Study and Analysis of Extracorporeal Ultrasonic Waves in Destruction of Bone Cement: A Review

Heba Hussien Kadum[1], Sadiq Jafar Hamandi[2], Ahamed Sabah Abd Ali[3]

Authors affiliations:

1) Dept. of Biomedical Engineering, Al-Nahrain University, Baghdad-Iraq.

heba.hussian.phd2023@ced.nahrainuniv.edu.iq

2) Dept. of Bio-Medical Engineering, Al-Nahrain University, Baghdad-Iraq.

sadiq.j.abbas@nahrainuniv.edu.iq

3) Dept. of Orthopedics and Traumatology, Medicine, Al-Nahrain University, Baghdad-Iraq

ahmed72sabeeh@yahoo.com

Paper History:

Received: 2nd Oct. 20xx

Revised: 9th Dec. 20xx

Accepted: 30th Jan. 2 0xx

Abstract

Bone cement (BC) is widely used in different orthopedic surgeries like prosthetic, osteoporotic fracture surgery and joint replacement surgeries. The two types of BC that are used most frequently are polymethyl methacrylate (PMMA) and calcium phosphate-based cement (CPC). Although useful in practice, BC emits poisonous gases during preparation and if in contact with patients or healthcare workers, results in respiratory, dermal and cardiovascular harms. Evaluating and taking off BC during the revision surgery are challenging, and multiple methods are used, mechanical method chemical method, and ultrasonic waves. Extracorporeal ultrasound waves (EUW)s is other way of removing BC without necessitating invasive measures through applying heat and vibration in removing the cement-bone interface. While studies have shown the efficacy of EUW in clinical and experimental cases of BC removal the costs involved cannot allow their expanded use in orthopedic surgery. In this review, the author examines the mechanisms of generating heat and mechanical vibrations through the application of ultrasound waves that help in breaking off the cement-bone bond in open and minimally invasive surgical operations. The clinical uses of EUW range over many types of operations, it provides a safe and efficacious mode of treatment besides mechanical and chemical modalities. However, there are always some possible weaknesses of using LASER though the strengths hence include, increased efficiency, and accuracy of the operation Conversely, possible demerits of using LASER includes for instance, there is always a possibility of thermal effect on the neighboring tissue.

Keywords: Bone cement, ultrasonic waves, PMMA, Extracorporeal ultrasound waves

1. Introduction

Bone cement(BC) is a bone spacer and belongs to the group of materials that are most frequently used in operating rooms. Concerning the type of BC there are various forms of which the two most used are polymethyl methacrylate (PMMA) and calcium phosphate-based BC (CPC) [1, 2]. BC remains toxic to the patient and the surgical crew as they can inhale toxic fumes arising from the preparation of the agent in case there is inadequate ventilation. The risk factor depends on the mode and period of exposure to these vapors. BC exposure can lead to skin, nervous system, respiratory, and cardiovascular issues [1]. It plays a fundamental role in the healing of osteoporotic vertebral fractures, prosthetic replacement, fixing of the implant to the bone, total knee arthroplasty, end-stage arthritis treatment in the knee and dentistry [3, 4]. The two main techniques used for the BC insertion are transdermal vertebroplasty and spinal kyphoplasty [5].

Removing of BC is an important step in the revision surgery accompanied by vigorous problems, including incomplete cement removal, periprosthetic fractures, holes [6]. So, several techniques are proposed to remove BC without any complications. A cortical hole is created above the cement plug using rasps to facilitate its extraction. This method takes longer than expected and requires precise planning to choose the correct size and position of the opening. The technique can be challenging because the bone is tightly attached to the BC. The hole must be secured with cerclage wires to prevent any defects [7]. Cement removal rasps eliminate some of the BC easily, but the remainder crumbles, making it difficult to fully remove. As a result, the time required for complete cement removal is prolonged, leading to fatigue for the surgical team. Hands-free circular burs are useful only in bones with large canals. The small size of the burs tends to wear away bone, which offers less resistance than the cement, as is often the case with tibias that have narrow canals, a common occurrence in our society. Sometimes a distal cement drill is applied, managed by radiography. Once the hole is penetrated, the cement plug can be gradually drilled out. However, since these drills are not designed for this task, they do not remove the cement very well. If the guide is not well aligned and the drill meets the bone, it tends to erode the bone, resulting in cortical holes. Another method involves using specific fixation techniques. After inserting a standard metal rod through the cement plug, the entire space is recemented. After polymerization, it is removed with hammer, allowing the elimination of both new and old cement, with the old cement adhering more intensely to the new cement than to the bone [7].

Extracorporeal ultrasound wave (EUW) is a non-surgical technique of therapy. Many papers investigate the effects of shock waves on bones research [8]. A procedure that applies ultrasound to break the BC interface allows the cement to be removed using clamps and rasps. Ultrasonic probes generate vibrations inside the bone using an elevation in local temperature to soft the cement-bone interface and cause thermal damage to the surrounding tissue. This procedure is not available in some centers due to its high cost [7].

2. Ultrasonic Waves: Mechanism and Principles

Ultrasonic waves are sound waves that travel as longitudinal oscillations through a medium, typically used in medical imaging or treatments. They consist of high- and low-pressure phases that propagate energy, with water, air, fats, body fluids, bone, and soft tissues being common media for clinical ultrasound [9]. Frequency refers to the number of cycles per second, measured in Hertz (Hz). It determines how often the waves oscillate within a second. Clinical ultrasound operates at frequencies higher than 20 MHz, which is above human hearing range [10]. Wavelength is the physical distance between two successive wave peaks, while period is the time for a full wave cycle to complete. Frequency and period are inversely related: higher frequency means shorter periods. Amplitude represents the strength of a wave, measured by the height from the peak to the baseline. Power in ultrasound refers to the square of the amplitude, and both power and amplitude can be adjusted by the sonographer to enhance image quality. Intensity describes the amount of power delivered over a specific area, typically expressed in watts/cm². The highest intensity, called the spatial peak, is where the ultrasound beams are most focused [11]. Ultrasonic waves are typically used in a pulsed mode, where short bursts of waves are emitted by the probe, allowing them to reflect as echoes when encountering different tissues. The time it takes for these echoes to return helps create an image, with denser materials reflecting more sound and appearing brighter on the screen (e.g., bone), while less dense materials appear darker (e.g., fluids).

3. Mechanism of BC removal by extracorporeal ultrasonic waves

Ultrasonic waves are especially useful in clinical settings for their non-invasive capabilities, such as breaking down BC or softening tissue interfaces. The frequency used affects the depth and resolution of the image: higher frequencies provide better resolution but lower penetration, while lower frequencies allow deeper penetration at the cost of resolution [12]. Previous studies have demonstrated that cement-in-cement techniques are reliable for revision arthroplasty. In most cases, the initial cement mantle is reconstructed, thus enhancing stem positioning and handling significantly. Ultrasonic devices for example in the Orthosonics System for Cemented Arthroplasty Revision Removal (OSCAR)selectively removes cement with much less impact on host bones and this has lower cortical perforation rates compared to other techniques. Nevertheless, the study of the effect of ultrasonic devices on the final cement-in-cement bonds had not been conducted [13].

In revision arthroplasty one other critical component is that of extracting the bone cement without a hitch and safely. Conventional methods which may include manual or power- assisted removal may be in-efficient and may cause osteotomy, leading to cortical perforation, fractures, and bone loss. Ultrasonic devices are therefore another technique that utilizes conversion of mechanical vibration into heat to soften the cement. This makes it possible to remove the cement selectively without compromising the holding ability of the bone, avoids cortical perforation and in most cases avoids the need for an osteotomy. However, it has a thermal risk that could cause an injury depending on the point location in relation to the train. This review covers the principles of operation of ultrasound and its uses, most especially concerning ways of avoiding excessive heat generation [14].

Assessment of the OSCAR device was carried out on cement removal efficiency and its influence on cement-in-cement bonding was also analysed by Liddle et al.,. Twenty four specimens were made using Simplex P Bone Cement (Stryker) and poured into stainless steel molds where the central rods were mechanically extracted after the cement had set. These specimens were divided into three groups based on their internal surface preparation: burr, OSCAR, and no treatment. The interior voids were then rehealed with cement, and the samples were cut into 5 mm slabs for shear break force determination. The tests were performed by a technician unaware of the sample groupings and SEM was used to surface imaging of shear tested specimens. It was noted that, My results showed that the mean shear strength for the specimens treated with OSCAR was lower than that of the control and burr treated groups. There were no differences in variance in the control and burr groups. In the current study, SEM analysis of the OSCAR treated specimens was noted to have porosity which was not present in previous researches. The results of the present in vitro study propose that ultrasonic cement removal decreases the ultimate cement-in-cement bonds more than conventional techniques or no therapy at all. Therefore, preference should be given to more detailed evaluation when selecting surgical methods used in the removal of cement in revision arthroplasty [13].

Roitzschet., focused on the efficiency of ultrasonic-based PMMA removal during septic total joint arthroplasty revision, a procedure associated with a high risk of bone fractures and perforations. Ultrasonic cement removal, using the OSCAR-3-System, was tested in a human cadaver model where femoral components of hip and knee prostheses were implanted and subsequently removed. The analysis showed that over 99% of PMMA was successfully removed using ultrasound, with only minimal residues detected, mostly smaller than 1 cm. Although ultrasonic removal proved highly effective, further investigations are needed to understand the clinical impact of the remaining small PMMA fractions on periprosthetic joint infection rates [15].

4.Mechanism of bone cement extraction

4.1. Use of instruments and manual tools

Although many categories of instruments to get rid of inserts are manual tools, some are recently advanced power and ultrasonic implements [16].

The process of substitutions of artificial inserts has evolved from the use of sharp manual devices to more advanced techniques involving mechanical vibrations and ultrasound waves [17, 18, 19]. Earlier approaches relied on drilling into the bone cement to reduce its volume, while utilizing sharp instruments such as reamers, saws, and chisels [20], as depicted in Figures 1 and 2. These methods were often time-consuming and carried significant risks, such as bone perforation or fractures.

Figure (1): Manual tools for Cemented revision [21]

Figure (2): Hand tools for implant and cement removal [21]

4.2. Effect of Ultrasound on Bone Cement

Bone cement possesses biological properties that allow it to remain in the body without causing complications [22]. Efforts have been made to enhance materials that promote bone growth without compromising the stability and functionality of the implant [23, 24]. The incorporation of antibiotics into bone cement [25–27] has been studied for its potential impact on mechanical properties; however, it has shown no significant effect on movement or other key mechanical aspects of the cement [27]. Ultrasonic waves have been effectively used to soften the cement securing an implant [18]. Despite the benefits, this method comes with drawbacks, such as the high cost of the equipment, which often leads surgeons to rely on mechanical tools like groovers, scrapers, piercers, hammers, and osteotomes to remove larger pieces of cement. The use of these manual tools makes the implant removal process both time-consuming and hazardous. Figure 3 illustrates the osteotome, an orthopedic surgical instrument, used for removing bone cement from a bone cavity [18].

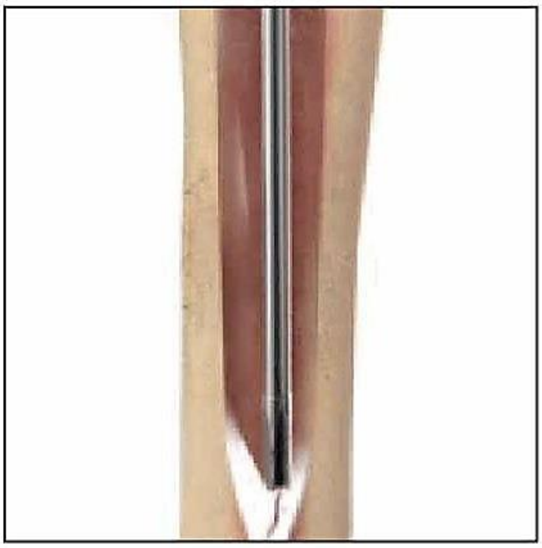

Figure (3): The osteotome instrument, which can be used to break up the cement mantle [21].

Bone cement can be softened by converting mechanical vibrations into thermal energy, making cement removal more efficient. However, heat generated during this process can lead to complications, especially when performed in vivo [28].

The OSCAR system utilizes ultrasound waves to remove bone cement from within a bone cavity. The ultrasound energy is transmitted to a long probe with an oscillating tip that liquefies the cement locally, allowing for easier removal through scraping. Originally developed in the laboratory [29], the OSCAR system has evolved into the OSCAR 3, incorporating experimental data from recent patient studies [19, 30]. This advancement differentiates between laboratory-based implant removal and in vivo procedures [31].

Research indicates that the implant's location and fixation within the body affect the ease of cement removal. For instance, replacing a femoral stem poses significant challenges using conventional methods, particularly when the implant is firmly anchored in bone cement [32]. During surgeries where ultrasound and thin probes are used to remove cement adhered to the bone, the process can take up to 15 minutes for a single area [33].

Efforts to convert electrical energy into mechanical action for heating and liquefying bone cement [34, 35] have shown potential, as this approach simplifies the removal process. However, challenges related to time and temperature during liquefaction remain.

5.Discussion:

Bone cement has become very popular as it has multiple applications in orthopedic surgeries, including vertebral fracture repair, implants scalpel fixation, and joint replacement [36, 37]. Fortunately, it is generally well tolerated, However, it has been shown that its removal during the course of revision surgery can be complex and potentially hazardous. It is also important to realised that the conventional methods of removing BC include use of mechanical instruments such as rasps and drills [38]. These techniques are often tiring and can take a long time to complete, in addition to making surgical procedures riskier because of the likelihood of bone fractures and perforation [39].

In recent years ultrasonic method has gained more attention as it is more effective and less invasive in nature [40]. Since ultrasonic waves can soften the cement, its removal is achieved with less invasion on the rest of the tissues [41]. One of the most often used system for this reason is the OSCAR system [42]. This method appears to be generally effective at BC removal but there is some evidence that its application may compromise cement-in-cement bond strength [43]. Nonetheless, manual methods are still used occasionally today because automated ones are not perfect; they have higher risks and procedural times.

An essential consideration of ultrasonic cement removal that deserves mentioning is the development of heat; when inappropriately used, it can cause adverse effects on tissue [44, 45]. These include; setting of the device, type of tissue and the nature of the surgical procedure. Elevation of the temperature can cause cell damage or death in bone, muscle and nervous tissues [45]. However, application of ultrasonic devices in surgical operations have been found to reduce heat production than conventional methods and enhances bone healing [46, 47, 48]. The treatment requires temperature control during the procedure, to avoid thermal tissue damage; therefore, ultrasonic instruments are believed to be safer and more effective for the overall BC removal [49,50,51].

However, more future studies are required to optimize the success and safety of the removal of BC in relation to revision arthroplasty.

6.Conclusion:

Bone cement is widely used to fix orthopedic and dental implant devices still, it is difficult to remove when used in revision surgeries. EUW presents a simple and effective way of BC removal which has no damaging impact on the bone as opposed to other techniques. Nevertheless, thermal injury and retention of cement are problems that have to be evaluated and managed cautiously. More research and development in EUW technology are still required to help achieve a better trade-off between treatment effectiveness and possible side effects in clinical setting. The results point out that no further research has been done to find out alternative safer methods with improved efficiency of BC removal to offer better results to patients undergoing revision surgeries.

7.References

[1] Merajikhah A, Soleimani M. BC and Occupational Hazards for Healthcare Providers and Patients: A Narrative Review. Current Surgery Reports. 28:1-8. May 2024.

[2] Patel R, Mcconaghie G, Webb J, Laing G, Roach R, Banerjee R. An overview of BC: Perioperative considerations, complications, outcomes and future implications. Journal of Perioperative Practice. 34(4):106-11. Apr 2024.

[3] Levashov G, Hasan MH, Frakulli A, Macaalay J, Nahad K. An Overview of BC Compositions used in Vertebroplasty and Their Viability in Clinical Settings. International Journal of Engineering Materials and Manufacture. 9(1):1-4. Jan 2024.

[4] Palanisamy Y, Prasad AR, Seetharaman K, Elango H, Rajan DV, Meena N. Analgesic eluting BC: A novel approach for targeted pain management in total knee arthroplasty–An in-vitro study. The Knee. 49:135-46. Aug 2024.

[5] Li SF, Li XY, Bai XH, Wang YL, Han PF, Li HZ. A meta-analysis comparing the efficacy of mineralized collagen-polymethylmethacrylate and polymethylmethacrylate BCs in the treatment of vertebral compression fractures. Plos one. 19(3):e0299325. Mar 2024.

[6] Tovar-Bazaga M, Sáez-Martínez D, Auñón Á, López-Oliva F, Pardos-Mayo B, Calvo E. Surgical technique of a cement-on-cement removal system for hip and knee arthroplasty revision surgery. Arthroplasty Today. 9:112-7. Jun 2021.

[7] Vita DC, Martín DA, Herrero AM, Cañas RG, Jiménez FA. A new technique for cement plug removal in hip and knee arthoplasty exchange. Revista Española de Cirugía Ortopédica y Traumatología (English Edition). 65(4):279-84. Jul 2021.

[8] Auersperg V, Trieb K. Extracorporeal shock wave therapy: an update. EFORT open reviews. 5(10):584-92. Oct 2020.

[9] Grogan SP, Mount CA. Ultrasound Physics and Instrumentation. [Updated 2023 Mar 27]. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2024 Jan-. Available from: https://www.ncbi.nlm.nih.gov/books/NBK570593/

[10] Silva-Ortiz VM, Chang Chien GC, Candido KD. Ultrasound Basics. InEssentials of Interventional Techniques in Managing Chronic Pain. 29; 597-602. Cham: Springer International Publishing. May 2024.

[11] Dudwiesus H, Merz E. How Safe Is the Use of Ultrasound in Prenatal Medicine? Facts and Contradictions. Part 1–Ultrasound-Induced Bioeffects. Ultraschall in der Medizin-European Journal of Ultrasound. 41(05):476-98. Oct 2020.

[12] Laugier P. Physical Principles of Ultrasound Propagation and Image Formation. Echography of the Eye and Orbit. 13:1-3. Jul 2024.

[13] Liddle A, Webb M, Clement N, Green S, Liddle J, German M, Holland J. Ultrasonic cement removal in cement-in-cement revision total hip arthroplasty: what is the effect on the final cement-in-cement bond?. Bone & joint research. 8(6):246-52. Jun 2019.

[14] Goldberg SH, Studders EM, Cohen MS. Ultrasonic cement removal in revision arthroplasty. Orthopedics. 30(8):632. Aug 2007.

[15] Roitzsch C, Apolle R, Jan Baldus C, Winzer R, Bellova P, Goronzy J, Hoffmann RT, Troost EG, May CA, Günther KP, Fedders D. Ultrasonic BC removal efficiency in total joint arthroplasty revision: A computer tomographic-based cadaver study. Journal of Orthopaedic Research®. 41(6):1365-75. Jun 2023.

[16] Berry DJ. Removal of the femoral and tibial components for revision total knee arthroplasty. InRevision Total Knee Arthroplasty. 95-101. Cham: Springer International Publishing. Aug 2024.

[17] He Z, Zhai Q, Hu M, Cao C, Wang J, Yang H, Li B. Bone cements for percutaneous vertebroplasty and balloon kyphoplasty: Current status and future developments. Journal of orthopaedic translation. 3(1):1-1. Jan 2015.

[18] 'The OSCAR 3 ultrasonic arthroplasty revision instrument for removing bone cement during prosthetic joint revision'. pp. 1–22. Nov 2014.

[19] Rogel MR. Effects of hydroxyapatite crystal morphology on osteoblast-like cell response (Doctoral dissertation, University of Notre Dame). 2006.

[20] Dimakos C, Radtke G, inventors. Instrument for removal of a bone cement tube in an artificial femur head reimplantation. United States patent US 4,476,861. Oct 1984.

[21] Kadoura AM. The release of damaged prosthesis from it's cemented position in human bone (Doctoral dissertation, Cape Peninsula University of Technology). 2019.

[22] Hu YC, Hart DJ. Complications of vertebroplasty and kyphoplasty. Techniques in

Regional Anesthesia and Pain Management. 11(3):164-70. Jul 2007.

[23] Caillouette JT, Gorab RS, Klapper RC, Anzel SH. Revision arthroplasty facilitated by ultrasonic tool cement removal. Part I: In vitro evaluation. Orthopaedic Review. 20(4):353-7. Apr 1991.

[24] Ding S, Zhang J, Tian Y, Huang B, Yuan Y, Liu C. Magnesium modification up-regulates the bioactivity of bone morphogenetic protein-2 upon calcium phosphate cement via enhanced BMP receptor recognition and Smad signaling pathway. Colloids and Surfaces B: Biointerfaces. 145:140-51. Sep 2016.

[25] Katsamenis OL, Chong HM, Andriotis OG, Thurner PJ. Load-bearing in cortical bone microstructure: Selective stiffening and heterogeneous strain distribution at the lamellar level. Journal of the mechanical behavior of biomedical materials. 17:152-65. Jan 2013.

[26] Shamsi M, Karimi M, Ghollasi M, Nezafati N, Shahrousvand M, Kamali M, Salimi A. In vitro proliferation and differentiation of human bone marrow mesenchymal stem cells into osteoblasts on nanocomposite scaffolds based on bioactive glass (64SiO2-31CaO-5P2O5)-poly-l-lactic acid nanofibers fabricated by electrospinning method. Materials science and engineering: C. 78:114-23. Sep 2017.

[27] Schwaller CA, Elke R. Revision hip arthroplasty facilitated by an ultrasonic device. Der Orthopäde. 30:310-6. May 2001.

[28] Smith PN, Eyres KS. Safe removal of massive intrapelvic cement using ultrasonic instruments. The Journal of arthroplasty. 14(2):235-8. Feb 1999.

[29] Shewale SB, Briggs RD. Gas chromatography-mass spectroscopy analysis of emissions from cement when using ultrasonically driven tools. Acta orthopaedica. 76(5):647-50. Jan 2005.

[30] Kocher T, Fanghänel J, Schwahn C, Rühling A. A new ultrasonic device in maintenance therapy: perception of pain and clinical efficacy. Journal of clinical periodontology.32(4):425-9. Apr 2005.

[31] Rodgers GW, Welsh R, King LJ, FitzPatrick AJ, Woodfield TB, Hooper GJ. Signal processing and event detection of hip implant acoustic emissions. Control Engineering Practice. 1;58:287-97. Jan 2017.

[32] Westerman RW, Howell JR. (vii) Fixation in femoral revision: the role of cement. Orthopaedics and Trauma. 1;29(2):131-9. Apr 2015.

[33] Fletcher M, Jennings GJ, Warren PJ. Ultrasonically driven instruments in the transfemoral approach–an aid to preservation of bone stock and reduction of implant length. Archives of orthopaedic and trauma surgery. 120:559-61. Oct 2000.

[34] Li T, Weng X, Bian Y, Zhou L, Cui F, Qiu Z. Influence of nano-HA coated bone collagen to acrylic (polymethylmethacrylate) bone cement on mechanical properties and bioactivity. PloS one. 3;10(6):e0129018. Jun 2015.

[35] Brooks AT, Nelson CL, Stewart CL, Skinner RA, Siems ML. Effect of an ultrasonic device on temperatures generated in bone and on bone-cement structure. The Journal of arthroplasty. 1;8(4):413-8. Aug 1993.

[36] Ramanathan S, Lin YC, Thirumurugan S, Hu CC, Duann YF, Chung RJ. Poly (methyl methacrylate) in Orthopedics: Strategies, Challenges, and Prospects in Bone Tissue Engineering. Polymers. 29;16(3):367. Jan 2024.

[37] Mounika C, Tadge T, Keerthana M, Velyutham R, Kapusetti G. Advancements in poly (methyl Methacrylate) bone cement for enhanced osteoconductivity and mechanical properties in vertebroplasty: a comprehensive review. Medical Engineering & Physics. 9:104049. Sep 2023.

[38] Vulcano E, Johnson H, Schipper O. Minimally Invasive Foot and Ankle Surgery: A Percutaneous Approach. Lippincott Williams & Wilkins. Sep 2023.

[39] Wronka KS, Gerard-Wilson M, Peel E, Rolfson O, Cnudde PH. Extended trochanteric osteotomy: improving the access and reducing the risk in revision THA. EFORT open reviews. 3;5(2):104-12. Feb 2020.

[40] Dolas R, Saravanan C, Kaur BP. Emergence and era of ultrasonic's in fruit juice preservation: A review. Ultrasonics Sonochemistry. 1;58:104609. Nov 2019.

[41] Hagan CP, Orr JF, Mitchell CA, Dunne NJ. Critical evaluation of pulse-echo ultrasonic test method for the determination of setting and mechanical properties of acrylic bone cement: Influence of mixing technique. Ultrasonics. 1;56:279-86. Feb 2015.

[42] Alphaeus O, Ngyarmunta AA, Fredrick OM. Development and Realization of an Ultrasonic Ranging Detection and Tracking Device. American Journal of Modern Physics. 8(1):22-31. Apr 2022.

[43] Guo A, Sun Z, Sathitsuksanoh N, Feng H. A review on the application of nanocellulose in cementitious materials. Nanomaterials. 10;10(12):2476. Dec 2020.

[44] Xiong G, Liu S, Yang G, Zhang S, Wang C, Poon CS. Preparation of reactive seedings by in-

situ precarbonation under power ultrasound-assisted mixing: Enhancing the hydration and mechanical properties of OPC. Cement and Concrete Composites. 13:105630. Jun 2024.

[45] Hosseinpour A, Soltani M, Souri M. Improving tumor treatment through intratumoral injection of drug-loaded magnetic nanoparticles and low-intensity ultrasound. Scientific Reports. 16;14(1):1452. Jan 2024.

[46] Palanisamy P, Alam M, Li S, Chow SK, Zheng YP. Low-intensity pulsed ultrasound stimulation for bone fractures healing: a review. Journal of Ultrasound in Medicine. 41(3):547-63. Mar 2022.

[47] Zhang L, Du W, Kim JH, Yu CC, Dagdeviren C. An emerging era: conformable ultrasound electronics. Advanced Materials. 36(8):2307664. Feb 2024.

[48] Tang J, Feng M, Wang D, Zhang L, Yang K. Recent advancement of sonogenetics: A promising noninvasive cellular manipulation by ultrasound. Genes & Diseases. 1;11(5):101112. Sep 2024.

[49] Tovar-Bazaga M, Sáez-Martínez D, Auñón Á, López-Oliva F, Pardos-Mayo B, Calvo E. Surgical technique of a cement-on-cement removal system for hip and knee arthroplasty revision surgery. Arthroplasty Today. 1;9:112-7. Jun 2021

[50] Berry DJ. Removal of the femoral and tibial components for revision total knee arthroplasty. InRevision Total Knee Arthroplasty. Cham: Springer International Publishing. 13 (pp. 95-101). Aug 2024.

[51] Marwa J.Mohammed, Sadiq J.Hamandi, and Marwan N.Arbilei. Evaluation of Novel Prosthesis Implant Adapter by Finite Element Analysis . University of Al-Nahrain, Jadriya, Baghdad, Iraq. SSN: 2296-9845, Vol. 61, pp 109-120. 2023.