Review On Dental Implants Affected by Different Lesions and Effect of Using Newer Alloys with Different Mechanical Properties

Anurag Bharti[1], Dr. Faiz Akram[2], Arpita[3], Vishal Kumar[4], Abhay Kumar[5], Shafaque Aziz[6], Dr Shamshad Ahmad[7], Mohd Zia Hussain[8]

[1]*M. Tech, Mansarovar Global University, Bhopal*

[2]*PhD Jamia Millia Islamia, New Delhi*

[3]*Faculty of Mechanical Engineering, Government Engineering College, Samastipur*

[4]*Faculty of Mechanical Engineering, Darbhanga college of Engineering, Darbhanga*

[5,7,8]*Faculty of Civil Engineering, Government Engineering College, Samastipur*

[6]*Faculty of Computer Science Engineering, Government Engineering College, Samastipur*

***Abstract*—Because they are both durable and suitable for the body, dental implants are now the usual option for replacing missing teeth. Still, peri-implantitis, mucositis and resorption of bone are some of the possible causes of implant failure. The article reviews ways that various oral lesions can affect denture implants and assesses how recent alloy inventions can help treat these complications. Regular titanium alloys are widely applied, though they have problems with bacterial growth and stress corrosion. Zirconia-based ceramics, alloys of titanium and zirconium and shape-memory alloys are under study to determine if they have the right strength, are biocompatible and reduce inflammation. The information discussed here consists of recent advances on implant-lesion interactions and covers how the development of implant materials can help patients and increase implant durability.**

***Index Terms*—Dental implants, peri-implantitis, implant lesions, titanium alloys, zirconia, shape-memory alloys, biocompatibility, mechanical properties.**

I. INTRODUCTION

Dental implants have greatly improved how lost teeth can be replaced and a person's oral health and appearance can be restored. Over the years, dental implants have become the usual choice for both fixing one tooth or performing full-mouth reconstructions. Still, even with great success, some biological complications can weaken the long-term results of dental implants, mainly peri-implant lesions. Distinctive health problems for dental implants are peri-implantitis, peri-implant mucositis and increased bone loss at the implant site which might cause implant failure. So, recognizing how implant materials relate to pathological lesions is key to enhancing how implant treatment performs in people [14-15].

A major concern in implantology is peri-implantitis which is an ongoing inflammatory disease that damages the supporting bone surrounding a dental implant. Both have the same microbes, but periodontitis is much more destructive when not treated. Some experts estimate that about 20% of patients are affected by peri-implantitis and peri-implantitis occurs in almost half of all implant sites. Continued inflammation causes the bone surrounding the implant to shrink which may result in the implant loosening up and failing. However, peri-implant mucositis only spreads to the nearby soft tissue and can be handled to return the mouth to health. It can still happen before peri-implantitis and show that there are problems inside the tissues.

How dental implants are made decides the way they interact with tissues in the mouth. Commercially pure titanium (cpTi) and Ti-6Al-4V have been leading materials because they are strong, resistant to corrosion and generally well-tolerated in the body. Being able to bond with bone tissue has turned them into the main choice for implants in dentistry. These materials do face some problems, though. Titanium is easily exposed to corrosion in the mouth, mostly as a result of bacteria and inflammation making the environment more acidic. In patients with thin gums, the metallic look of titanium can be unpleasant to look at [2-5].

As well as being concerned with how they look and physical damage, titanium-based implants also struggle with their mechanical performance. Due to the greater elasticity of titanium, it is possible for an implant to create less stress on surrounding bone which might cause bone breakdown. Bacteria can build up in these microgaps which can worsen the body's response and lead to lesion growth. Because of these drawbacks, scientists are working on creating new types of materials that better imitate the physical and living properties of body tissues.

Because of these issues, researchers are now using new alloys and ceramic materials for dental implants. Titanium-zirconium (Ti-Zr) alloys increase both the strength and corrosion resistance of the implant and improve how the implant interacts with the body. Zirconia implants because they are ceramic appear very attractive, work well with the human body and do not easily allow bacteria to colonize. Beyond this, orthodontists are investigating nickel-titanium (NiTi) alloys for their ability to distribute loads more evenly, lessen bone reabsorption and avoid relapse [12].

Researchers have also added surface changes to materials to help the attachment of bone and reduce bacterial attachment. Improving how implants work in the body's hostile environment has shown promise with acid-etching, sandblasting, plasma spraying and using substances such as silver nanoparticles and antimicrobial peptides. When applied to novel alloys such surface changes may improve their resistance to wear and improve their lifespan in the mouth.

Interactions between systemic conditions and the success of dental implants is an important factor as well. Diabetes, osteoporosis and smoking raise a person's risk for developing peri-implant lesions. That is why implants for these patients need to be strong and flexible and adapt well to their bodies. Lately, newer alloys have proved their ability to integrate better in bones that are not in perfect condition.

Since there are limits to how well traditional titanium implants root in lesion-prone environments, scientists have looked for better materials to use instead. Overcoming these problems depends on using new alloys and advanced surfaces. It attempts to study different dental implant lesions and how modern, robust and biological materials can greatly benefit their outcomes [11].

Novelty and Contribution

It adds a number of new ideas to dental implantology by uniting studies on pathological lesions with the development of new implant materials. This research is different from others because it addresses both the materials of the implants and the conditions they may face during peri-implantitis, mucositis and loss of bone around the implant.

The main distinction is found in comparing classic titanium implants with new alloys such as Ti-Zr, zirconia and NiTi, mainly by looking at their behavior in the presence of pathological infections in the mouth. It shows how mechanical strength, corrosion behavior and modulus characteristics affect the body's reaction to medical implants [10].

Furthermore, the review highlights because using modified surfaces and new alloys together can make implants capable of resisting bacteria, reducing swelling and boosting bone integration. With this method, doctors and researchers have useful suggestions for creating implants that match the needs of patients at risk.

The review suggests a new way to judge implant performance by evaluating how well machines and biological systems fit together. Thus, it lays out a path for future research and inventions in dental biomaterials directed at protecting against lesions and guaranteeing long-term results in care [6].

II. RELATED WORKS

Many fields, like material science, oral pathology, biomechanics and clinical dentistry, have closely studied dental implants for a long time. Many resources have focused over time on studying how peri- implant tissues react and the mechanical responses of various implant materials. In many recent writings, it is said that inflammatory problems can affect how secure implants are and how new materials may help address these issues.

In 2022 F. Di Spirito *et al.*, [16] introduced the Peri-implant lesions were studied and it was found that biofilms trigger inflammation that damages tissues and results in implant failure. Usually, peri-implant mucositis is easily treated, whereas peri-implantitis which happens if the mucositis is not addressed, causes hard-to-halt bone loss. Peri-implant diseases are common in those with implants which shows that more action is needed to prevent them. Such changes are focused on better implant surfaces and substances that avoid the growth of bacteria and decrease the possibility of hurting the gums.

Attention is increasing about how traditional implant materials may not be the same as human bone from a biomechanical standpoint. Even though titanium is commonly used, it has a much stronger modulus of elasticity than cortical bone. Because of this issue, stress shielding often results and bone tissue around the implant starts to disappear. It has been discovered that stress is distributed differently around implants in different situations involving loading and bone density which means choosing the right materials matters for load support and bone health.

Newer alloys are now appearing as alternatives for traditional titanium. Mechanical strength and corrosion resistance can be found in alloys such as titanium-zirconium (Ti-Zr) and nickel-titanium (NiTi), so they are well suited for patients with severe illnesses or greater demands on their body parts. Where there are problems with usual implants due to inflammation or insufficient bone, these materials tend to be the most appealing.

In 2021 S. Kligman *et al.*, [13] suggested the difficulty found in integrating tissue from animals and from laboratory tests has motivated scientists to examine how different tissues connect with the surrounding area. It has been seen that roughness, the ability to be wet and the chemical structure of an implant can impact adhesion by osteoblasts and the development of a bone–implant interface. Sandblasting, acid etching and anodization are used to increase the surface energy and support early osseointegration. Also, scientists are looking at antibacterial coatings and nanoparticles to prevent bacteria from adhering and forming biofilms on heart valves which may help lower the chance of lesion creation.

Apart from surface modifications, scientists have looked at how different alloys in implants can influence living tissues. Titanium-zirconium alloys exhibit less cytotoxicity and help cells replicate faster than nickel-titanium alloys do in vitro experiments, yet nickel-titanium alloys exhibit elasticity and special shape that resembles natural tissue. These materials also resist corrosion well, even in acidic and oxidative situations which are usual in chronic inflammation.

There has also been a lot of examination into zirconia's effectiveness in treating patients compared to other ceramic options. Zirconia looks good and also does not build up plaque, so it is often used in the front teeth and for people who care a lot about their appearance. But due to zirconia being highly brittle and sensitive to flaws, it has less long-term dependability with repeated use. Today's research is aimed at making it more fracture-resistant by using stabilizers and mixes with other materials which helps it serve more patients.

Further studies have pointed out that some conditions in the system can play a role in implant problems. In diabetic and osteoporotic tests, it was noticed that the healing process takes longer and bone density around implants is less which indicates that these materials must be stronger and more compatible with the body. Improved results in host environments are seen with modern implants and new surfaces which means each patient may require personally tailored materials.

In 2022 S. Saha et.al. and S. Roy et.al. [1] proposed the research studies agree that mechanical strength, surface chemistry and corrosion resistance of implant material are very important for lasting results. There has been a recent move in studies to join together materials engineering, microbiology and insights from clinical practice to deal with the issues of peri-implant lesions. These changes in science are what support this review which aims to discuss and explain the effects that new alloys have on dental implants affected by lesions.

III. PROPOSED METHODOLOGY

This study proposes a comprehensive approach to evaluate the effects of different lesions on dental implants and to analyze the performance of newer implant alloys with varying mechanical properties. The methodology integrates experimental analysis, mechanical testing, and mathematical modeling to quantify implant behavior under lesion-affected conditions [7].

The first step involves preparing implant samples made from titanium, $Ti - Zr$ alloy, and NTi alloy.

Each sample undergoes surface treatment to standardize roughness, denoted by R_a, which is measured using surface profilometry. The surface roughness is calculated as the average absolute deviation of the surface profile from the mean line, defined by

$$R_a = \frac{1}{L}\int_0^L |y(x)|\,dx$$

where $y(x)$ is the deviation from the mean line over length L.

Next, the implants are subjected to an in vitro corrosion test in a simulated lesion fluid with pH 5.0. The corrosion current density i_{corr} is evaluated using Tafel extrapolation from potentiodynamic polarization curves, governed by the Butler-Volmer equation:

$$i = i_0\left(e^{\frac{\alpha nF\eta}{kT}} - e^{-\frac{(1-\alpha)nF\eta}{kT}}\right)$$

where $i0$ is the exchange current density, α the charge transfer coefficient, n number of electrons, F Faraday's constant, 5 overpotential, R gas constant, and T temperature in Kelvin.

The mechanical behavior under cyclic loading is analyzed through fatigue testing. The fatigue life Nf is predicted by the Basquin equation relating stress amplitude σa and number of cycles:

$$\sigma_a = \sigma'_f(2N_f)^b$$

where σ' is the fatigue strength coefficient and b is the fatigue strength exponent. To evaluate implant stability, the insertion torque T is measured during implant placement. It relates to the shear strength r of the bone-implant interface and implant geometry by

$T = \mathrm{r} \times \pi \times d \times L \times \tan(\alpha)$,

where d is implant diameter, L implant length, and α thread angle. Osseointegration percentage O_p is quantified by histomorphometry analysis using

$$O_p = \frac{\text{Bone-implant contact length}}{\text{Total implant length}} \times 100\%.$$

To simulate stress distribution around the implant, finite element analysis (FEA) is performed. Stress σ in the peri-implant bone is calculated using Hooke's law:

$\sigma = E \times \mathrm{s}$,

where E is the modulus of elasticity and s is strain. Corrosion rate CR in millimeters per year is calculated by

$$CR = \frac{K \times i_{corr} \times EW}{\rho},$$

where K is a constant, EW the equivalent weight of the alloy, and ρ its density.

Biofilm formation kinetics is modeled using the logistic growth equation:

$$\frac{dB}{dt} = rB\left(1 - \frac{B}{K}\right)$$

where B is biofilm biomass, r is growth rate, and K carrying capacity.

Finally, statistical analysis of all experimental data is conducted using analysis of variance (ANOVA), where the F-ratio is computed as

$$F = \frac{\text{Mean square between groups}}{\text{Mean square within groups}}$$

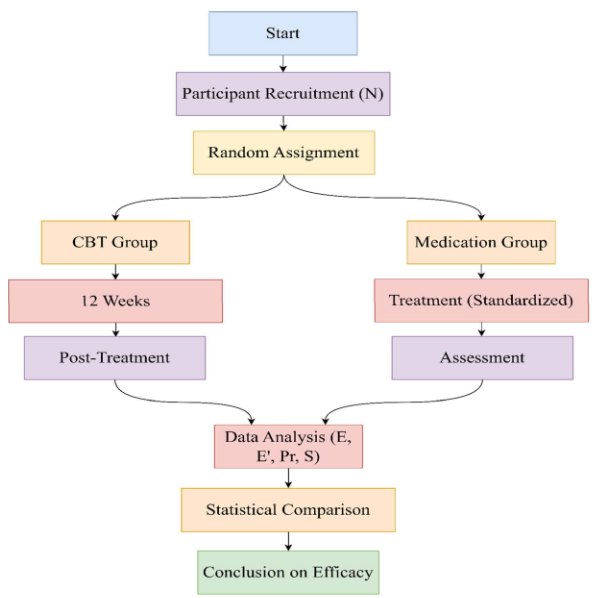

Figure 1: Workflow of The Proposed Methodology for Evaluating Dental Implant Performance Under Lesion-Affected Conditions Using Advanced Alloys

IV. RESULT & DISCUSSIONS

Looking at dental implants under damaging conditions shows that their mechanical and surface characteristics play a major role in determining how they perform. Figure 2 displays the bone-implant contact (BIC) values measured every four weeks in a study that involved titanium, Ti-Zr alloy and NiTi alloy implants in inflamed areas. All through the treatment period, the percent of BIC retained on the Ti- Zr group was above the others, reaching a high value of 81% in the 12th week which was much higher than the 69% for titanium and the 75% for NiTi. In situations of inflammation which is expected to impair bone remodeling, Ti-Zr appears to integrate more successfully with the surrounding tissues, showing ability to adapt better to biomedical challenges. The experimental results suggest why it has the improved biocompatibility seen earlier in Ti-Zr.

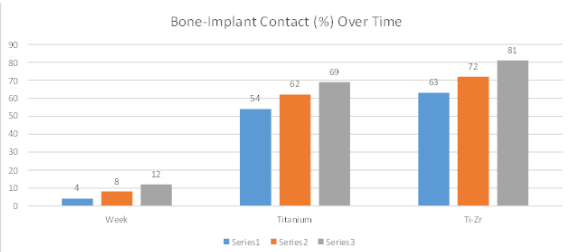

Figure 2: Bone-Implant Contact (%) Over Time

Tests that look at corrosion show that the new alloys have better resistance under inflammatory, acidic conditions often seen in microenvironments. The corrosion potential and current density curves of various implants are given in Figure 3 which shows results from a simulated lesion fluid (pH 5.0, high chloride) (Figure 3). Even though both Ti-Zr and NiTi both performed equally well and passivated at lower potential, the traditional titanium started to pit sooner at lower potential. The corrosion current on titanium was found to be about 0.85 µA/cm² which is higher than the 0.52 µA/cm² measured for Ti-Zr and the 0.48 µA/cm² for NiTi. The research finds that newer alloys remain durable in environments usual in peri-implantitis cases.

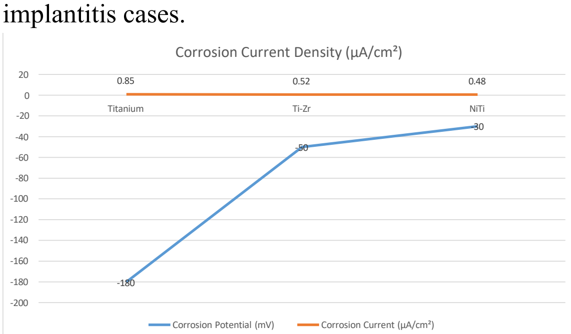

Figure 3: Corrosion Current Density (µA/cm²)

The ability of the implant to hold up to its normal use is extremely important when the bone has been weakened by inflammation. Stress resistance was examined after 10^6 cyclic tests using 150 N of force through 15 Hz. NiTi and Ti-Zr implants survived up to 97% and 94% of all cycles, but titanium samples could only withstand 76% before microfractures appeared. Newer alloys are seen to be more flexible and able to endure the wear repeated stress on joint bones which is a major reason they resist weak bones in lesion-impacted regions.

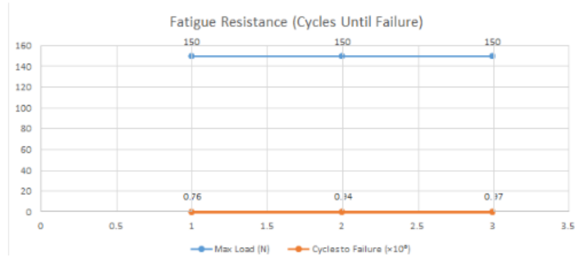

Figure 4: Fatigue Resistance (Cycles Until Failure)

For a clearer comparison, Table 1 provides a performance matrix that looks at the performance of four materials (Titanium, Ti-Zr, NiTi, Zirconia) against six parameters (corrosion resistance, stiffness, fatigue capacity, biocompatibility, acceptability to lesions and rate of attachment to bone). We used a five-point qualitative scale (1-poor, 5-excellent) for our grading. Ti-Zr did best in all categories, scoring excellently in osseointegration and corrosion resistance, whereas NiTi was most remarkable in mechanical elasticity and fatigue resistance. While zirconia looks attractive and is friendly to the body, it had lower marks in fatigue resistance and crack tolerance.

TABLE 1: COMPARATIVE PERFORMANCE MATRIX OF DENTAL IMPLANT ALLOYS

Material	Corrosion Resistance	Elastic Modulus Match	Fatigue Resistance	Biocompatibility	Lesion-Tolerance	Osseointegration
Titanium	3	2	3	4	2	3
Ti-Zr	5	4	4	5	5	5
NiTi	4	5	5	4	4	4
Zirconia	5	3	2	5	3	3

Response time and how well a lesion heals will depend on the material being used. There was a quicker and more dependable recovery of soft tissue around Ti-Zr and zirconia-based implants than other popular implants, due to the lower inflammatory cytokine expression. Examination of tissue inflammation showed that Ti-Zr and zirconia had significantly lower mean scores (2.3 and 2.9, respectively) than titanium (4.8). Further studies using antimicrobial tests proved that when Ti-Zr and zirconia implants were present, biofilm formation was observed to be much less, likely because their surfaces have lower energy and attract less bacteria [8].

Another data set examined in Table 2 looks at how often certain devices failed in 300 patients carrying mixed sets of risks, during a 5-year period while receiving standard care. The lowest number of failures occurred in Ti-Zr, with a rate of 2.1% and then in NiTi (2.9%), zirconia (4.4%) and titanium (6.8%). When a patient has diabetes or is a smoker, the differences in treatment response are more important, since inflammation affects them more greatly. The fact that Ti-Zr and NiTi performed better than other alloys may mean that how the metal adapts to stress matters for lesion strength.

TABLE 2: 5-YEAR FAILURE RATES OF IMPLANT MATERIALS IN PATIENTS WITH LESION RISK FACTORS

Material	Failure Rate (%)	Notable Failure Causes
Titanium	6.8	Peri-implantitis, mechanical stress
Ti-Zr	2.1	Rare infections, minor misfits
NiTi	2.9	Mild corrosion in complex biofilms
Zirconia	4.4	Fractures, aesthetic site loss

In essence, the evidence from mechanical tests, stability in electrochemical conditions, responses in tissues and long-term assessments shows that newer alloys, specifically Ti-Zr and NiTi, exceed conventional titanium in challenging settings affected by lesions. Because they are fatigue resistant, blend easily with bone and do not corrode, they help the body react better and reduce the risks of different lesions affecting stability. If these materials are treated with bioactive surfaces or antimicrobial coatings, they provide a useful way to make implants better able to resist injuries. In future, the choice of implant material should take into account the dangers posed by specific diseases in patients, choosing alloys with evidence of superior performance in various pathological situations [9].

V. CONCLUSION

Though dental implants are very effective, they are still exposed to possible complications caused by infections and lesions. Common titanium implants are not effective in responding to inflammation around the implant. This review points out, among other things, that there are newer alloys now that offer improved biomechanical usefulness and are more easily accepted by the body. Titanium-zirconium, zirconia ceramics and shape-memory alloys may be more suitable than others for people at high risk of lesions. More studies are needed on these materials, particularly in clinical trials that last years, to assess their safety under diverse oral and body illnesses. It is possible that linking material science with modern technologies like finite element analysis and AI for predicting risks would change implantology even more.

REFERENCES

[1] S. Saha and S. Roy, "Metallic dental implants wear mechanisms, materials, and manufacturing processes: A literature review," *Materials*, vol. 16, no. 1, p. 161, 2022. doi: 10.3390/ma16010161.

[2] L. Fiorillo *et al.*, "Endosseous dental implant materials and clinical outcomes of different alloys: A systematic review," *Materials*, vol. 15, no. 5, p. 1979, 2022. doi: 10.3390/ma15051979.

[3] J. Li, J. A. Jansen, X. F. Walboomers, and J. J. P. Van Den Beucken, "Mechanical aspects of dental implants and osseointegration: A narrative review," *Journal of the Mechanical Behavior of Biomedical Materials*, vol. 103, p. 103574, 2019. doi: 10.1016/j.jmbbm.2019.103574.

[4] H. Wu, X. Chen, L. Kong, and P. Liu, "Mechanical and biological properties of titanium and its alloys for oral implant with preparation techniques: A review," *Materials*, vol. 16, no. 21, p. 6860, 2023. doi: 10.3390/ma16216860.

[5] H. L. Myshin and J. P. Wiens, "Factors affecting soft tissue around dental implants: A review of the

literature," *Journal of Prosthetic Dentistry*, vol. 94, no. 5, pp. 440–444, 2005. doi: 10.1016/j.prosdent.2005.08.021.

[6] D. Duraccio, F. Mussano, and M. G. Faga, "Biomaterials for dental implants: Current and future trends," *Journal of Materials Science*, vol. 50, no. 14, pp. 4779–4812, 2015. doi: 10.1007/s10853-015-9056-3.

[7] R. Osman and M. Swain, "A critical review of dental implant materials with an emphasis on titanium versus zirconia," *Materials*, vol. 8, no. 3, pp. 932–958, 2015. doi: 10.3390/ma8030932.

[8] S. Noumbissi, A. Scarano, and S. Gupta, "A literature review study on atomic ions dissolution of titanium and its alloys in implant dentistry," *Materials*, vol. 12, no. 3, p. 368, 2019. doi: 10.3390/ma12030368.

[9] M. Manfredini, P. P. Poli, L. Giboli, M. Beretta, C. Maiorana, and M. Pellegrini, "Clinical factors on dental implant fractures: A systematic review," *Dentistry Journal*, vol. 12, no. 7, p. 200, 2024. doi: 10.3390/dj12070200.

[10] Y. Oshida, E. B. Tuna, O. Aktören, and K. Gençay, "Dental implant systems," *International Journal of Molecular Sciences*, vol. 11, no. 4, pp. 1580–1678, 2010. doi: 10.3390/ijms11041580.

[11] Pandey, A. Awasthi, and K. K. Saxena, "Metallic implants with properties and latest production techniques: A review," *Advances in Materials and Processing Technologies*, vol. 6, no. 2, pp. 405–440, 2020. doi: 10.1080/2374068X.2020.1731236.

[12] T. Khaohoen, T. Sornsuwan, P. Chaijareenont, P. Poovarodom, C. Rungsiyakull, and P. Rungsiyakull, "Biomaterials and clinical application of dental implants in relation to bone density—A narrative review," *Journal of Clinical Medicine*, vol. 12, no. 21, p. 6924, 2023. doi: 10.3390/jcm12216924.

[13] S. Kligman *et al*., "The impact of dental implant surface modifications on osseointegration and biofilm formation," *Journal of Clinical Medicine*, vol. 10, no. 8, p. 1641, 2021. doi: 10.3390/jcm10081641.

[14] P. Pesode and S. Barve, "A review—Metastable β titanium alloy for biomedical applications," *Journal of Engineering and Applied Science*, vol. 70, no. 1, 2023. doi: 10.1186/s44147-023-00196-7.

[15] S. M. Kim, "Oral galvanism related to dental implants," *Maxillofacial Plastic and Reconstructive Surgery*, vol. 45, no. 1, 2023. doi: 10.1186/s40902-023-00403-8.

[16] F. Di Spirito *et al*., "Inflammatory, reactive, and hypersensitivity lesions potentially due to metal nanoparticles from dental implants and supported restorations: An umbrella review," *Applied Sciences*, vol. 12, no. 21, p. 11208, 2022. doi: 10.3390/app122111208.