boron, with its unique properties, is an element that has the potential to overcome these problems. Therefore, in recent years, the importance of boron elements in the health field as well as in the industrial field has been noticed, making the use of boron in medicine very popular

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Introduction

Technology is advancing quickly today, affecting human life in many ways. The advancement of technology in the world of health has led to new initiatives for illness prevention, earlier diagnosis and treatment for patients, and an increase in successful treatment outcomes. In response to lowering death rates (World Health Organisation [WHO], 2020) and initiatives to enhance health care, life expectancy and reasonable life expectancy have grown. A longer average lifespan is linked to a rise in the variety and prevalence of age-related diseases and disorders. Increasing traffic accidents, sedentary lifestyle prevalence, unhealthy diet, a propensity for obesity, the loss of natural areas, increased radiation exposure, and so on are just a few of the causes of other diseases. Of course, this increase cannot be explained solely by extending life expectancy. These lead to a rise in musculoskeletal system problems across the board. When treating musculoskeletal conditions, orthopedic surgeons use a specific type of biomaterial. A material produced to interact with biological systems to develop, treat, or replace a tissue, organ, or bodily function is known as a biomaterial. Sutures, dental fillings, needles,

catheters, bone plates, and orthopedic implants are the most frequently used medical devices.

Although biomaterials science is relatively new, its applications date back to the first medical concerns in human history. According to research, implants, prostheses, and their use in the body have a history of more than 7000 years (Almasry, 2019). In Egyptian mummies, artificial eyes, noses, and teeth have been discovered. Gold has been used in dentistry since 2000 B.C. Since the middle of the 19th century, in-body implants have become more popular. Ivory prostheses were first inserted inside the body in 1880. In 1938, the first metal prosthetic vitalium was created. Numerous biomaterials were employed, including artificial sutures, hip prostheses, and blood vessel replacement, in the 1950s, 1960s, and 1970s, respectively. The first artificial heart was created in 1976. The use of implants has undoubtedly increased due to advancements in anesthesia, X-ray discovery, and sterile surgical techniques. Figure 1 shows the general use of biomaterials in the human body (Ak 2020).

There is still much interest in developing new technologies to enhance the clinical performance of modern treatment modalities and devices, especially given the growing use of orthopedic implants globally. Applying antibacterial coatings to the implant surfaces, boronizing titanium alloy to improve its mechanical properties and biocompatibility, increasing the osteogenic differentiation of mesenchymal stem cells with boron-containing nanohydroxyapatite composites, and coating titanium with nanobiphasic calcium-phosphate and hydroxyapatite to improve corrosion resistance are some examples. Only a few of the most recent studies on the biomaterials industry in this field have been found (Fathi et al., 2020).

Boron is a necessary element for life. Humans have used it since the beginning of time and are involved in many biological processes. The importance of boron, which is difficult or nearly impossible to collect in a single substance, is growing every day in the health field. In the area of business, "The unique properties of boron, which is referred to as "the oil of the 21st century" and "white gold," are studied in a variety of biomaterials. Boron is currently the subject of numerous studies.

Failure to perform the intended function of an implant (to support or replace) in the body is known as implant failure. The long-term success of the implant is mainly dependent on biocompatibility, osseointegration, corrosion resistance, wear resistance, and other mechanical properties of the biomaterials. Other significant risk factors for implant failure include infection, trauma, and pathological fractures. Materials like titanium, cobalt chromium, ceramic, aluminum, and stainless steel that have been used extensively in implant construction up until now fail due to complications like wear, loosening, mechanical failure, and infection. Therefore, the search has begun in biomaterials for a biomaterial like boron that can readily adapt to the human body and reduce the difficulties we mention (Fathi et al., 2020). In this section, we aimed to describe the elements of boron, its significance for human health, the areas in which it is used as a biomaterial, and its potential uses. We also reviewed the issues that arise after the use of orthopedic implants.

Methods

Definition and properties of boron

An element at the start of the third group of the periodic system is boron (B), which has the following properties: atomic number 5, atomic weight 10.81 g/mol, density 2.84 g/cm3, hardness 9.3 Mohs, melting point 2300 ºC, and semiconductor properties between metal and nonmetal. It has two stable isotopes, with masses of 10 and 11. In nature, boron minerals come in about 250 different varieties. In nature, it is found in the form of B_2O_3 along with the oxides of other elements; it is not found free. Compounds with metal boron and oxygen are

known as borates. Figure 2 shows some boron minerals (Figure 2) (Fieldnotes 2022).

Given their wide range of applications, boron minerals are arguably the most fascinating minerals in the world. Since the dawn of civilization, people have been aware of its various advantages and applications. The USA comes in second with 6.7% of the world's reserves, trailing Turkey with 72.1% (Sarı et al., 2021). Boron is found in the air, soil, and water in small amounts. It has received extensive research in numerous biochemical studies on the metabolism of plants, people, and animals. According to studies, this trace element can impact how proteins, amino acids, triglycerides, glucose, and estrogenic compounds are metabolized. Because it contributes to strengthening the cell membrane, boron is necessary for growth (Deliboran 2020).

Although boron intake with food and water varies depending on geographical conditions and dietary characteristics, it is reported that there is a total daily intake of 1-7 mg of boron. The World Health Organization initially determined the safe upper intake level as 13 mg/day. However, then they increased it and determined it to be 0.4 mg/kg or about 28 mg/day boron for a 70 kg person. According to The Dietary Supplement Label Database of the United States, boron is present in 2357 different food supplements (Söğüt et al., 2020). Boron can enter the human body through the mouth, the respiratory tract, and the skin. About 85-90% of the boron entering the body is excreted unchanged in the first 24 hours through urine (Rüya et al., 2017). Boron, taken into human and animal bodies naturally, is not in amounts that can cause acute poisoning.

Borates have also revealed their effects as anti-inflammatory and antioxidant agents in cancer, immunological functions, wound healing, disease control, reducing genotoxicity, and modulating mitochondrial membrane activity. An antineoplastic drug called ‘’bortezomib’’, a boric acid analog is used to treat multiple myeloma caused by plasmacytomas in the bone marrow (Dicleli et al., 2022).

Result and Discussion

Boron’s role in the world of biomaterials

Since the beginning of time, nature and humanity have been intertwined, and man has created many tools by copying nature. Material science has been the most critical factor in developing these inventions. Finding new materials has become necessary due to recent technological advancements, which have increased the importance of materials science (Akkurt et al., 2019). With the development of mechanics, studies to find biomaterials appropriate for bone's unique mechanical properties were also initiated. The surface of the implants, which is in constant contact with the body, is a great candidate for a surface coating. Boron-containing coatings enable the creation of antibacterial surfaces, wear-resistant surfaces with low friction, and surfaces that resist corrosion and oxidation. Materials close to the desired Young's modulus can be synthesized while the boron-containing material is being created in the lab. Because it lowers the coefficient of friction, boron nitride is a common material used in surface coating (Hernandez et al., 2014; Falin et al., 2017; Joy et al., 2020).

The steel becomes stronger and harder after boron is added. Up to 50 ppm of boron can be observed in steel. Additionally, stainless steels contain boron. High corrosion and wear resistance is a property of boronized steels. Additionally, it improves the steel's impact toughness and extensibility (Ghali et al., 2012; Tenmak et al., 2022). The production of wastes that are harmful to human and environmental health is not brought on by boron compounds. In reality, liquid waste generated during the production of boron is used to make lithium batteries. Many modern machines, including electric cars, autonomous robots, and electronic devices, use lithium batteries (Şensöz et al., 2021).

There is an increasing number of studies in the literature on the element boron: In a study conducted in Turkey, the surface coating materials of drills used in dental implant surgery were examined and the surface coating was found to be Boron Nitride, which caused no bone necrosis with minimal heat damage during drilling among seven groups. The black diamond and zirconium groups available in the market were determined as the groups with the highest temperature increase (Er 2012). In this study, strontium borate glass was demonstrated to be a "next-generation biomaterial" and to stimulate the growth of new bone (Pan 2010). Treatment of osteosarcoma with boron neutron capture therapy is effective (Bortulossi et al., 2020). A 54-year-old woman was treated with boron neutron capture therapy for clear cell sarcoma in her foot, and the tumor tissue vanished entirely without causing any damage to the surrounding tissue (Fujimoto et al., 2020). According to a study done in our country and published in 2020, cubic boron nitride coating, intramedullary implants offer superior fracture healing properties and may reduce the union time (Özmeriç et al., 2019).

A 2019 study found that adding boron to the Cobalt-Chromium-Molybdenum (Co-Cr-Mo) alloy, frequently used to make prostheses, increased its wear and corrosion resistance (Xie et al., 2009; Özmeriç et al., 2019; Hernandez et al., 2019). The treatment of osteomyelitis and bone defects is successful with vancomycin-releasing bioactive borate glass (Gonzales et al., 2022). In a study carried out in our nation, the Ti6Al4V alloy underwent the boriding process, which increased its hardness by 8.5 times, its resistance to wear in synthetic body fluid by 36 times, and its resistance to corrosion by 1.2 to 5 times. Additionally, it was mentioned that tests using intradermal irritation with boronized titanium samples revealed no toxic effects (Kaplan 2917).

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Conclusion

Post-implant wear, corrosion, and mechanical failure are the most common causes of implant failure. Boron-containing biomaterials seem to be more resistant to these problems. Implant infection is one of the leading causes of amputation and even patient death. Drug resistance can increase 100-1000 times when bacteria form a biofilm. This resistance complicates the treatment. Despite the increasing resistance rates, the number of new antimicrobial compounds synthesized is very low. In recent years, "boron-containing bioactive compounds," candidates to be defined as a new drug class, are noteworthy. These compounds are candidates to be one of the molecular weapons we can apply to human health in the current and near future when anti-microbial resistance is alarming.

Authors Contributions

The author carries out tasks from data collection, data analysis, making discussions to making manuscripts

Conflicts of Interest

All research teams agree with the final results of this study, and there is no conflict of interest in this study.

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References

WHO, A. (2020). WHO Methods and Data Sources for Life Tables 1990–2019.

Almasry, M. G. *ORTOPEDİK İMPLANTLARIN HASTA VÜCUDUNA BIRAKTIĞI ATIKLAR VE ALERJİK ETKİLERİ* (Master's thesis, Fen Bilimleri Enstitüsü).

AK D. (February 23, 2020). Biyomalzeme nedir? Medium https://medium.com/@denizak/biyomalzeme-nedir-a3138e2869f6 (Accessed:2.10.2022).

Fathi, A. M., Mandour, H. S., & Abd El-Hamid, H. K. (2020). Corrosion protection of nano-biphasic calcium phosphate coating on titanium substrate. *Current Nanoscience*, *16*(5), 779-792.

https://fieldnotes.nationalgeographic.org/expedition/mars (Accessed: 03.10.2022)

SARI, E. N., & SOYSAL, Y. Bor Elementi ve Biyolojik Sistemlere Etkisi. *Tıp Fakültesi Klinikleri Dergisi*, *4*(2), 57-65.

DELİBORAN, A. (2020). NEDEN BOR? BORUN ÇEVRE İLE İNSAN, HAYVAN VE BİTKİ SAĞLIĞI AÇISINDAN ÖNEMİ. *Bahçe*, *49*(2), 127-141.

Söğüt, Ö., & Acar, O. (2020). Bor ve sağlık. *Literatür Eczacılık Bilimleri Dergisi*, *9*(1), 11-7.

Rüya, K. U. R. U., & Yarat, A. (2017). Bor ve sağlığımıza olan etkilerine güncel bir bakış. *Clinical and Experimental Health Sciences*, *7*(3), 107-114.

Dicleli, M., Alabalık, U., Bıçak, T., Yıldız, G., Sertakan, H., & Nacir, M. (2022). Plasmacytoma: A Rare Case of Bone Malignancy. *Journal of Clinical Trials and Experimental Investigations*, *1*(1 (March-June)), 17-21.

Akkurt, F., Kalender, E., & Yörükoğlu, A. (2019). Üstün özelliklere sahip ileri teknoloji seramiği: Titanyum diborür. *Journal of Boron*, *4*(4), 203-208.

Joy, J., George, E., Haritha, P., Thomas, S., & Anas, S. (2020). An overview of boron nitride based polymer nanocomposites. *Journal of Polymer Science*, *58*(22), 3115-3141.

Falin, A., Cai, Q., Santos, E. J., Scullion, D., Qian, D., Zhang, R., ... & Li, L. H. (2017). Mechanical properties of atomically thin boron nitride and the role of interlayer interactions. *Nature communications*, *8*(1), 1-9.

Hernandez-Sanchez, E., Domínguez-Galicia, Y. M., Orozco-Álvarez, C., Carrera-Espinoza, R., Herrera-Hernández, H., & Velázquez, J. C. (2014). A study on the effect of the boron potential on the mechanical properties of the borided layers obtained by boron diffusion at the surface of AISI 316L steel. *Advances in Materials Science and Engineering*, *2014*.

Tenmak Boren Bor Araştırma Enstitüsü (b.t.). Borlu alaşımlar. T.C. Enerji ve Tabii Kaynaklar Bakanlığı. https://boren.tenmak.gov.tr/tr/calisma alanlari/arastirma-alanlari/borlu-alasimlar.html (Accessed:24.09.2022).

Ghali, S. N., El-Faramawy, H. S., & Eissa, M. M. (2012). Influence of boron additions on mechanical properties of carbon steel. *Journal of Minerals and Materials Characterization and Engineering*, *11*(10), 995-999.

ŞENSÖZ, H., SAYIN, Z. E., SAVAŞ, M., & ERDOĞAN, Y. Emet Bor Üretim Tesisleri Atıklarının Lityum İçeriğinin İncelenmesi. *Afyon Kocatepe Üniversitesi Fen Ve Mühendislik Bilimleri Dergisi*, *21*(6), 1460-1469.

Er N. (2012). Farklı yüzey özelliklerine sahip dental implant drillerinin kemikte oluşturdukları ısınma etkilerinin değerlendirilmesi. Erciyes Üniversity.

Pan, H. B., Zhao, X. L., Zhang, X., Zhang, K. B., Li, L. C., Li, Z. Y., ... & Chang, J. (2010). Strontium borate glass: potential biomaterial for bone regeneration. *Journal of the Royal Society Interface*, *7*(48), 1025-1031.

Bortolussi, S., Postuma, I., Protti, N., Provenzano, L., Ferrari, C., Cansolino, L., ... & González, S. J. (2017). Understanding the potentiality

of accelerator based-boron neutron capture therapy for osteosarcoma: dosimetry assessment based on the reported clinical experience. *Radiation Oncology*, *12*(1), 1-12.

Fujimoto, T., Suzuki, M., Sudo, T., Fujita, I., Sakuma, T., Sakurai, Y., ... & Akisue, T. (2020). Boron neutron capture therapy for clear cell sarcoma. *Applied Radiation and Isotopes*, *166*, 109324.

Özmeriç, A., Tanoğlu, O., Ocak, M., Çelik, H. H., Fırat, A., Kaymaz, F. F., ... & Kaftanoğlu, B. (2020). Intramedullary implants coated with cubic boron nitride enhance bone fracture healing in a rat model. *Journal of Trace Elements in Medicine and Biology*, *62*, 126599.

Hernandez-Rodriguez, M. A., Laverde-Cataño, D. A., Lozano, D., Martinez-Cazares, G., & Bedolla-Gil, Y. (2019). Influence of boron addition on the microstructure and the corrosion resistance of CoCrMo alloy. *Metals*, *9*(3), 307.

Xie, Z., Liu, X., Jia, W., Zhang, C., Huang, W., & Wang, J. (2009). Treatment of osteomyelitis and repair of bone defect by degradable bioactive borate glass releasing vancomycin. *Journal of Controlled Release*, *139*(2), 118-126.

Gonzalez-Chapa, J. A., Peña-Martinez, V. M., Gonzalez, G. M., Vílchez-Cavazos, J. F., Treviño-Rangel, R. J., Salinas-Carmona, M. C., & Rosas-Taraco, A. G. (2022). Glucose and leukocyte esterase levels are possible biomarkers for bacterial septic arthritis. *Cirugía y cirujanos*, *90*(3), 319-331.

Kaplan, Y. (2017). İmplant yapımında kullanılan Ti6Al4V titanyum alaşımının mekanik özelliklerine ve biyouyumluluğuna borlama işleminin etkisi.