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A Review of Whole-Body Vibration on Human Physical Pain and Biomaterials

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Abstract

Whole-body vibration (WBV) is regular for heavy machinery operators such as tractor drivers, earthmover operators, crane operators, and helicopter pilots. Whole-body vibration is the primary source of musculoskeletal illnesses and joint pain, which gradually impairs motor ability. On the other hand, random human body vibration is a prevalent treatment for postural refinement in Parkinson's patients. Whole-body vibration can be eliminated through measures such as ergonomics and a variety of other inventions. Additionally, a condition exists when specific components become damaged due to vibration and require replacement/repair. Biomaterials, on the other hand, are taken into consideration in this case. This review article discusses whole-body vibration, its health implications, appropriate treatments for whole-body vibration, the role and future developments of biomaterials, Human Body Vibration, Biomaterials, Health effect, Engineering Technologies, Reviewas well as technologies used to mitigate the vibration's effects.

Keywords: Human Body Vibration, Biomaterials, Health effect, Engineering Technologies, Review

Introduction

Vibrations are of much importance in several different healthy branches and engineering factors, where in general, they are an undesirable phenomenon. Environmental factors cause vibration rotating components and human activity which has the possibility of causing vibrations in a structure [1] - [2]. The effects of these vibrations include (i) excessive variable stress on machine components, (ii) undesirable noise looseness of parts, (iii) shortening the fatigue life of the structure, and (iv) the failure of the system [3]. Exposure to excessive vibration can also be harmful to the human body, such as muscular pain and human discomfort [4]. The vibrations imparted to the human body by machinery in operation are referred to as human body vibrations. Vibrations can be both beneficial and detrimental. We are constantly exposed to vibrations in our daily lives, whether through the vehicles we drive in, such as buses, trains, and automobiles, or from the devices we work. Vibrations are frequently desired and provide pleasure; for example, the messages we receive often involve vibration, which assists in relaxing our muscle tissue and relieving physical pain. However, vibration can also be the source of panic and despair. It may have both transient and permanent consequences.

Additionally, nausea is an effect of vibration [5]. Vibrations of less than 20 Hz and higher than 70 Hz, which we frequently encounter daily, are incredibly detrimental to the human body's functioning. Even exposure to whole-body vibration can alter vestibular function [6]. Prominence to whole-body beat also carries a risk of cancer, as the operator or anyone in contact inhales many carcinogenic chemicals during operation [7].

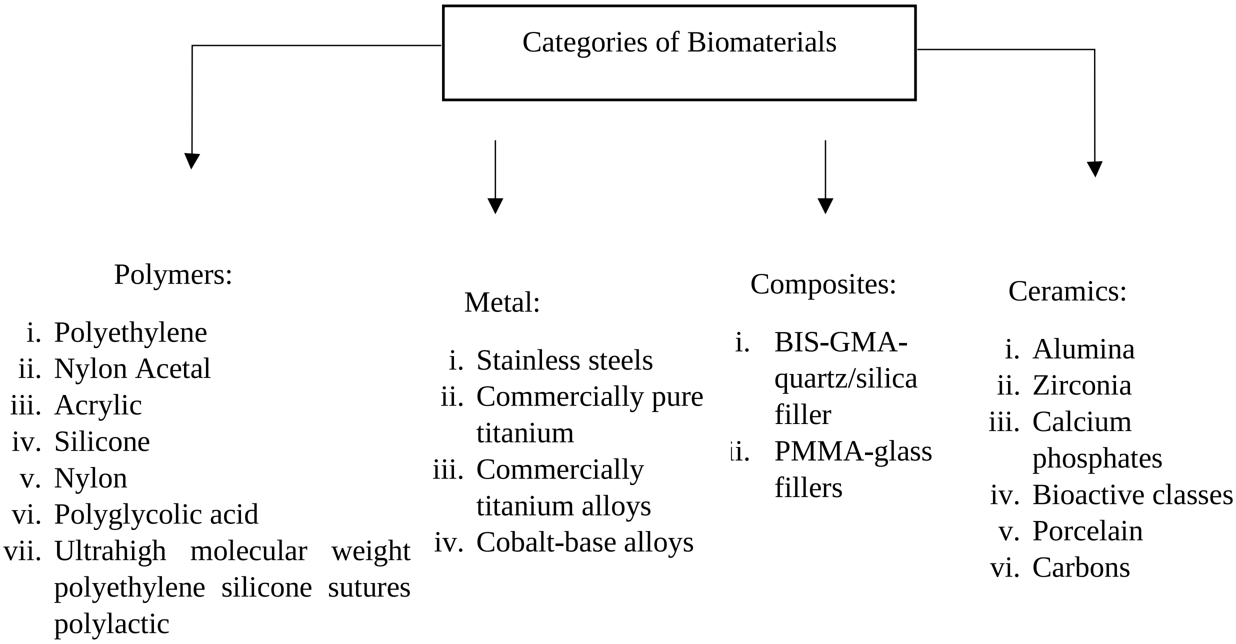

Fig. 1. Categories of biomaterials.

Figure 1 shows the categories of biomedical that contain polymers, metal composites, and ceramic. This type of material has its chemical mixture where the material depends on the percentage of material that is not good for health in the long term.

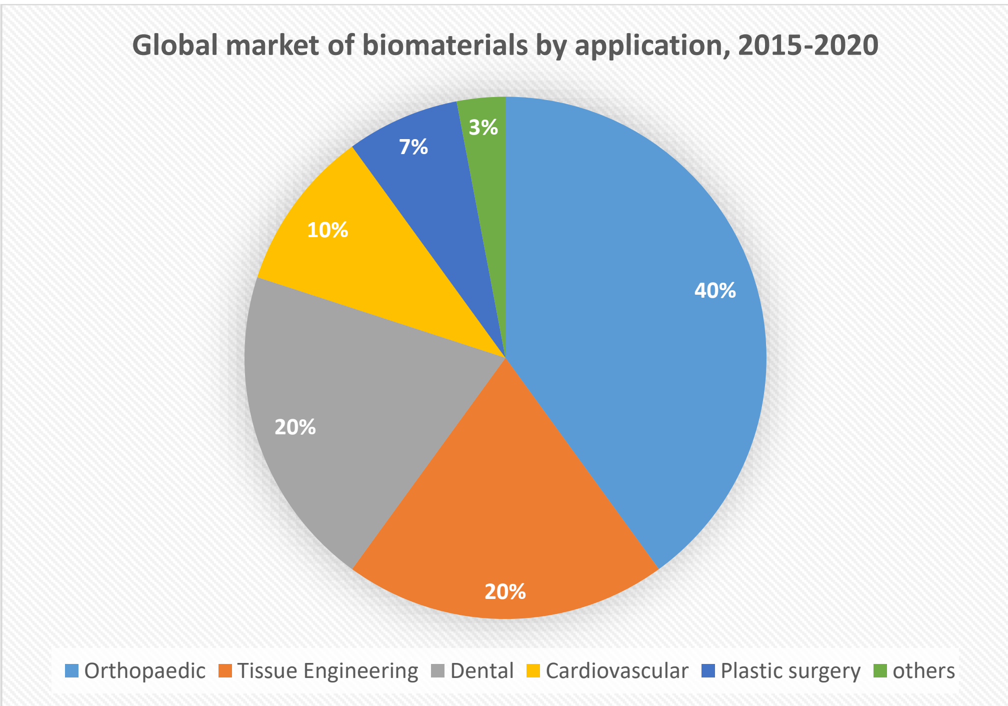

Fig. 2. The global market of biomaterials by application, 2015–2020, (Source: www.sciencedirect.comwww.grandviewresearch.com).

Table 1: Characteristics of various biomaterials

Ref No	Materials	Advantages	Limitation	Application
[8] [9]	Metals	• High strength and toughness. • Significant fatigue resistance. • High elasticity and malleability	• High Young's modulus. • High density	Load bearing implants like bone replacements, screws, dental root implants, etc.
[10]	Ceramics	• Biocompatible. • High strength and stiffness. • Good corrosion and wear resistance. • Low density	• Brittle. • Low fatigue resistance. • Anisotropic mechanical properties under different loading conditions.	Dental and orthopedic implants, coating for load-bearing implants, medical sensors, etc.
[11]	Polymers	• Biocompatible. • Good resilience. • Lightweight. • Easy to fabricate. • Good corrosion resistance	• Low strength. • Deform with time. • May degrade	Hip joint socket, blood vessels, contact lenses, heart valves, artificial hearts.
[12] [13]	Composites/ Bio composites	• Strong. • Tailor-made. • Good corrosion and wear resistance. • High Biocompatibility	• Lack of consistency or • Homogeneity • Difficult to prepare	Bone cement, joint replacements, Dentistry, bone plates, rods, screws, etc.

Characteristics of several types of biomaterials are discussed in detail in the table above.

This article presents a state-of-the-art review of vibration's impact on the human body and control systems, emphasizing the use of health and material structure in passive structural vibration management. The remainder of this article is structured as follows: Section 2 discusses the notion of literature review and its numerous physical manifestations; Section 3 discusses the implications for human health; Section 4 discusses the uses of technology in various vibration control systems, and Section 5 draws some conclusions.

Identification Method of Human Body Vibration

Numerous studies have been conducted to determine the effect of human vibration and the methods for reducing it and preventing its transfer from the equipment to the human body via insulation. Akinnuli et al. [14] studied the effect of whole-body vibration on earthmover operators working on construction sites. Daily, operators are exposed to vibrations over the recommended level. The study was conducted using a tri-axial accelerometer. The measurements were made in all three coordinates, and properties such as weighted root mean square, vibration dosage, time to exceed the recommended exposure level, and crest factors were analyzed. It was concluded that necessary steps should be adopted to protect operators from health concerns, whether through technology or implementing more stringent procedures.

In 1918, Hamilton researched the biodynamic system of the human body. As a result of his work, he identified the vibration white finger syndrome [15]. M. Bonvezi outlined the health risks of extended exposure to whole-body and hand-transmitted vibration [16]. Kamalakar, Guru B. Mitra, and Anirban C. investigated the possibility of hand injuries caused by hand-transmitted vibration (HTV) and handheld power tools. They advocated utilizing anti-vibration isolators as a preventative measure to minimize the risk of injury [17]. Moreover, Kamalakar researched the biodynamic reactions of the human hand to various postures and grip positions under different vibration magnitudes. As a consequence, they indicate the best poses for safety [18] [19]. Additionally, Dong et al. advocated a preventative step in the form of anti-vibration gloves in addition to the biodynamic response [20]. Dong considered the significance of random versus harmonic stimulation for the human finger and advised that safer powered handheld tools be designed [21]. Tarabini et al. investigated the influence of various hand grips on handheld instruments and concluded that a suitable handle form is necessary [22].

Krol Piotr et al. [23] assessed the efficacy of an amplitude signal and frequency modulation training strategy for whole-body vibration. The effect of WBV on the myoelectric activity of the vastus laterlis and vastus medialis in 29 females was investigated using electron myography. Two trials were conducted without vibration, while the remainder were born with a random frequency in random order. The EMG amplitude of both muscles was found to be greater during pulse than when not vibrating, and it improved with amplitude and frequency. The most significant values obtained were at 60 Hz and 4 mm amplitude. The findings significantly aided in the development of customized vibration platform training sessions.

Qassem et al. [24] analyzed a recently developed model's vibration performance on a human weighing 100 kg. Additionally, an analogous electric simulation was performed and analyzed using computer software. The vibration moves from the combined hand and seat, as well as from each of them independently. The lower hand, torso, head, lumber spine, and cervical Spine were all affected when the sound wave from the hands was more significant than the vibration from the chair. Similar findings were obtained when the body was confined to vertical vibration.

Using dynamic modeling, Rosen et al. [25] investigated the viscoelastic characteristics of a human body while sitting. The study was conducted to conduct a qualitative analysis of the ride quality caused by vertical vibration. The experiment used a five-degree-of-freedom multibody to model the movements of a sitting body. The viscoelastic properties of the seats are formulated using nonlinear stiffness characteristics and convolute integrals to reflect time-delay terms. Due to the nonlinear features of the chairs, the transfer functions of the floor input were found to be different from the input magnitude. Xu et al. [26] analyzed a cab operator and an isolating mount technology using a model. The process for calculating the natural frequency of the methods is illustrated. The ideal design was introduced to minimize motion coupling and achieve the desired natural frequency. It was discovered that selecting an appropriate mount location can aid in achieving the desired mode coupling and frequency. The vibration isolation performance will significantly improve by reducing the disruption caused by one motion to the next.

Types of diseases

Considering that it is self-evident that body vibration affects health concerns, determining how and which organs are most affected is critical [27] - [28].

3.1 Lower back:

Nevertheless, distinguishing the impacts of whole-body vibration on the lower back from the bent and aberrant posture is difficult [29]. Even though there was no reported harm, whole-body vibration affects the vertebrae and endplates because continuous vibration induces malfunction and fracture in the endplates after several cycles. Additionally, the angle of such a backrest plays a significant effect on comfort [30].

3.2 Spondylolysis:

Long-term exposure to whole-body vibration has been linked to spine tissue damage. It is most frequently reported by helicopter pilots, tractor drivers, farmers, earthmovers, and other individuals who have been exposed to prolonged whole-body vibration [31].

3.3 Parkinson disorders:

Arbitrary whole-body vibrations were already evaluated as a measure of posture correction in people with Parkinson's disease. Recently, no such drug has been available for posture correction, although it does result in crystallinity, allowing for a healthier lifestyle [32].

3.4 The body's musculature:

Musculoskeletal problems are incredibly prevalent and might originate in the joints, skeletons, ligaments, tissues, nerves, or interstitial cells. Vibration has a detrimental effect on the musculoskeletal system due to tissue deterioration. However, it is considered anabolic when taken in regulated doses and may provide a unique biomechanical prophylactic for osteoporosis [33]. It is a highly effective technique for delaying the onset of musculoskeletal aging. Additionally, it has been demonstrated as a means of preventing osteoporosis in females [34].

The biomechanics of the Lumbar Spine is influenced by both whole-body vibration and osteoporosis. Whole-body vibration is regularly exposed to lumbar interbody fusion patients while driving, taking the bus, or working in particular settings. Vibration loads exert a more significant hazard on the lumbar Spine than static loads do. In addition, since the world population's average lifespan has increased, the prevalence of osteoporosis has been steadily rising over the past few decades. Osteoporosis can decline the lumbar Spine's bone mineral density, bone strength, and stiffness. Following lumbar interbody fusion, patients may develop osteoporosis. Both whole-body vibration and osteoporosis may improve adjacent segmental degeneration (ASD) following lumbar interbody fusion [35].

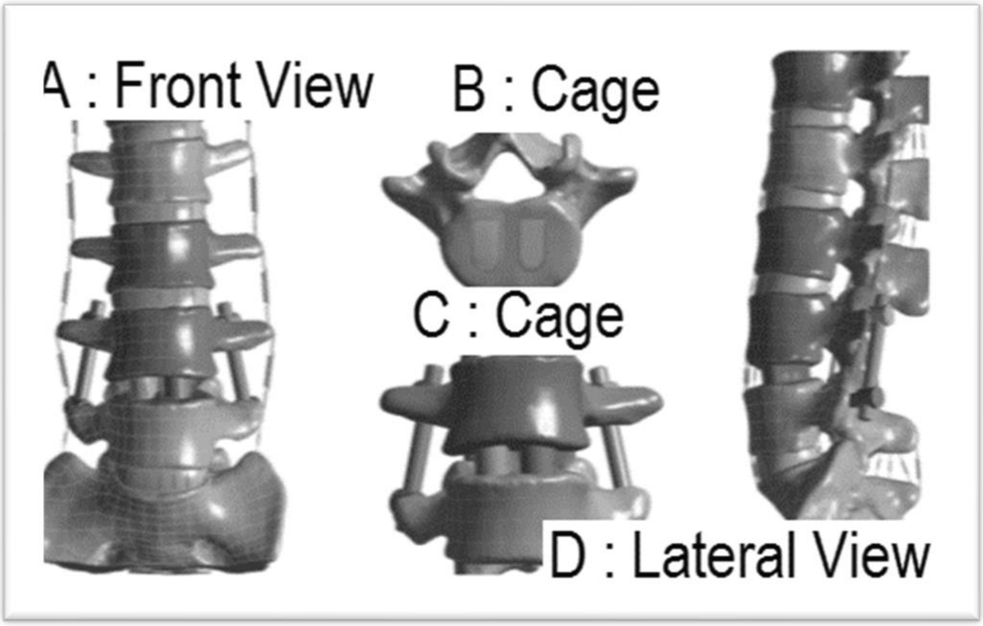

Figure 2: The finite element model of posture lumbar interbody fusion (PLIF) [35].

There are four parts to the lumber shown in this diagram: (A) is an anterior view of the lumber, (B and C) are posture lumbar interbody fusions, and (D) is an external view of the posture model.

Anti-vibration technologies for the whole body

When evaluating the body's response to structural vibration or the impacts of the human body on structural vibrations, it is necessary to include both the human nervous system and the structure as a whole, producing a human contact system. Historically, body biomechanics research has focused on the dynamic features of stationary humans, those sitting cross-legged, and the human body's behavioral reaction to vibration; however, structural engineering research has focused on human-induced vibration of systems. The research on human interactions necessitates familiarity with both disciplines. Lenzen et al. [36] was arguably the first structural engineer to state that human occupants produced a significant amount of dampening, based on his research on steel joist-concrete slab platforms. Ellis and Ji [37] demonstrated human-structure interaction in a grandstand experiment with and without about 4000 spectators. 1) When there was a crowd present, there was an additional frequency, which meant that the stand had two fundamental modes; 2) the natural frequency of the empty stand was found to be between the resonant signals of the occupied stand, and 3) damping improved exponentially when people were involved. Additional testing on other constructions was conducted to corroborate the findings. These observations suggest that the body functions as an extra mass-spring-damper for the structure. Subsequent research [38] [39] [40] confirmed that the inhabitant functions as a mass-spring-damper on a network, contributing to the structure's damping. The occupants and the frame form a biological system. However, no additional findings of two vibrational (natural) frequencies have been made in human-structure interaction experiments in the manufacturing industries [41].

The rapid growth of technology has altered how the advanced manufacturing industry operates, resulting in lighter structures. A thin plate is a lightweight construction frequently utilized in various disciplines, including aircraft, machinery, civil engineering structures, electronic equipment, computer peripherals, modern housing, and the marine industry. The effort toward lighter systems, on the other hand, has the potential to make structures more vulnerable to vibration. Consequently, fatigue, instability, and performance degradation may occur, eventually damaging highly strained systems. Due to the interaction between mechanical vibration and acoustic fields, these vibration concerns may also result in acoustic disruption. As a result, vibration management with the appropriate approach is required to avoid all situations above. Numerous studies have been conducted in the past to establish a control strategy for reducing machine-generated vibration. These include the following: (i) modifying the system so that the natural frequency does not coincide with the operating speed, (ii) adding damping to prevent excessive response, (iii) installing isolation devices between adjacent subsystems, and (iv) adding discrete masses to equipment to absorb vibration. Despite these investigations, it has not been possible to develop an adequate control system that applies to all vibration scenarios. Indeed, the first three approaches are challenging to implement and ineffective due to their design complexity, high cost, and unfeasibility at lower frequencies. However, the latter solution, which employs discrete masses or what is known as dynamic vibration absorbers, is more sound because it does not introduce additional vibration energy to the structure [42].

Additionally, they are frequently found to be efficient and are regarded as low-cost gadgets. While this is the more feasible option, they are concerned about adding additional weight to the host structure. It will undoubtedly be detrimental to the automotive and aerospace industries, as the importance of a host system is critical to overall performance, as it affects the vehicle's fuel economy. Apart from that, the dynamic vibration absorber can only deal with or address vibrations occurring in the intended mode, not throughout a broad frequency range [43]. As a result, this method still has some space for improvement in terms of device system upgrades. Muhammad et al. [44] have produced a passive lightweight Dynamic Vibration Absorber (DVA) to reduce thin plate vibration amplitude. The dynamic features of a plate structure are studied using a finite element approach in the first portion of the study. A thin plate with all sides clamped is considered in this work. The primary objective of this study is to determine the plate's modal characteristics, such as natural frequency, mode shape, and vibration amplitude, before the container is coupled to a vibration absorber. This section examines the efficiency of the vibration absorber in reducing the vibration of structural plates. Finally, the derived model is tested using experimental modal analysis to confirm the reliability of the provided results.

Conclusion

Several studies on whole-body vibration and the involvement of biomaterials in the repair of fracture joints and tissues have been described in this review. It is noted that whole-body vibration is the primary cause of musculoskeletal illnesses and joint discomfort, gradually impairing a person's motor ability. It causes a variety of health impacts, including pain in the lower back of the body, spinal cord dysfunction, and musculoskeletal illnesses. Human vibration is the primary cause of these effects. Parkinson's disease is one in which much work remains to be done to mitigate the influence on the human body caused by whole-body vibration associated with an active lifestyle. Whole-body vibration can be eliminated through strategies such as ergonomics and various other inventions to reduce the effect of WBV on humans. The vibration control design is a challenging problem for engineers. Professionals must develop numerous elements unique to each workstation that influence the selection of vibration insulators and system mounting processes. Biomaterials are being used to replace/repair injured, bodily parts, such as joints, bones, and tissue. Life cycle analyses of these materials are especially critical, as each category has a unique influence on the human body as it ages. Numerous control system methods have been developed and implemented in structural vibration control, particularly in the last five years. This article provides an in-depth examination of this subject. The concept, physical realizations, engineering models, and passive structural vibration control applications are discussed.

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