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Neurotechnology for Circadian Sleep Optimization using AI Smart Beds for Mitigating Osteoarthritis and Arthroplasty

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ABSTRACT

Circadian biology is playing an increasingly vital role as a biomechanical driver for gene regulation in musculoskeletal diseases, including osteoarthritis. Osteoarthritis is a rising challenge in New Zealand with one in eleven adults affected. Enhancing restorative sleep to aid healthy ageing through innovations such as AI-enabled Smart Beds in combination with Neurotechnology holds significant promise. Neurotechnology refers to technologies that connect with the nervous system and improve deep sleep, health, brain performance, etc. Research shows that Neurotechnology combined with AI-Smart Beds can lead to deeper restorative sleep due to greater circadian entrainment and synchronization of slow-wave sleep. Although most studies are being performed in laboratory conditions, there should be a paradigm shift and success in home-based applications with AI smart beds integrating Neurotechnology in future. Intersecting the boundary between Chronobiology and Neurophysiology of deep sleep may be the way forward by introducing cutting-edge, user-friendly, AI sleep technology innovations that can be used within homes that stimulate prolonged non-REM/slow-wave sleep. The Smart Tek AI dynamic mattress recently launched could be used to restore musculoskeletal health by enhancing sleep quality and circadian alignment. The goal of this position paper is to review osteoarthritis as a disease and scientifically postulate how Neurotechnology and AI Smart Bed integration could enhance slow-wave sleep to mitigate health risks arising from osteoarthritis to minimize the need for Arthroplasty surgeries worldwide, which are increasing as a public health burden in New Zealand.

Keywords
AI Smart Bed, Smart Tek AI, Neurotechnology, Slow-Wave Sleep, Circadian Entrainment, Osteoarthritis, Arthroplasty, Chronotherapy, Preventive Sleep Medicine.

Introduction
Sleep performs a fundamentally restorative role in human physiology, and sleep surfaces directly influence comfort, posture, pressure distribution, and musculoskeletal recovery. Prolonged exposure to suboptimal sleep biomechanics may contribute to discomfort, impaired recovery, and potentially accelerated degenerative changes in vulnerable individuals over time. Osteoarthritis remains highly prevalent in New Zealand, affecting approximately one in eleven adults, with steadily increasing rates of osteoarthritis-associated hip and knee arthroplasty reported nationally. An ageing population further compounds this burden, with adults aged over 65 years representing an increasingly large 17% proportion of the national population requiring Arthroplasty surgeries [1,2].

Molecular mechanisms of circadian rhythms are interlocked transcription–translation feedback loops wherein clock genes produce endogenous ~24-hour oscillations which allow the synchronization of physiological and behavioral functions with respect to the light–dark cycle a discovery that has earned the Nobel Prize in Physiology or Medicine [3]. Circadian biology is also increasingly perceived as a pivotal regulator of musculoskeletal health, closely related to the pathogenesis of osteoarthritis or bone cartilage degeneration [4,5]. Chondrocytes of articular cartilage have unique molecular clocks that control the timing of extracellular matrix synthesis, repair and inflammation in a circadian ~24-hour cycle [4,6]. There is evidence that disruption of these rhythms due to inadequate sleep, circadian misalignment, or age has a long-term negative effect on cartilage homeostasis inducing degenerative changes [7,8]. *In-vivo* experiments show that dysregulated circadian gene expression (PER2, BMAL1) causes osteoarthritis-like changes to chondrocyte activity whilst synchronized circadian signaling promotes chondrogenesis and tissue healing [4,5]. Moreover, aging-related circadian decline suppresses the amplitudes of cartilage rhythmicity, resulting in an enhanced vulnerability to chondral degeneration, thereby adding further to the burgeoning demand for arthroplasty surgeries [9,10].

Relatedly, one approach is to understand the impact of circadian alignment as it relates to systemic inflammation and immune responsiveness. Chronic low-grade inflammation (also known as "inflammaging") is a major determinant of osteoarthritis (OA) evolution [11]. Circadian rhythms have additionally been found to coordinate the release of inflammatory cytokines and cortisol patterns, with rhythm dysfunction driving sustained inflammatory states [9,12]. Neurotechnology-based sleep systems offer the opportunity to minimize inflammatory burden, through circadian synchrony and thereby mitigate cartilage degradation and improve longer term joint health outcomes [10,13]. Circadian neurotechnology and AI-enabled sleep systems represent emerging, non-invasive approaches that may avoid complications or restore musculoskeletal health by improving sleep quality, circadian alignment, and pain modulation in individuals with osteoarthritis (OA) [12,13].

Scientists have known for decades that the growth hormone is closely tied to deep sleep, especially the early stages of non-REM sleep. Even a lack of sleep for a single night can reduce hormone levels. Recently, researchers at the University of California, Berkeley, have identified the brain circuits responsible for controlling growth hormone release during sleep. The findings provide a clearer picture of how circadian rhythm of sleep and hormone regulation are connected. The neurons responsible for regulating growth hormone release during the sleep-wake cycle are located deep within the hypothalamus, a brain region shared across mammals. These include growth hormone releasing hormone (GHRH) neurons and two types of somatostatin neurons. After growth hormone is released, it increases activity in the locus coeruleus, a brainstem region involved in attention, arousal, cognition, and responses to new experiences. Problems affecting the locus coeruleus have been associated with several psychiatric and neurological disorders. Growth hormone not only helps build muscle and bones and reduce fat tissue but may also have cognitive benefits as well [14]. Too little sleep reduces growth hormone release, and too much growth hormone can in turn push the brain toward wakefulness. So deep sleep does drives growth hormone release, and growth hormone level rise feeds back to regulate wakefulness, and this balance is essential for growth, repair, and metabolic health.

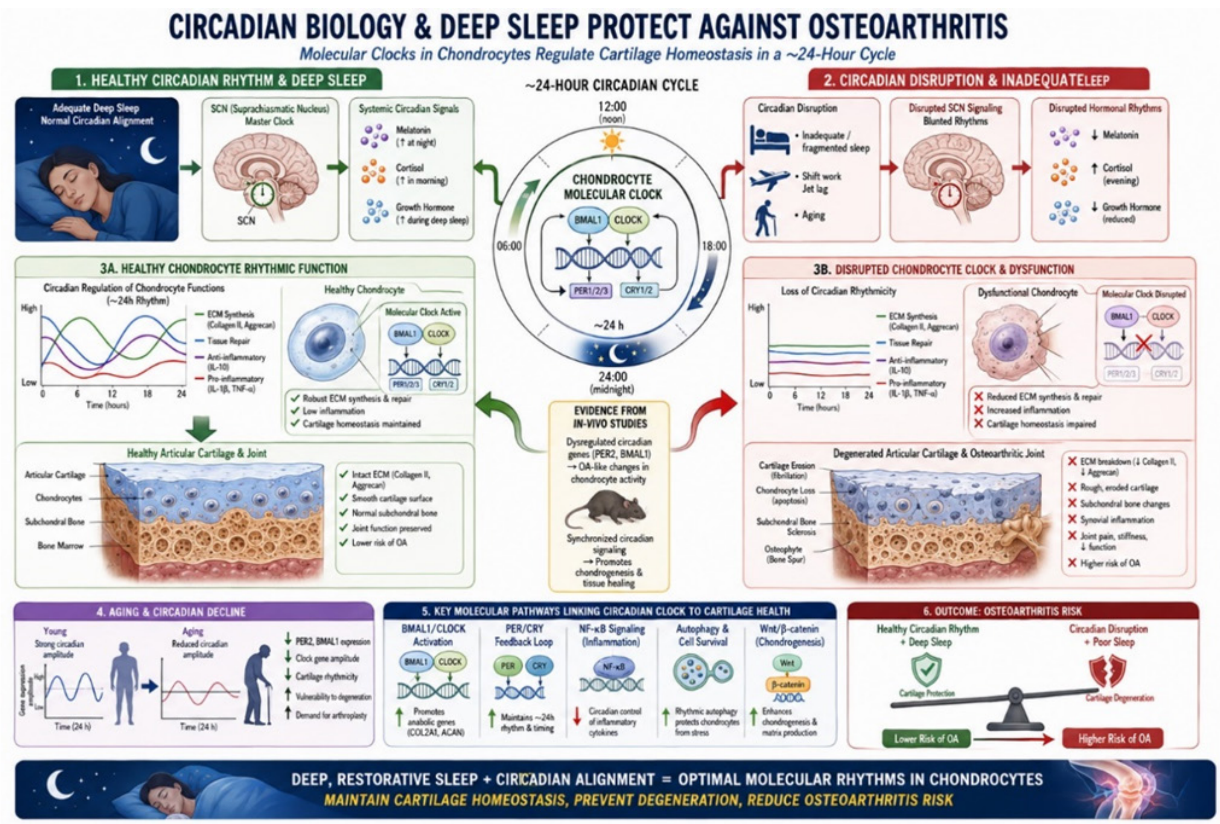

Figure 1: How Molecular Clocks in Chondrocytes Regulate Bone Cartilage Homeostasis in a 24 hr Circadian Cycle.

The Smart Tek AI mattress recently launched in April 2026 in New Zealand is an innovation in sleep science with potential to improve sleep health and clinical outcomes [15] and this paper positions it for integration with Neurotechnology to augment its use in preventive sleep medicine. Fully functional AI-enabled Sleep Systems can practically act as external circadian modulators by integrating real-time physiological sensing (e.g., heart rate variability, movement, temperature) with adaptive environmental controls (light, pressure redistribution and thermal regulation) [16,17]. In such systems, circadian alignment can be bolstered by improved sleep architecture (notably slow-wave sleep induction) through wearable Neurotechnology critical for helping hydroxy trophic compare and local engrossment repair [12]. As circadian disruption correlates with both increased inflammatory signaling, and impaired bone and cartilage metabolism, the promotion of synchrony via smart sleep environments may help combat chronic low-grade systemic inflammation, a central component of osteoarthritis [11,13].

Since about one in eleven adults in New Zealand are estimated to have osteoarthritis [18], projections show that proportion of people aged over 65 years in New Zealand affected with the disease are expected to grow from 17% in 2026 to 25% by 2050 [19]. Consequently, older people, especially those over 65 years of age and notably in the 70–74 age group, have the highest occurrence of arthroplasty surgeries [20]. Arthroplasty is not only in increasing demand it also forms an important and evolving area of public health cost and burden in New Zealand [20,21]. Whether interfacing biological rhythms with regenerative processes, AI-driven sleep neurotechnology provides a potential radical change non-invasive strategy to even delay orthopedic degeneration and decrease the future demand for joint replacement surgery within ageing populations like New Zealand [22,23]. This study thus provides a conceptual framework that is theoretically underpinned and clinically feasible to inform safe implementation of neurotechnology-enabled AI-enabled sleep systems within homes in the context of preventive medicine.

Materials and Methods

The newly launched Smart Tek AI is essentially a dynamic intelligent mattress system with 6-Zone Adaptive Sleep Surface which integrated pressure and biometric sensors to constantly track body posture movement, respiration, heart rate and sleep stages metrics. It features automated micro-adjustment tech for instant pressure redistribution and musculoskeletal support; it also has low-frequency wave decompression modules with graphene-based thermal regulation to optimize comfort circulation and sleep temperature. The mattress has been integrated with a motorized adjustable base and controlled via app-based and voice-enabled interfaces to enhance user interface for sleep ergonomics. Versions could incorporate massage (rolling wave vibrations) and other features within its scope of functioning. To break down its composition, internally the smart bed is composed of an integrated, multi-layered system combining embedded physiological sensing, adaptive support structures. At its core, sophisticated architecture of the sleep system surface comprises high grade breathable materials with multiple zones, gel-foam layer, and a foot constant-temperature graphene heating feature with air chambers.

Adaptive air-cells as a responsive sleep system adjust firmness and load distribution across multiple zones to maintain best possible ergonomic support [17]. The physiological sensing through the mattress architecture allows minute pressure detection and sleep monitoring [24]. The significance of its broad ecosystem integration enables it to connect with diverse sleep bands and pressure detection modules. The highly granular body-zone support has six zones for hardness adjustment which is useful for customizing spinal alignment and comfort to different body types. The mattress has a nice thick girth with excellent comfort fit. The smart mattress can be elevated upwards and downwards based on voice or remote. The mattress has a preset memory and auto-inflation, so different users can return it to preferred settings quickly and maintain consistency. A central AI control unit in smart-bed processes real-time data using machine learning algorithms to infer sleep patterns and health related data [25].

Smart beds combine AI-driven analytics using sensors and adaptive biomechanics using a mattress that is therapeutic as a sleep surface since it provides real-time postural alignment throughout the night [16]. They have the potential to influence an individual's sleep and health differently, particularly adults. Smart beds use multiple biosensors for pressure sensing and modulate the dynamic sleep surface for pressure redistribution of each user, irrespective of his or her height or weight or age [22]. Smart beds are known to improve sleep quality in clinical recovery [26]. The Smart Tek AI seems to be a remarkable breakthrough as possibly the most affordable smart-bed in New Zealand for use in homes. Its advanced features include effects of adaptive firmness, cradling, zero-G, relaxation, decompression, etc. which have the potential to restore and rehabilitate the body. The Smart Tek AI could shape behavior and customize lifestyles owing to comprehensive health metrics generated via its Sleep App. The Smart Tek AI bed's main strengths are customization, monitoring, and automation.

AI-enabled sleep systems, including the newly launched Smart Tek AI, may act as external circadian modulators by integrating real-time physiological sensing (e.g., heart rate variability, movement, temperature) with adaptive environmental controls such as light modulation, pressure redistribution, and thermal regulation [16,17]. In such systems, circadian alignment may be enhanced through improvements in sleep architecture, particularly slow-wave sleep, which is critical for tissue restoration, metabolic recovery, and neuroendocrine regulation [12,27]. As circadian disruption correlates with increased inflammatory signalling and impaired bone and cartilage metabolism, the promotion of synchrony via smart sleep environments may help reduce chronic low-grade systemic inflammation, a central contributor to osteoarthritis progression [8,11]. By interfacing biological rhythms with regenerative processes, AI-driven sleep neurotechnology represents a potentially transformative non-invasive strategy to delay orthopaedic degeneration and reduce future demand for joint replacement surgery within ageing populations such as New

Zealand, where musculoskeletal disorders are highly prevalent [10,20]. Research further suggests that advanced AI-sleep systems may support preventive health strategies by reducing prolonged tissue loading, poor spinal alignment, and sleep disruption causing chronic musculoskeletal and neurological disorders.

Results

Recent advances in neurotechnology suggest that process of closed-loop sleep systems can artificially promote deep (or slow-wave) sleep (SWS) by delivering auditory stimuli aligned with endogenous brain oscillations, as recorded via electroencephalography in a sleep laboratory. Evidence of this is that rhythmic acoustic stimulation has been used to induce and enhance slow oscillations during non-REM sleep, while improving both the activity rate of slow-wave activity as well as sleep architecture [28]. Clinical research with automated closed-loop stimulation devices from a controlled lab group found improved executive functioning and increased deep sleep in healthy middle-aged adults [29]; while home-based wearable auditory stimulation systems markedly increased slow-wave activity during the night of older adults in domestic homes [30]. Acoustic stimulation enhanced slow oscillation activity and improved overnight memory consolidation in mild cognitive impairment patients [31]. In line with these results, comparable pilot studies on individuals suffering from Alzheimer`s disease have confirmed that acoustic neurostimulation can also be used to enhance slow-wave sleep and neurophysiological restoration within homes [32]. Collectively, these results indicate that AI-enabled neurotechnology and smart sleep systems may comprise effective external neural modulators to augment endogenous slow-wave synchronization with the promise of improving overall health through improved deep-restorative sleep.

Circadian neuroscience affects long-term health by matching daily endogenous biological cycles with external environmental cues. One way this can be uniquely facilitated is by tailoring sleep surfaces that directly influence deeper sleep or sleep latency, sleep efficiency and sleep cycle duration [33]. It is important for us to reorient our focus to understand that static sleep surfaces and dynamic sleep surfaces are both very different. Culturally and traditionally more use of static surfaces/beds/mattresses is currently afforded in society. However, on newer provisions, the options of choice, availability, perception and comparison of innovations can be systematically carried out qualitatively and quantitatively. Dynamic surfaces may influence user satisfaction differently when compared with static surfaces [34]; and a comparative analysis of ethnic preferences in user satisfaction for sleep surfaces may also be seen [34]. It will be interesting to note trends on how certain ailments affect certain ethnic populations more than others and correlate these to sleeping surfaces used. Although current static sleep surfaces are quite robust and restorative, AI enabled sleep systems may allow for better entrainment of circadian sleep-wake rhythm via the body clock with external sleep surfaces since they can be modulated by zeitgebers (time givers) like, temperature, light, relative humidity, pressure redistribution, other cues, etc. [35]. An earlier study on AI-smart bed with controlled thermoregulation improved sleep quality metrics including sleep score, sleep

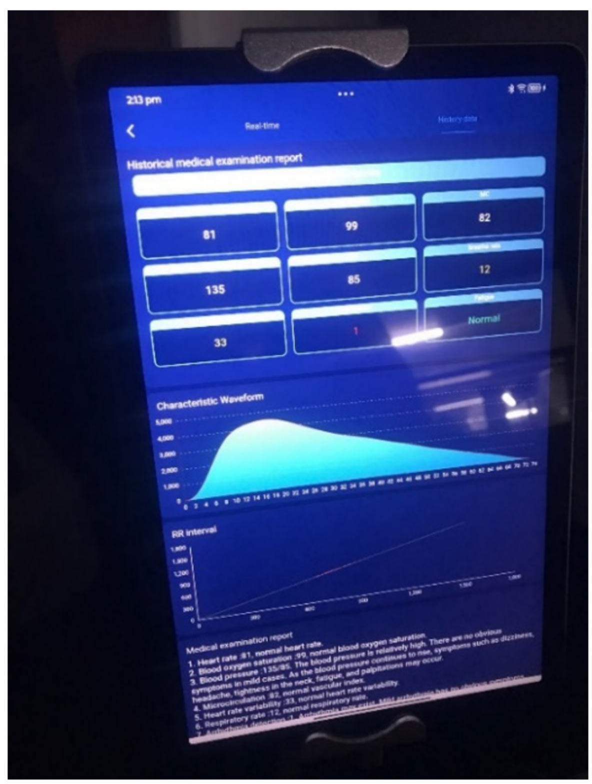

Figure 2: Original Photograph of “Smart Tek AI” launched by Serene Life & New Zealand Company, April 2026.

latency, and restorative sleep parameters at lower temperature [36]. Therapeutic sleep surfaces have been recommended for restorative support for alleviation of sleep disorders as well as rehabilitation both of which are essential in New Zealand [33].

It is essential to clear the misunderstanding that AI-Sleep Systems are only suitable for hospitals, clinics or elderly patients although this is true as a fact [37,38], they can be used by normal healthy people. AI-enabled adaptive sleep systems were shown to provide superior sleep comfort, pressure redistribution, and physiological sleep optimization compared with conventional static sleep surfaces in healthy adults [39]. Research also proposed AI-driven personalized sleep-quality prediction and feedback systems using IoT and smart sleep technologies to improve long-term sleep health in adults [40]. Hence, this paper would like to provide advantages of the Smart Tek AI as a case-study for normal healthy adults or couples for smart lifestyles within homes, improving both sleep and health especially when coupled with Neurotechnology in future. Infact, most individuals may favor a dynamic surface after knowing its advantages or after trialing its amazing snug comfort-fit, it is just the cost factor that may be limiting initially, but that may change in future.

The junction of circadian neuroscience, sleep technology, and musculoskeletal health has provided a unique translational opportunity for the amelioration of chronic degenerative diseases such as osteoarthritis (OA), which continues to be one of the leading causes of disability and a major driver of arthroplasty surgeries globally, including in New Zealand.

The concept of a neurotechnology-enabled Smart Tek AI system for circadian alignment represents a forward-looking, non-invasive strategy to intervene early within the osteoarthritic disease cascade through enhancement of sleep architecture, neuromuscular recovery, and cellular homeostasis. Smart sleep systems integrated with neurotechnology may modulate circadian sleep-states, monitor physiological biomarkers, and optimize restorative sleep stages, particularly slow-wave sleep (SWS). Deep sleep is characterized by dominant delta-wave activity ranging between 0.5 and 4 Hz, representing the slowest electrical oscillations produced by the brain and critically involved in tissue restoration, hormonal regulation, glymphatic clearance, and synaptic recovery at $0.5\ \text{Hz} \le f_\delta \le 4$ HZ. Neuromodulation devices, sensory entrainment systems, and sleep stimulation technologies capable of enhancing deep sleep and circadian synchrony may therefore emerge as valuable tools in preventive medicine and regenerative musculoskeletal health. Such technologies could potentially support circadian entrainment of cartilage metabolism, reduce inflammatory signaling, improve neurophysiological recovery and contribute to healthier ageing trajectories in populations at risk of degenerative joint disease [41].

Fully functional neurotechnology-enabled systems as in Figure 3 may function as advanced external circadian modulators through the integration of real-time physiological sensing—including heart rate variability (HRV), movement patterns, respiratory activity, and

Figure 3: Model integrating Smart Tek AI with Neurotechnology: Framework for Preventive Medicine.

thermoregulation—with adaptive environmental controls such as intelligent lighting, pressure redistribution, and dynamic thermal regulation [42,43]. Within such systems, circadian alignment may be enhanced through optimization of sleep architecture, particularly slow-wave sleep (SWS), which is critically involved in neuroendocrine recovery, growth hormone secretion, tissue restoration, glymphatic clearance, and local cellular repair processes. Deep sleep is characterized electrophysiologically by dominant delta-wave oscillations between 0.5 and 4 Hz. 0.5 Hz"$\leq f\delta \leq 4$ Hz and these can be artificially induced and sustained.

Schematic illustration of the low frequency oscillatory dynamics adopted in the slow-wave sleep neurotechnology:

$$f(t)=A\sin(2\pi ft+\phi)$$

where typical cortical slow-wave activity correlating with restorative deep sleep is expressed in roughly the frequency range of 0.5–4 Hz as shown in Figure 4.

Thus, there are four stages of sleep as shown in Figure 4, these stages replicate over 5 to 6 times a night in humans depending on the age. The key stage in adults is NREM3 or SWS (20-40 mins) that allows growth hormone release, tissues are repaired and immune system bolstered. This sleep stage is lowered or skipped in older adults as compared to younger people and becomes increasingly weak in elderly people especially ailing patients,

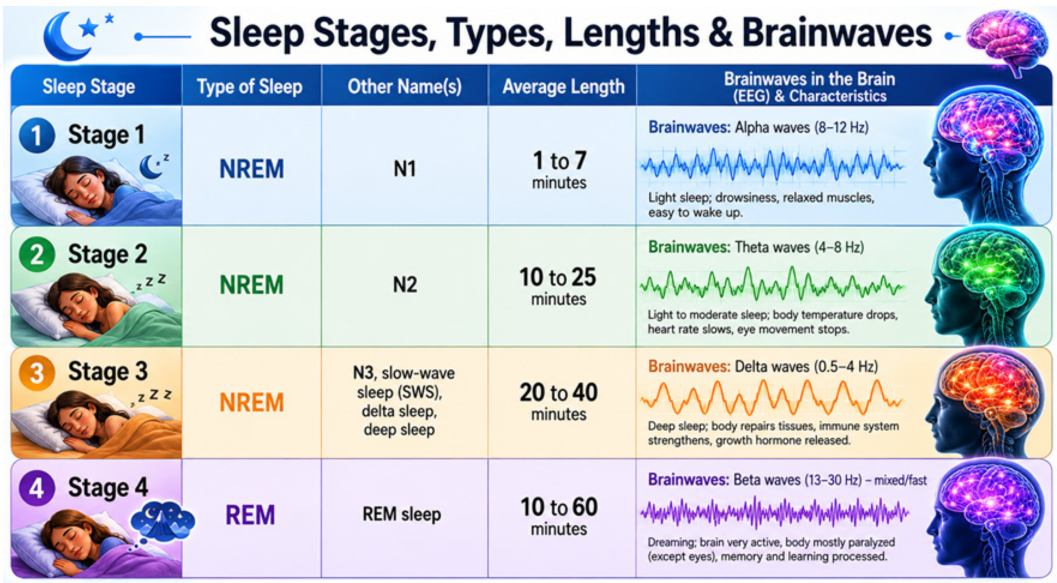

Figure 4: Stages of Sleep and Delta Brain Waves during Slow Wave Sleep for Growth and Repair.

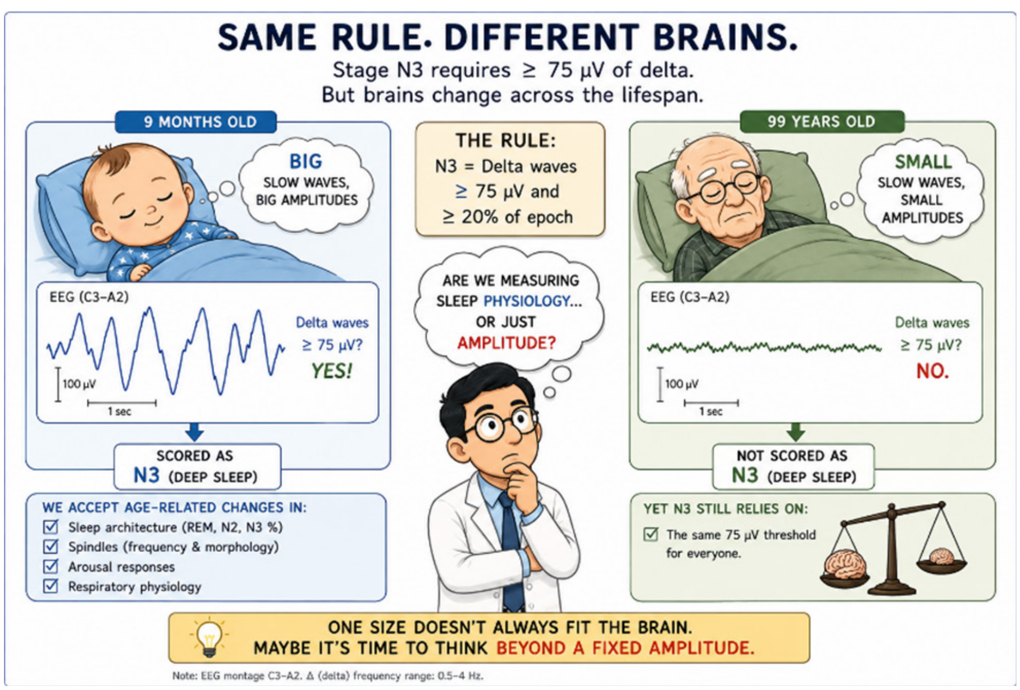

Figure 5: Sleep Stages and Sleep Health (N3 in Elderly is Small).

hence giving rise to several associated health problems.

Existing research shows that such closed-loop acoustic stimulation can modulate slow-wave activity, improve memory consolidation and sleep quality in both controlled laboratory conditions as well as under the more naturalistic home-based settings [44,45]. As a result, the application of AI-assisted sleep neurotechnology is on an increasing trajectory in preventive sleep medicine for neurodegenerative disease prevention and intervention, chronic pain treatment, basic circadian neuroscience concepts or musculoskeletal recovery (e.g., osteoarthritis related sleep disturbance).

The concept of developing a neurotechnology-enabled Smart Tek AI system for circadian alignment represents a forward-looking, non-invasive strategy to intervene early within the disease cascade through optimization of sleep architecture, neuromuscular recovery, autonomic balance, and cellular homeostasis. By aligning sleep architecture with endogenous circadian rhythms, such technologies may enhance slow-wave sleep and maximize the timing of physiological recovery processes as shown in Figure 4. This is especially relevant given the importance of deep sleep in tissue regeneration, glymphatic clearance of neurotoxic metabolites, autonomic restoration, and suppression of chronic inflammatory pathways implicated in degenerative joint disease as seen in Figure 3. Neurotechnology-guided systems may also integrate principles of Chronotherapy, enabling therapeutic interventions to coincide with periods of highest biological responsiveness. In osteoarthritis, this may involve optimizing nighttime thermal regulation, mechanotherapy, pressure redistribution, and muscle recovery rhythms to support cartilage remodeling and reduce nocturnal joint loading. Importantly, the AI-driven analytical engine allows for real-time personalization, addressing substantial inter-individual variability through adaptation to individual circadian phenotypes, behavioral patterns, and recovery signatures.

Studies have also demonstrated how transcranial magnetic stimulation can artificially activate delta-waves for deep sleep but again this is in nascent research stages as it must take place within laboratory environments under stringent supervision and tends to be trialed on individuals who are suffering ailments. For instance, in an experimental method, trans cranial magnetic stimulation (TMS), evoked slow-wave-like brain activity and has been developed to investigate sleep mechanisms. Research demonstrates that magnetic stimulation can evoke cortical slow waves resembling those seen during deep sleep [46] as shown in Figure 6.

Discussion

AI Smart Beds in future could be integrated with robust Neurotechnology as modern sleep-health systems in preventive medicine. There are very few being developed to promote deep slow-wave sleep (SWS), the restorative state associated with glymphatic clearance, tissue repair and immune regulation as well as memory consolidation and other forms of neurophysiological recovery [44,47]. Since these systems consist of biosensors, artificial intelligence and adaptive environmental modulation that monitor sleep architecture occurs real time. The shift from clinics to homes should be attempted as today, AI Smart Beds can be used along with other neurotechnology gadgets and mechanisms all

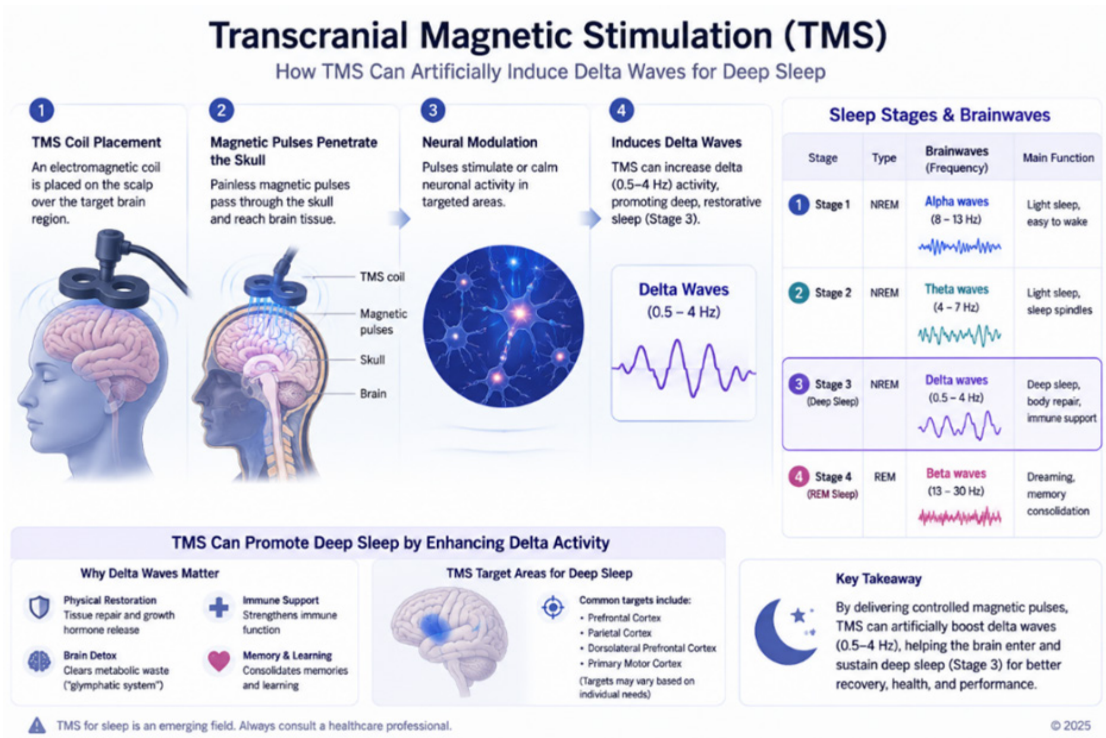

Figure 6: TMS for inducing Delta Waves Artificially.

over the world. EEG-headbands and devices for neurofeedback such as Dreem or Elemind track brain-wave activity to provide closed-loop auditory stimulation conditioned with endogenous slow oscillations in non-REM sleep [44]. Globally, companies such as Oura Health and Whoop produce wearable physiological trackers that measure heart-rate variability, respiration rate, skin temperature variation and accelerometer data to estimate sleep stages or recovery states. Eight Sleep is an example of AI-enabled smart bed systems which include a combination of embedded sensors, thermal regulation and pressure redistribution based on man-machine learning techniques to analyze sleep condition dynamically [48].

Smart AI beds aim to induce or stretch the deep slow-wave sleep utilizing multiple neurophysiological mechanisms in a series of steps. The first approach utilizes closed-loop auditory stimulation systems, i.e., a stimulus that detects slow-wave oscillations and delivers accordingly timed acoustic pulses often pink noise during the upstate of cortical slow oscillations to acutely promote increase in amplitude without waking up the sleeper [44,45]. Second, thermoregulatory optimization is applied due to reductions in core body temperature during deep sleep. The AI of Smart Beds can automatically regulate mattress zones dynamically with cooling or warming as necessary to promote faster onset of sleep and increase length of non-REM stage N3 [48]. Thirdly, the combination of adaptive pressure redistribution and posture correction attenuate discomfort, nociceptive signaling and micro-arousals that otherwise fragment sleep. Fourth, circadian synchronization algorithms bring together sleep timing and environmental light exposure along with chronobiological modeling to better disentangle endogenous circadian rhythms from regular sleep cycles improving the efficiency of restorative slow wave sleep [49]. Fifth, neurotechnology systems incorporate biofeedback, vibration or relaxation acoustics and some autonomic regulation strategy to enter the stage of low sympathetic nervous system activity promoting parasympathetic dominance that is favorable for deep sleep initiation. This last critical stage needs more research and application especially for domestic use as postulated in Figure 7.

The Future of Sleep Medicine is to understand the entire system and not just the symptoms. The functional role of Sleep is critical as it plays an important neurophysiological role in metabolic and inflammatory clearance. Research suggests that lateral sleep positioning facilitates glymphatic transport and clearance of inflammatory metabolites and neurotoxic waste products, potentially supporting neurological recovery and brain health. Emerging neuro-aligned sleep technologies designed to optimize posture and restorative sleep stages may therefore have broader implications extending beyond musculoskeletal health into neurodegenerative disease prevention and cognitive ageing. The

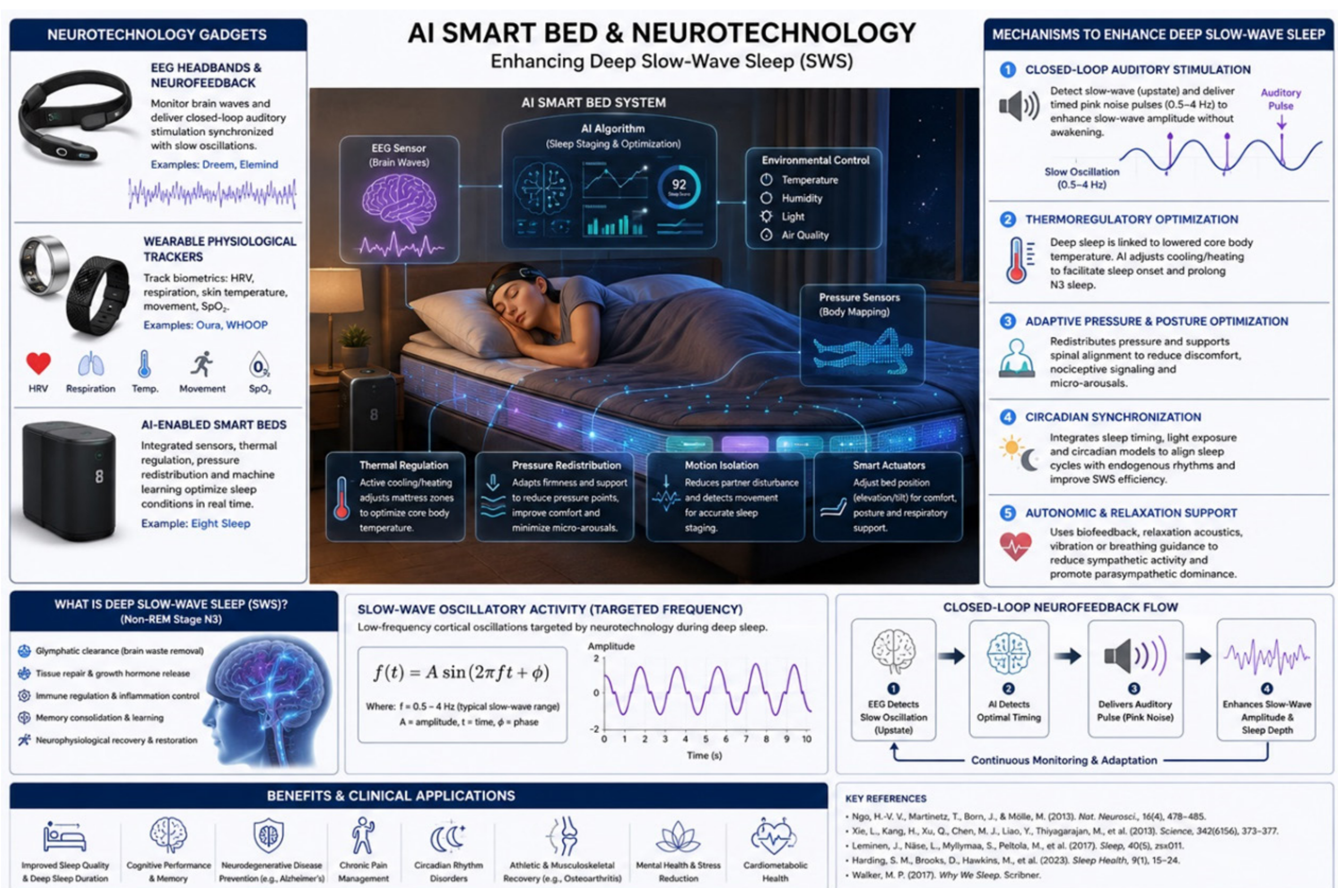

Figure 7: Integrating AI Smart Bed with Neurotechnology Gadgets – Process of Enhancing Slow Wave Sleep.

process of integration of Neurotechnology with the AI of the Smart Bed if fine-tuned to enhance slow wave sleep this will have tremendous applications in preventive medicine and precision health especially for older adults and healthy aging in countries like New Zealand.

The Smart Tek AI bed without any modifications also has the potential to enhance sleep health in healthy adults; however, individuals with sleep disorders, chronic pain syndromes, orthopedic impairments, or postural dysfunctions may derive greater clinical benefits [15]. Earlier studies have demonstrated that intelligent smart-bed systems may be highly relevant for orthopedic rehabilitation, musculoskeletal recovery, chronic back pain management, and posture optimization [50]. Unlike traditional classifications of mattresses based on subjective descriptors such as soft, medium, plush, or adjustable firmness settings, the Smart Tek AI offers a dynamic adaptive sleep surface capable of modifying pressure distribution, firmness characteristics, and biomechanical support in response to an individual's body mass index (BMI), sleeping posture, movement patterns, and physiological feedback in real time. Such adaptive systems may therefore provide a more universally optimized sleep interface across diverse body types and sleeping behaviors.

Advanced sleep-technologies may additionally contribute to New Zealand's broader aspirations in digital health innovation, preventive healthcare, and personalized medicine. Smart Tek AI systems could potentially be implemented within hospitals, rehabilitation facilities, assisted living centers, aged-care environments, and home-based care models as frontline preventive tools designed to improve patient engagement while reducing long-term dependence on pharmacological and surgical interventions. This modality represents a scalable, safe, and potentially cost-effective approach aimed at preserving musculoskeletal integrity, functional independence, and quality of life among older adults and at-risk populations.

Furthermore, these technologies may empower individuals through real-time sleep analytics and behavioral feedback mechanisms, enabling users to independently identify, monitor, and self-regulate patterns of sleep disruption and circadian misalignment [51]. Smart beds incorporating directed pressure redistribution and biomechanical balancing may enhance comfort and reduce musculoskeletal strain associated with poor sleep posture and prolonged static loading [52]. From a preventive medicine perspective, it is plausible that AI-enabled smart beds integrated with neurotechnology may provide greatest long-term benefit when introduced earlier during mid-adulthood rather than human and medical intervention during latter years after disease progression. Such an approach could function as a foundational preventive strategy aimed at delaying, mitigating, or reducing the severity of degenerative musculoskeletal disorders. Such automated systems will not only generate psychological and clinical awareness but also build on the direction of New Zealand's aspirations in terms of digital health innovation, preventive care and personalized medicine.

Traditionally, osteoarthritis has been conceptualized primarily as a centripetal and mechanically induced degeneration of articular cartilage; however, increasing evidence now supports its characterization as a chronobiological and systemic disorder involving disruption of intrinsic circadian timing systems (CTS), thereby warranting a broader re-definition of the disease process [41]. Circadian dysregulation has been implicated in inflammatory signaling, altered chondrocyte metabolism, extracellular matrix degradation, oxidative stress, and impaired skeletal repair mechanisms, all of which contribute to osteoarthritic progression. Automated lateral rotation therapy and AI-driven dynamic pressure redistribution systems have already demonstrated efficacy in reducing interface pressure, shear stress, and prolonged tissue compression during immobility, thereby decreasing the risk of pressure injuries in vulnerable clinical populations such as critically ill or bedridden patients. While sustained static loading during sleep may contribute to transient musculoskeletal discomfort, the principal indication for elective hip and knee arthroplasty remains osteoarthritis, a multifactorial degenerative disorder influenced by ageing, obesity, biomechanical stress, chronic inflammation, and cumulative joint loading.

While osteoarthritis has traditionally been defined as a centripetal, mechanically induced degeneration of articular cartilage, increasing evidence supports its characterization as a chronobiological and systemic disorder involving disruption of intrinsic circadian timing systems (CTS), thereby warranting a broader re-definition of the disease process [53]. Disturbances in circadian clock genes such as *BMAL1*, *CLOCK*, *PER*, and *CRY* have been associated with altered chondrocyte metabolism, extracellular matrix degradation, inflammation, and accelerated cartilage ageing [54,55]. Emerging chronobiological evidence indicates that circadian disruption contributes to increased inflammatory signaling, oxidative stress, altered immune responses, and impaired bone and cartilage metabolism, all of which are central to osteoarthritis (OA) pathophysiology [41,56]. Consequently, the promotion of circadian synchrony through AI-driven smart sleep environments may offer a novel preventive strategy against chronic low-grade systemic inflammation, now recognized as a key driver of degenerative musculoskeletal disease. Thus, through interfacing biological rhythms with regenerative physiology neurotechnology-enabled sleep systems could represent a radical, non-invasive translational approach in preventive medicine globally.

AI-smart beds are a new breed of domestic sleep technologies that need to be given more importance as they are user friendly and can enable an individual combine and customize the science of sleep, AI, biomechanics, and non-invasive health monitoring for continuous real-time monitoring of heart rate, respiration, body movements and sleep disturbances without wearable devices [22,57,58]. These systems incorporate multi-zone adaptive adjustment of pressure to reduce pressure points in both spinal alignment and biomechanical support for a variety of body types and sleeping positions, thereby supporting recovery and rehabilitation from orthopedic surgeries [56,59]. Since AI-driven smart beds can offer automatic postural adjustments according to the body motion and change in sleep posture this relieves long-term static load, improves comfort and enhances the quality of sleep [25,52,60].

Circadian rhythm support systems further incorporate environmental and physiological cues which act as potential zeitgebers, entraining sleep timing by enhancing individualized adaptive responses to sleeping patterns [61]. AI generated sleep insights, personalized feedback [25], long-term trend analysis and individualized sleep optimization strategies can also be enabled. The integration of therapeutic pressure-relief surfaces within AI-enabled mattresses have proved beneficial for greater pressure redistribution, reduced tissue loading and more optimal healing outcomes in patients with chronic pressure injuries [52,62], outlining potential applications in rehabilitation, elderly care and musculoskeletal recovery. In addition, the implementation of neurotechnology and biomechanics can transform smart beds from passive sleeping surfaces into active sleep-health platforms that can measure cardiovascular and autonomic nervous signaling activity across clinical populations [35,63].

Due to their non-intrusive and non-invasive monitoring functionality, they enable continuous physiological assessments during sleep under natural conditions without interruption of the sleep cycle [58]. Moreover, these systems can quantify sleep physiology at the individual level, provide tailored recommendations, reduce immobility and overall work towards better health outcomes [25,37]. Additionally, machine-learning algorithms built into smart bed technologies have shown potential for early sleep-health interventions and associations between sleep timing, sleep regularity, cardiorespiratory health and other

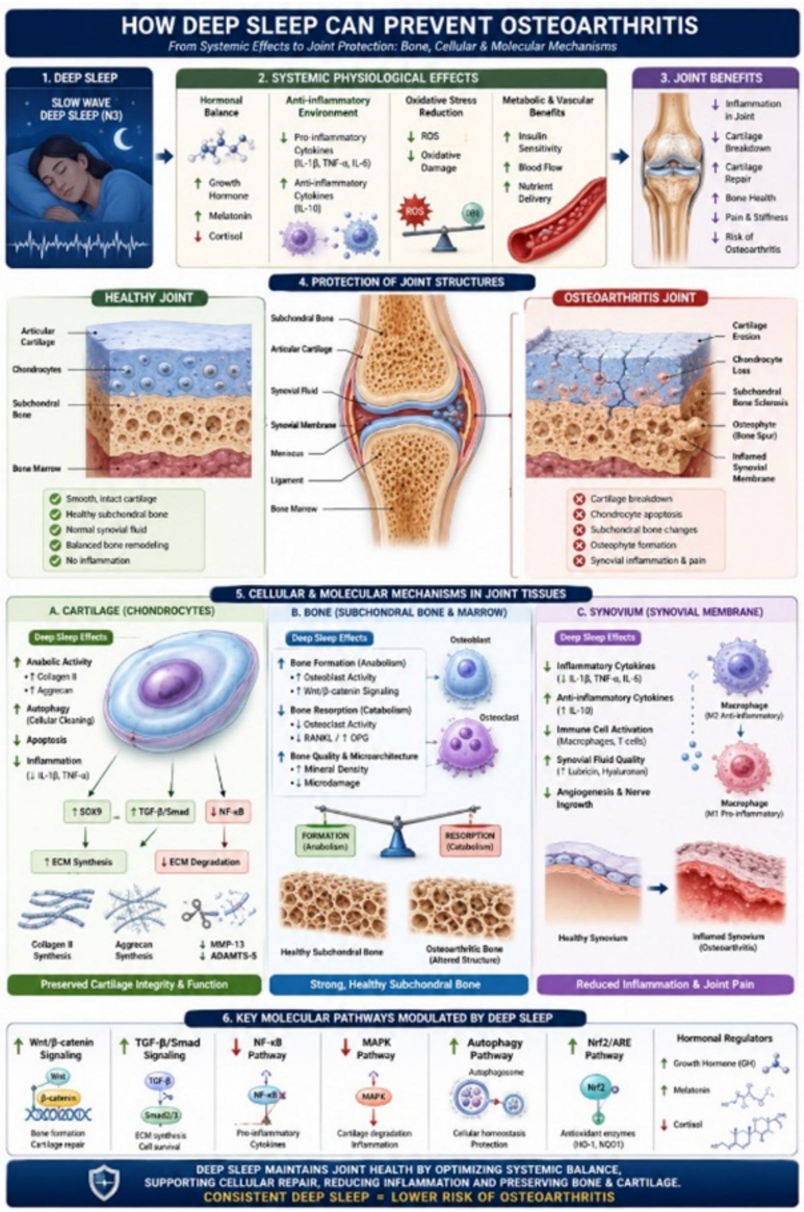

Figure 8: Role of Slow-Wave or Deep Sleep in Osteoarthritis Prevention.

clinically relevant metrics of sleep [64,65], indicating increasing role in preventive healthcare and disease detection.

It is necessary to compare the realistic effect of Static versus Dynamic (Smart Tek AI) Sleep Surfaces in Preventive Medicine illustrated in Figure 9 and outline the procedure of Arthroplasty Hip and Knee Replacement Surgery shown in Figure 10.

Conclusion

In New Zealand, where musculoskeletal injury, neurological disorders, chronic pain, and sleep disturbances constitute major public health challenges, sleep technologies may offer an upstream preventive strategy aimed at reducing long-term dependence on surgical intervention. Hip and knee replacement procedures in New Zealand are associated with substantial healthcare costs, often ranging between approximately NZD $25,000 to $40,000

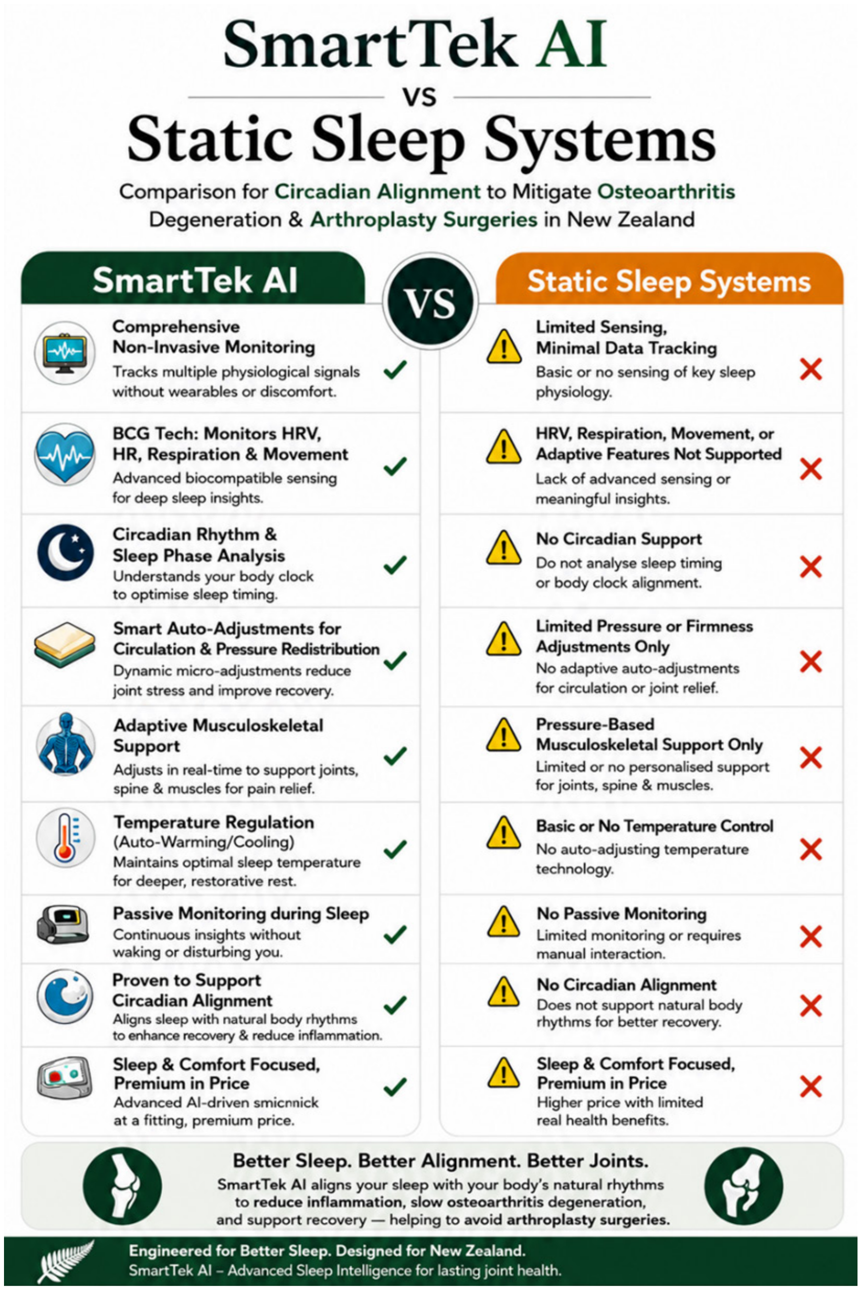

Figure 9: Comparative effect of Static versus Dynamic (Smart Tek AI) Sleep Surfaces in Preventive Medicine.

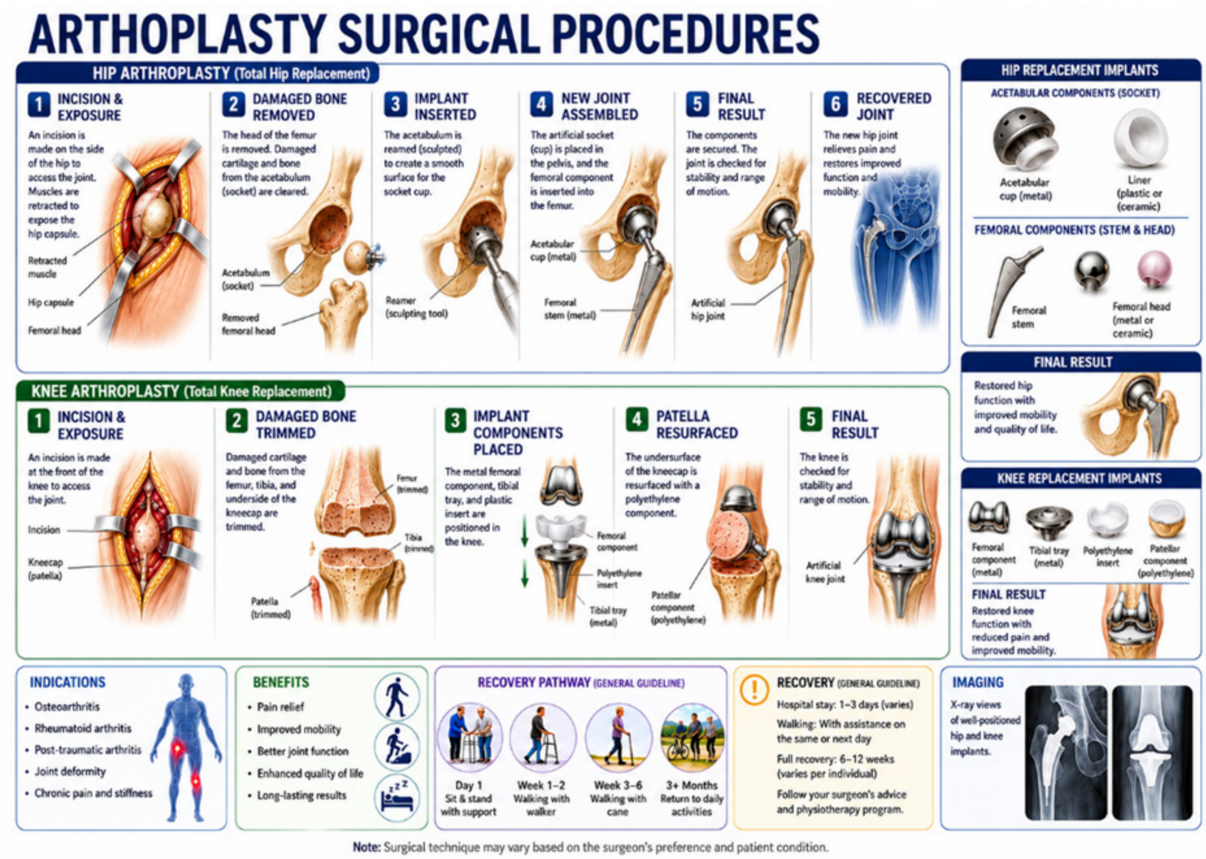

Figure 10: Arthroplasty Hip and Knee Replacement Surgery: Affects 17% to 25% of aging population in New Zealand.

per procedure within private healthcare settings depending on surgical complexity, implant requirements, and hospital-related expenses. Publicly funded orthopedic surgeries require specialist referral and clinical prioritization assessment, with waiting times frequently extending beyond 12 months due to increasing demand and surgical backlog pressures. Thousands of patients within the public healthcare system continue to experience prolonged waiting periods for orthopedic procedures annually.

It is absolutely essential to study compelling evidence in favor of a preventive dietary approach for osteoarthritis and also relative protection against advancements to joint degeneration that necessitate arthroplasty, is sustained compliance with an anti-inflammatory Mediterranean-style diet consisting mainly of plant foods; healthy fats like olive oil, nuts and seeds; fish and poultry instead of meats. This dietary pattern encourages fruits, vegetables, whole grains legumes nuts and olive oil with fish rich in omega-3 fatty acids consumed regularly while ultra-processed food groups refined carbohydrates saturated fat are limited which have been associated with reduced systemic inflammation oxidative stress as well metabolic risk factors acting through the breakdown of cartilage degeneration leading to joints [66,67]. Antioxidants (e.g., vitamins C and E, polyphenols) and micronutrients such as vitamin D and calcium are thought to help maintain cartilage matrix integrity, subchondral bone health and musculoskeletal resilience while omega-3 fatty acids may modify osteoarthritis pathophysiology through modulation of inflammatory cytokines [6,68]. In addition, achieving and maintaining a healthy body weight with energy balanced micronutrient rich food is one of the most critical modifiable risk factors forming part of OA prevention since excess adiposity increases mechanical shear force on joints as well as formation pro inflammatory mediators through unregulated activity by inappropriately activated adipocytes to induce joint degeneration [66,68]. Altogether, available evidence supports the hypothesis that more sustained adherence to a Mediterranean-style dietary pattern coupled with effective weight management may lower odds for incident osteoarthritis development and reduce future surgery risk as joint arthroplasty at older ages [67].

Clinical evidence increasingly supports a bidirectional association between osteoarthritis (OA) and sleep disturbances. Insomnia, fragmented sleep, circadian rhythm disruption, and altered rest–activity patterns are commonly reported among individuals with OA and are strongly associated with heightened pain perception, fatigue, reduced physical functioning, and poorer quality of life [69,70]. Nocturnal pain frequently disrupts sleep continuity, while sleep deprivation and circadian dysregulation further amplify nociceptive signaling, central sensitization, and inflammatory activity, thereby creating a self-perpetuating cycle in which poor sleep exacerbates joint pain and pain subsequently impairs sleep quality [71]. This interaction is particularly relevant in ageing populations, where reductions in circadian rhythm amplitude, melatonin secretion, and sleep efficiency may accelerate degenerative musculoskeletal processes and impair tissue recovery.

The potential role of neurotechnology-enabled sleep systems lies in their ability to provide highly personalized circadian and sleep optimization through continuous physiological monitoring and adaptive intervention. However, the effectiveness of such systems depends substantially on accurate modelling of individual circadian profiles, behavioral adherence, and long-term user engagement. Future research should therefore integrate wearable biomarkers, longitudinal follow-up studies, and randomized controlled clinical trials to establish the clinical efficacy and translational utility of AI-enabled sleep neurotechnology for each case separately. More specifically, studies combining advanced imaging modalities such as magnetic resonance imaging (MRI) assessment of cartilage thickness, inflammatory biomarkers, autonomic measures, and objective sleep analytics may provide stronger evidence regarding disease modification and preventive orthopedic outcomes.
Awareness of sleep science and circadian health may facilitate more informed decision-making regarding preventive health strategies and smart living technologies. Experimental evidence suggests that healthy young adults sleeping on adjustable smart zoned air mattresses demonstrate improvements in sleep efficiency, autonomic nervous system regulation, and physiological sleep responses when compared with conventional mattresses [57]. In contrast, traditional static sleep systems lack dynamic pressure adaptation, circadian integration, and physiological monitoring capabilities, meaning that mechanical loading patterns remain relatively unchanged throughout sleep and sleep-related physiological states cannot be continuously optimized. Although, sleep health and musculoskeletal outcomes arise from a highly complex interaction of multiple variables, including genetics, lifestyle behaviors, obesity, diet, stress exposure, environmental conditions, occupational loading, sleep habits, and broader psychosocial determinants; therefore, the potential benefits of AI-driven sleep ecosystems and neurotechnology-enabled systems cannot be generalized uniformly across all individuals. Ultimately, individuals and healthcare providers must critically evaluate the emerging evidence surrounding sleep science and digital health innovation, weighing potential benefits, limitations, accessibility, and economic considerations when considering investment in advanced dynamic sleep ecosystems designed to optimize sleep, health, and quality of life.

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