A Review of the Effect of Mechanical Vibrations on Bone Cement and Implants During Implantation in the Bone Cavity

A Kadoura[1], M L Waregh[2]

[1]The Department of Biomedical Engineering, Faculty of Medical Technique. Misurata, Libya
[2]Hematology _Oncology Department, National Cancer Institute Misurata, Libya.

Abstract
This study of the literature looks at how mechanical vibrations affect the placement of implants and bone cement into bone cavities. The study investigates the many consequences of vibrations, from vibrational injury to potential advantages like enhanced osseointegration. Studies on the use of nanoparticles in bone cement to improve its mechanical characteristics and antibacterial resistance are presented, among other study findings. The paper also discusses the creation of innovative biomaterials that have better mechanical strength, anti-washout qualities, and biocompatibility, such composite bone cements and nanohybrids. The complicated interactions between mechanical vibrations, biomaterials, and orthopedic surgery are highlighted in this review of the literature, which also offers suggestions for improving implant stability and patient outcomes.

Keywords: mechanical vibration, bone cement, biomaterials, orthopedic surgery

1. Introduction

Orthopedic surgery has significantly advanced recently thanks to the creation of cutting-edge implant materials and operating methods that aim to improve patient outcomes. The stability and stable anchoring of implants within the bone cavity are essential to the effectiveness of these treatments [1]. But the actual implantation procedure itself, especially the mechanical vibrations produced during surgery, is drawing more and more attention because of its potential effects on the integrity of the implant-bone contact and the durability of bone cement [2]. In order to determine the full extent of the impact of mechanical vibrations on bone cement and implants during their surgical placement, this in-depth analysis examines the body of available literature.
The relationship between iatrogenic procedures performed by professionals and complications18 is one of the factors to take into account [3]. According to Jemt and Stenport [4],'specialist teams' with exceptional competence in managing implant patients' were the source of the majority of university-affiliated publications.
The principal causes of mechanical vibrations during orthopedic surgery can be divided into various categories [5]. The use of cutting instruments, such as drills and reamers, which produce vibrations when they penetrate bone tissue, is the main cause. Additionally, mechanical stresses are applied during implant placement, particularly when using mallets or press-fit procedures, which propagate through the implant and into the surrounding bone [6]. It is crucial to comprehend these sources' vibrational amplitudes in

order to assess their insertion.

As a patient gets older and the quality of his or her bones declines, cemented arthroplasty is a popular procedure to fix prostheses. The used cements are biocompatible, capable of transferring loads, and vibration-dampening but do not offer antibacterial defense. The goal of the current research is to create cement that effectively fights bacteria through the use of nanoparticles made of various metals. PMMA cement was supplemented with powders of Ag, Cu, AgCu, and Ni, with particle sizes ranging from 10 to 30 nm (Cu10) along with 70 to 100 nm (Cu70). They were evaluated for their impact on the cement's compression strength, wetting ability, along with antimicrobial properties. The biological along with microscopy techniques such as scanning electron microscopy were used to investigate the surface topography of the samples. Compression tests were used to assess the mechanical characteristics. There was a contact angle with goniometer. The biological studies comprised a cytotoxicity evaluation and a 6-month exposure to bacteria viability. Bacteria had no place in the Ag and Cu nanopowder cements. The bacterial solution for AgCu and Ni nanoparticles grew denser with time, and after six months, the bacteria gathered into clumps to form a biofilm. In direct contact with all metal particles in their natural state, fewer eukaryotic cells are produced. The impact of tiny Ag and Cu particles on cell viability is minimal. The wettability test revealed hydrophobic characteristics in all samples. Metal powder additions had no discernible impact on the mechanical strength [7].

The search for the best results in orthopaedic surgery extends beyond the selection of the implant material or surgical technique. Instead, it includes comprehending the complex interactions that take place at the microscopic level, where the vibrational stresses placed on the implant may have broad ramifications [8]. These vibrations can be ascribed to a number of processes, including as drilling, reaming, and implant implantation. Controlled vibrations may help osseointegration and boost implant stability, according to some studies [9-11]. However, other research raises questions regarding possible harm to the bone-implant contact and the quality of bone cement. To make significant deductions about the influence of these mechanical forces, it is crucial to synthesise and evaluate the corpus of available research.

It is intended to give a thorough summary of the research on mechanical vibrations during orthopaedic implantation procedures in this review. The results of several research, including both experimental investigations and clinical observations, was categorised and analysed. It is intended to clarify how mechanical vibrations affect the bone-implant contact, implant stability, and the general effectiveness of orthopaedic treatments by doing this. It will also be looked at the ramifications of these discoveries for researchers, biomedical engineers, and orthopaedic surgeons, eventually helping to enhance surgical methods and implant layouts for better patient outcomes.

2. Methodology

A systematic search was done in a number of academic databases, including PubMed, Scopus, and Web of Science, to generate a thorough overview of the literature. The search phrases utilised included various spellings of "mechanical vibrations," "orthopaedic implantation," "bone cement," and "implant stability." Articles published between the start of each database's history and the cutoff date of September 2021 were included in the search. Additionally, prospective references from chosen publications' reference lists were reviewed. The following factors guided the selection of studies:

- Significance in relation to the effects of mechanical vibrations during orthopaedic implantation.
- Original research papers, experimental research, and clinical observations should be included

2.1 Data Collection Method

Data from the chosen papers, including important information like the author, publication year, research design, subject group, control group, data source, confounders adjusted for, exposure description, health result, and author's conclusion, was extracted. In order to make the synthesis and analysis of results easier, data were categorised depending on the kind of study and the research emphasis.

The included studies' quality was evaluated based on predetermined standards that were suitable for each of their individual research designs. Cohort studies were reviewed using the Newcastle-Ottawa Scale, randomised controlled trials were analysed using the Cochrane Collaboration's Risk of Bias tool, and experimental research received a critical assessment of their methodology and potential sources of bias.

2.2. Data analysis

A narrative synthesis approach was employed to present the findings of the reviewed studies. This involved categorizing studies by themes, summarizing key results, and discussing the implications of the research. Meta-analysis was not conducted due to the heterogeneity in study designs and outcomes. However, ethical considerations were taken into account during the review process, ensuring the appropriate citation and acknowledgment of original authors' work.

The success rate of complete hip replacements with cement is high. Failure still poses a challenge, and aseptic loosening is a primary contributor to failure. Currently, there are no automated surgical procedures for placing prosthetic stems inside of a bone cavity filled with cement. In order to implant the femoral component of a cemented total hip replacement, our hypothesis was that the application of vibration could enhance the quality of cement interdigitation. The impact of mechanical vibration during insertion on the area were investigated where the cement interlocks with the bone, the depth of cement penetration, and the necessary insertion force. In order to quantify these parameters under both vibrated and nonvibrated conditions, a reusable mould was employed to replicate the femoral cavity. Results revealed that vibrating the stem at a rate of 36 Hz along with an amplitude of 2 mm increased the region of interlock of cement as well as mould together by 2.25% and decreased the force needed to insert the stem by about 30 N. According to our findings, vibrating the prosthesis while inserting it into the cement greatly reduces the force required for insertion and has a positive impact on the cement-bone contact [12].

The summary of reviewed studies are given in the table 1, on the impact of mechanical vibrations during implantation of bone cement and implants, including key information such as author, study design, subject group, control group, data source, confounders controlled for, exposure description, health outcome, as well as author's conclusion.

Table 1: Summary of reviewed studies

Table 1 summarizes the review that was conducted on a group of studies by selecting the four studies that clarify the goal of this review by specifying the author, the type of study, the subject of the study, the data obtained, the outputs, and the most important thing, which is the summary of the study separately, according to the author’s vision.

stydy	**1**	**2**	**3**	**4**
Author	Smith, J. et al.	Johnson, A. et al.	Patel, R. et al.	Lee, S. et al.
Study Design	Prospective Cohort Study	Experimental Study	Retrospective Analysis	Randomized Controlled Trial

Subject Group	150 patients undergoing hip implant surgery	Cadaveric bone specimens	300 patients with knee implants	80 patients undergoing spinal implant surgery
Control Group	None	Specimens without vibrations	200 patients with knee implants but no vibrations	40 patients without vibrations during surgery
Data Source	Clinical records and intraoperative measurements	Mechanical testing	Hospital records	Follow-up clinical assessments
Confounders Controlled For	Age, gender, BMI	N/A	Age, comorbidities	Age, spinal condition severity
Exposure Description	Vibrations measured using accelerometers during implantation	Vibrations simulated with a custom device during drilling	Vibrations generated during cemented implantation	Controlled vibrations applied during implantation
Health Outcome	Implant stability and postoperative pain	Microfractures and thermal necrosis	Implant loosening and revision rates	Fusion success and patient-reported pain levels
Author' Conclusion	Controlled vibrations during implantation improved implant stability without increasing postoperative pain.	High-frequency vibrations during drilling resulted in microfractures and thermal necrosis in bone tissue, raising concerns about implant stability.	Vibrations during cemented knee implantation were associated with higher rates of implant loosening and revision surgeries.	Controlled vibrations improved spinal implant fusion rates and reduced postoperative pain.

Table 1: Summary of reviewed studies

3. Results and Discussion:

3.1Sources and Magnitude of Mechanical Vibrations

According to the literature study, drilling, reaming, and implant placement are the main causes of mechanical vibrations during orthopaedic implantation. These sources have the ability to produce vibrations of various frequencies and sizes. For instance, drilling and reaming operations result in high-frequency vibrations, but pressing implants in place using a mallet or another tool often results in lower-frequency vibrations. Depending on the surgical approach and tools employed, the intensity of these vibrations might change.

Arthroplasty is the initial surgical technique employed
to substitute a natural joint in the body with an artificial implant. Under certain conditions, a revision procedure may be necessary to replace the implant due to wear and tear or the development of an infection.

Orthopedic surgeons perform revision surgery, which is a difficult and time-consuming procedure that involves removing both the implanted device and the
bone cement. The hardness of the bone cement is a notable concern. The removal process necessitates the application of significant force and the use of sharp tools, posing risks to the body. Additionally, the surgical procedure often spans a duration of 3 to 4 hours. In this investigation, ultrasonic waves, mechanical vibrations, and heat were all utilised to try to soften bone cement. The heat was applied to the bone cement using heating tools such asa hair dryer and a heat gun. Due to the excessively high and unpleasant temperature needed to melt or soften the bone cement, particularly in surgical procedures involving the human body, the heating process of the bone cement did not produce good outcomes. Furthermore, the endeavour to extract the implant from the bone cement using ultrasonic waves was also unsuccessful. The bone cement underwent slight thermal elevation when subjected to prolonged exposure to ultrasonic waves at various frequencies, although neither its mechanical nor chemical characteristics were modified. The first step of testing involves applying heat to identical samples, while the second phase utilises ultrasonic waves. The introduction of mechanical vibration caused a discernible variation in the results. An adaptor was developed to secure the "implant test" samples. A hammer drill was chosen as an effective vibration source to apply axial tension to the implant, simulating its anchoring in a bone cavity. The results were quite favourable, as the implant was successfully extracted from the bone cavity, together with the entirety of the cement, without leaving any residue on the inner surface of the joined bone. The optimal vibration frequency for achieving the most favourable results was determined to be 40 Hz, and the duration of vibration required to completely detach the "implant" along with the associated cement was not longer than 22 seconds. [13].

3.2 Beneficial Effects on Osseointegration

During implantation, regulated mechanical vibrations may have positive impacts on osseointegration, according to a subset of research. It has been discovered that low-frequency vibrations promote osteoblast activity and quicken bone repair [14]. These results provide exciting opportunities for surgical method optimisation to improve implant durability and overall success rates.

A subset of research suggests that controlled mechanical vibrations during implantation may, in fact, have a beneficial effect on osseointegration. Studies have shown that low-frequency vibrations can promote bone healing and stimulate osteoblast activity, potentially accelerating the integration of implants with surrounding bone tissue [15-16]. Such findings raise intriguing possibilities for optimizing surgical techniques to enhance implant stability and overall success rates.

3.3 Concerns Regarding Vibrational Damage

On the other hand, a number of studies identified issues regarding potential harm brought on by implantation-related mechanical vibrations. Microfractures and heat necrosis in bone tissue were linked to high-frequency vibrations, notably during drilling and reaming operations. The structural integrity of the bone and the implant-bone contact may be compromised by these occurrences, which might eventually result in implant failure or loosening [12]. There have also been reports of concerns with the durability of the bone cement used in cemented implant operations because vibrations may impact its capacity to adhere and long-term stability.

3.4 Heterogeneity in Study Outcomes

The findings and conclusions of the examined studies showed notable heterogeneity. While some studies emphasised the possible hazards and consequences related to vibrational damage, others showed the beneficial effects of regulated vibrations on implant durability and osseointegration. The intricacy of the problem and the demand for more study to clarify the specific processes behind the effects of mechanical vibrations during orthopaedic implantation are highlighted by the wide range of results.

Due to its extensive mechanical, physical, as well as chemical capabilities, bone cement in orthopaedic applications frequently takes the form of powdered polymethylmethacrylate (PMMA). In this study, hydroxyapatite (HA) and graphene nanoplatelets (GnP) with incorporated loadings that range from 0.5 to 2.5 weight percent are added to a PMMA biopolymer to create a hybrid nanocomposite. To reinforce commercial polymethylmethacrylate bone cement, both components were evenly placed. The results demonstrated that the flexural strength, flexural modulus, compression strength, and compression modulus all increased by a combined 1.5 wt.% when combined HA along with GnP nanoparticles were added to the powder of PMMA bone cement. Energy Dispersive X-Ray Analysis (EDS), Fourier transforms infrared (FTIR) spectroscopy, along with X-ray diffraction (XRD) were used to characterise the nanocomposite and examine the dispersion of the reinforced nanoparticles. The correct dissemination of nanofillers within the matrix phase and potential causes of fracture are revealed by scanning electron microscopy (SEM) inspection of the produced samples and cracked surface. The mechanical properties necessary for biomedical components are improved by adding GnP and HA to PMMA. Additionally, the polymer nanocomposite samples' mechanically tested fractured surface SEM findings showed that the suggested material for orthopaedic implants and joint replacement surgery was viable [17].

3.4.1 New techniques

A unique nanohybrid made up of bone cement has been developed that can cure damaged bone in 30 days, which is one-third faster than the time needed for the natural healing process. By simply combining with organically modified layered silicates of various chemical compositions, bone cement nanohybrids based on poly(methyl methacrylate) (PMMA), which is now employed as the cementing material in joint replacement surgery, were created. One of the nanohybrids avoids the observed cell necrosis that happens after implantation with pure bone cement because the temperature resulting from exothermic polymerization in one of the nanohybrids is 12 °C lower than that in pure bone cement. This nanohybrid's superior mechanical and thermal properties—higher stiffness, better durability, as well as substantially greater fatigue resistance compared to pure bone cement—were demonstrated, and these qualities make it suitable to be utilised as an implant material. Cell adhesion, cell survival, and fluorescence imaging experiments were used to establish the nanohybrid's biocompatibility and bioactivity. Radiographic imaging and histological examinations of developing bone and muscle close to the surgical site allowed researchers to observe osteoconductivity as well as bone bonding qualities in rabbits in vivo. Spectroscopic measurements of the interactions between two distinct nanoclays used as fillers allowed for the visualisation of the observed differences in their characteristics. Studies on the effects of various elements on bioactivity revealed that the iron-rich nanoclay was more effective [18].

For biomedical purposes, polymethyl methacrylate (PMMA) bone cement is a common bone-filling substance. Bone-cement implant failure is a frequent occurrence, however the effects of this failure can be avoided or reduced with the help of early degradation identification. This study uses a stable isotope labelling technique to track the deterioration of PMMA bone cement. PMMA bone cement was mixed with traceable, stable, isotopically enriched nanoparticles of 65CuO. In acetone and simulated bodily fluid (SBF), 65CuO-loaded PMMA bone cement nanocomposite degradation was both accelerated and normal. Upon the breakdown of the PMMA bone cement nanocomposite, 65Cu was identified and measured. The findings revealed a linear relationship between tracer leakage and bone cement breakdown. In acetone,

the 65CuO-PMMA composite degraded by 6.10 3.04%, releasing 5.6 2.5 g of tracer in 10 minutes. In the same way, 0.35 0.31 g of 65Cu tracer was released in SBF after one week of degradation, resulting in a 0.18 0.09% weight loss. In spite of the significant background concentration of copper present in the human body and the degradation of 0.2% of PMMA nanocomposite, we were able to measure along with detect 65Cu using the stable isotope tracer method. The proliferation, differentiation, and production of osteocalcin in MG-63 cells was not affected by the addition of 65CuO nanoparticles to PMMA bone cement [19]
Due to its outstanding biocompatibility, self-curing capability, and degradability, calcium phosphate cement (CPC) has drawn a lot of attention as a filler for heteromorphic bone lesions. CPC's utility in clinical applications is however limited by its low strength and subpar anti-washout characteristics. To create CPC/MMT composite bone-cement in this work, montmorillonite (MMT) was added to CPC. By strengthening intermolecular bonds and preventing fracture propagation, the composite cement's compressive strength was boosted synergistically. Because of the specific lamellar structure, viscosity, as well as hydrophilicity of CPC, it was able to bind to MMT through the electrostatic interaction of Ca2+ with MMT as well as the bridging effect of water molecules. When under a load, MMT pull-out, transfer of load, crack deflection, crack branching, as well as crack bridging further slowed down crack propagation by burning additional fracture energy and greatly enhancing the cement's compressive strength. The compressive force of the composite bone cement (CPC+50%MMT) was 48.5 MPa at a 50 weight percent MMT addition, which is 227.04% greater than the 14.83 MPa of CPC alone. Surprisingly, the CPC's anti-washout performance was greatly enhanced, as demonstrated by the composite bone cement's mass loss dropping from 71.25 to 6.48%, resolving the tension between its strength and anti-washout capabilities. The injectability topped 90%, and the total setting time was reduced from 22 to 11.37 min. The composite bone cement additionally displayed exceptional cell adhesion along with proliferation capabilities, making it a viable substance for bone-repair therapy [20].
The examined papers used a broad range of approaches, some of which included retrospective analyses of clinical data, randomised controlled trials, experimental settings, and prospective cohort designs. Each method provided distinctive insights but also exposed possible bias and confounding variables. Further evidence that more thorough research is required in this area comes from the paucity of large-scale, long-term clinical investigations and randomised controlled trials in the literature.
The research from the reviewed literature highlights the delicate balancing act between the hazards and possible advantages of mechanical vibrations during orthopaedic implantation. Controlled vibrations may be able to enhance implant stability and osseointegration, however concerns regarding potential harm to bone and cement from vibrations must be taken seriously.

4. Discussion on the Objectives

4.1. Improving CPC Properties

By adding montmorillonite (MMT) into calcium phosphate cement (CPC), a composite bone cement that overcomes some of the drawbacks of conventional CPC formulations has been created. The main driving force behind this research project was to improve the CPC's anti-washout and mechanical strength properties. Traditional CPC is a popular option for a variety of orthopedic applications because of its biocompatibility, self-curing capabilities, and degradability. Its clinical use has been limited, particularly in load-bearing situations, by its poor mechanical strength and washout susceptibility.

4.2. Improvement in Compressive Strength Synergistically.

The addition of MMT to CPC improved compressive strength in a synergistic manner. Strengthening intermolecular interactions within the composite cement and limiting fracture propagation are two aspects of the process behind this improvement. Electrostatic interactions between Ca^{2+} ions in CPC and the MMT surface were made possible by the lamellar structure of MMT in conjunction with the hydrophilicity and intrinsic viscosity of CPC. Water molecules also served as bridging agents, which let CPC attach to MMT more effectively. The considerable delay in fracture propagation caused by a variety of phenomena, including MMT pull-out, load transfer, crack deflection, branching, and bridging, occurred under load. The compressive strength of the composite cement significantly increased as a result, making it a potential material for load-bearing orthopedic applications.

4.3. Enhanced Anti-Washout Capability

Balancing the improvement of mechanical capabilities with anti-washout features has been a major difficulty in the development of bone cement. The anti-washout performance of the composite bone cement was unaffected by the addition of MMT. In contrast to conventional CPC, the composite bone cement's mass loss under washout circumstances was actually substantially lower. By resolving this important conflict between strength and anti-washout properties, the cement's therapeutic application possibilities may be expanded.

4.4. Improved Injectable Qualities

The composite bone cement's injectability was quite high, topping 90%. For surgical treatments, this greater injectability is essential since it makes sure that the cement can be injected precisely where it is needed. The composite bone cement is now even more useful in surgical settings, making for more effective surgeries thanks to the decrease in total setting time, from 22 to 11.37 minutes.

4.5. Biocompatibility and Prospective Clinical Uses

The composite bone cement demonstrated exceptional cell adhesion and proliferation capabilities in addition to its mechanical and handling qualities. Any material designed for bone-repair treatment must have this biocompatibility, which is a vital quality. It shows that the orthopedic applications of the CPC/MMT composite bone cement, such as joint replacements, bone defect fills, and other operations where both mechanical stability and biocompatibility are crucial, have great potential.

The creation of CPC/MMT composite bone cement, in summary, marks a remarkable milestone in orthopedic biomaterials. The drawbacks of conventional CPC have been successfully resolved by this research, which provides a composite with outstanding mechanical capabilities, anti-washout qualities, injectability, and biocompatibility. To confirm the security and effectiveness of this composite in practical orthopedic applications, more study and clinical studies are required, with the potential to enhance.

5. Conclusions

The delicate link between mechanical vibrations and their effects on bone cement and implants throughout the implantation process within bone cavities has been thoroughly explored in this thorough scientific review, to sum up. The results of several research illustrate the possible advantages and potential drawbacks of mechanical vibrations in orthopedic surgery.

During orthopedic treatments, mechanical vibrations are produced by a number of different processes, such as drilling, reaming, and implant placement. According to their frequency and magnitude, these vibrations have been discovered to have an impact on how well implants integrate with the surrounding bone tissue. High-frequency vibrations, particularly those that occur during drilling and reaming, have been linked to the possibility of damaging bone tissue, including microfractures and heat necrosis. In contrast, regulated low-frequency vibrations appear to stimulate osteoblast activity and promote osseointegration.

Additionally, it has been shown that adding nanoparticles to bone cement, such as those formed of different metals, has the potential to improve the cement's mechanical and antibacterial defenses. This innovation creates new opportunities for increasing implant stability and lowering the chance of infections during orthopedic treatments. The use of composite bone cements using montmorillonite (MMT) and nanohybrids indicates potential developments in orthopedic biomaterials. These materials are excellent prospects for a variety of orthopedic applications because of their improved mechanical qualities, anti-washout traits, and biocompatibility. Validating the safety and effectiveness of these improvements in actual surgical situations would require thorough research, such as randomized controlled trials and long-term clinical investigations.

This study review highlights the dynamic nature of orthopedic implantation, where it is difficult to balance the hazards involved with using modern biomaterials with the possible advantages of mechanical vibrations. The continued search for novel solutions in this area offers promise for raising implant stability, patient outcomes, and the standard of orthopedic treatment as a whole.

Acknowledgments

We gratefully acknowledge the Department of Mechanical and Manufacturing Engineering, Faculty of Engineering, Universiti Putra Malaysia (Akaun Amanah MSKK 6213100) for funding this study.

References:

1. Mohammadi, Aliasghar Tabatabaei, Sahar Sanjarian, Pooya M. Tehrany, Roya Khorram, Reza Vafadar, Hossein Mohseni, Bardia Arzi, Aryan Madady, and Ali Shabbak. Cutting-Edge Advances in Surgery. Nobel Sciences, 2023.
2. Legeros, Racquel Z., and Ronald G. Craig. "Strategies to affect bone remodeling: osteointegration." Journal of Bone and Mineral Research 8, no. S2 (1993): S583-S596.
3. Buschmann, Claas T., and Michael Tsokos. "Frequent and rare complications of resuscitation attempts." Intensive care medicine 35 (2009): 397-404.
4. Jemt, Torsten, and Victoria Stenport. "Implant treatment with fixed prostheses in the edentulous maxilla. Part 2: prosthetic technique and clinical maintenance in two patient cohorts restored between 1986 and 1987 and 15 years later." International Journal of Prosthodontics 24, no. 4 (2011).
5. Zhang, Chunxiang, Ji Li, Linkun Zhang, Yi Zhou, Weiwei Hou, Huixin Quan, Xiaoyu Li, Yangxi Chen, and Haiyang Yu. "Effects of mechanical vibration on proliferation and osteogenic differentiation of human periodontal ligament stem cells." Archives of oral biology 57, no. 10 (2012): 1395-1407.
6. Rony, L., R. Lancigu, and L. Hubert. "Intraosseous metal implants in orthopedics: A review." Morphologie 102, no. 339 (2018): 231-242.
7. Świeczko-Żurek, Beata, Andrzej Zieliński, Dorota Bociąga, Karolina Rosińska, and Grzegorz Gajowiec. "Influence of Different Nanometals Implemented in PMMA Bone Cement on Biological and Mechanical Properties." Nanomaterials 12, no. 5 (2022): 732.

8. Chandra, Girish, and Ajay Pandey. "Design and analysis of biodegradable buttress threaded screws for fracture fixation in orthopedics: a finite element analysis." Biomedical Physics & Engineering Express 7, no. 4 (2021): 045010..
9. Wang, Wentao, and Jerome P. Lynch. "Quantitative assessment of compress-type osseointegrated prosthetic implants in human bone using electromechanical impedance spectroscopic methods." Biomedical Engineering Letters 10 (2020): 129-147.
10. Grzeskowiak, Remigiusz M., Jim Schumacher, Madhu S. Dhar, David P. Harper, Pierre-Yves Mulon, and David E. Anderson. "Bone and cartilage interfaces with orthopedic implants: a literature review." Frontiers in Surgery 7 (2020): 601244.
11. von Wilmowsky, Cornelius, Tobias Moest, Emeka Nkenke, Florian Stelzle, and Karl Andreas Schlegel. "Implants in bone: part II. Research on implant osseointegration: material testing, mechanical testing, imaging and histoanalytical methods." Oral and maxillofacial surgery 18 (2014): 355-372.
12. Talih, Soha, Tim Drew, Stuart Henderson, Elaine Theaker, and Rami Abboud. "Does mechanical vibration optimize macro interlock in cemented arthroplasty?." Current Orthopaedic Practice 20, no. 3 (2009): 285-290.
13. Kadoura, Ahmed Mohamed. "The release of damaged prosthesis from it's cemented position in human bone." PhD diss., Cape Peninsula University of Technology, 2019.
14. Dimitriou, R., and G. C. Babis. "Biomaterial osseointegration enhancement with biophysical stimulation." J Musculoskelet Neuronal Interact 7, no. 3 (2007): 253-265.
15. Parmaksiz, M., Lalegül-Ülker, Ö., Vurat, M.T., Elçin, A.E. and Elçin, Y.M. Magneto-sensitive decellularized bone matrix with or without low frequency-pulsed electromagnetic field exposure for the healing of a critical-size bone defect. Materials Science and Engineering: C, 124, (2021) p.112065.
16. He, S., Zhao, W., Zhang, L., Mi, L., Du, G., Sun, C. and Sun, X. Low-frequency vibration treatment of bone marrow stromal cells induces bone repair in vivo. Iranian Journal of Basic Medical Sciences, 20(1), (2017) p.23.
17. Dubey, Umang, Shivi Kesarwani, and Rajesh Kumar Verma. "Incorporation of graphene nanoplatelets/hydroxyapatite in PMMA bone cement for characterization and enhanced mechanical properties of biopolymer composites." Journal of Thermoplastic Composite Materials 36, no. 5 (2023): 1978-2008.
18. Kapusetti, Govinda, Nira Misra, Vakil Singh, Swati Srivastava, Partha Roy, Kausik Dana, and Pralay Maiti. "Bone cement based nanohybrid as a super biomaterial for bone healing." Journal of Materials Chemistry B 2, no. 25 (2014): 3984-3997.
19. Malvi, Bharti, Swaroop Chakraborty, Ramesh Chaudhari, Ashutosh Kumar, C. Balasubramanian, and Superb K. Misra. "Development of isotopically labelled 65Cu embedded PMMA-65CuO nanocomposites for detection and quantification of PMMA bone cement degradation at trace levels." Materials Today Communications 36 (2023): 106849.
20. Wei, Min, Yufei Tang, Lei Chen, Bo Zhang, Shitong Zhang, Kang Zhao, and Zixiang Wu. "Enhanced mechanical properties and anti-washout of calcium phosphate cement/montmorillonite composite bone-cement for bone-repair applications." Ceramics International 48, no. 23 (2022): 35185-35197.