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AIMS AND SCOPE

The primary aim of *World Journal of Orthopedics* (*WJO*, *World J Orthop*) is to provide scholars and readers from various fields of orthopedics with a platform to publish high-quality basic and clinical research articles and communicate their research findings online.

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OPINION REVIEW

COVID-19 and its effects upon orthopaedic surgery: The Trinidad and Tobago experience

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Abstract

The World Health Organisation (WHO) declared coronavirus disease 2019 (COVID-19) a pandemic on March 11, 2020. COVID-19 is not the first infectious disease to affect Trinidad and Tobago. The country has faced outbreaks of both Chikungunya and Zika virus in 2014 and 2016 respectively. The viral pandemic is predicted to have a significant impact upon all countries, but the healthcare services in a developing country are especially vulnerable. The Government of Trinidad and Tobago swiftly established a parallel healthcare system to isolate and treat suspected and confirmed cases of COVID-19. Strick 'lockdown' orders, office closures, social distancing and face mask usage recommendation were implemented following advice from the WHO. This approach has seen Trinidad and Tobago emerge from the second wave of infections, with the most recent Oxford COVID-19 Government Response Tracker report indicating a favourable risk of openness index for the country. The effects of the pandemic on the orthopaedic services in the public and private healthcare systems show significant differences. Constrained by shortages in personal protective equipment and inadequate testing facilities, the public system moved into emergency mode prioritizing the care of urgent and critical cases. Private healthcare driven more by economic considerations, quickly instituted widespread safety measures to ensure that the clinics remained open and elective surgery was not interrupted. Orthopaedic teaching at The University of the West Indies was quickly migrated to an online platform to facilitate both medical students and residents. The Caribbean Association of Orthopedic Surgeons through its frequent virtual meetings provided a forum for continuing education and social interaction amongst colleagues. The pandemic has disrupted our daily routines leading to unparalleled changes to our lives and livelihoods. Many of these changes will remain long after the pandemic is over, permanently transforming the practice of orthopaedics.

Trinidad and Tobago

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Key Words: COVID-19; Coronavirus; Orthopaedics; Trinidad and Tobago; University of the West Indies; The Caribbean association of orthopaedic surgeons

Core Tip: A government-led disciplined response to coronavirus disease 2019 (COVID-19) is an essential component in the fight against this pandemic. Orthopedic surgeons have been at the forefront of the struggle, maintaining essential surgical services while ensuring the safety of the public. Developing countries with under-resourced healthcare facilities have fared far better than many developed countries. In this war against COVID-19 the resilience and innovative spirit of the people may be our most effective weapons.

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INTRODUCTION

Severe acute respiratory syndrome coronavirus 2 was first reported from Hubei province of the People's Republic of China in December 2019[1,2]. This highly infectious pathogen named coronavirus disease 2019 (COVID-19) rapidly spread throughout many countries, compelling the World Health Organisation to declare it a pandemic on March 11, 2020[3,4].

The beautiful islands of the Caribbean have not been spared the effects of COVID-19 with Trinidad and Tobago reporting its first case on March 12, 2020[5]. The Republic of Trinidad and Tobago is a twin-island state covering 1980 sq miles and located just 6.8 miles off the coast of northeastern Venezuela. Classified as a developing country, it has a population of 1363985 and is world-renowned for its colorful carnival, steelpan and Pitch Lake[6]. The healthcare system of Trinidad and Tobago includes both public and private sectors (Figure 1). Public healthcare is centrally funded, delivering its services, free at the point of access through five Regional Health Authorities; conversely the private sector operates on a fee for service basis[7,8] (Figure 2).

The response from the Government of Trinidad and Tobago (GoRTT) to the virus was quick and decisive, with infected cases and those persons exposed being placed in state quarantine. The country's international borders were closed on March 22, 2020 and a national stay-at-home order put in place from March 30, 2020, resulting in a "lockdown" of the country. A parallel public health system consisting of separate and independent tiered medical facilities, staff and laboratories was established to treat persons in state quarantine, while allowing the normal public health system to serve the needs of the rest of the population. These measures resulted in an initial flattening of the curve, and Trinidad and Tobago was ranked number one by the Oxford COVID-19 Government Response Tracker (OxCGRT) in a report published by the University of Oxford on May 1, 2020[9].

In an attempt to restart the economy the Prime Minister announced plans to lift restrictions on a six-tier phased basis beginning on May 10, 2020. The announcement of General Elections on July 3, 2020 signaled the start of an intense election campaign, marred by numerous breaches of the public health safety protocols. Leading up to Election Day, there was a gradual increase in daily confirmed cases and on August 15, 2020, five days after elections, the Chief Medical Officer confirmed that there was now community spread of COVID-19 in Trinidad and Tobago[10].

The GoRTT has maintained a lively response to the pandemic, with the OxCGRT derived Stringency Index trend for TnT mirroring the daily reported new cases of infection. At the time of writing we are emerging from the second wave of infections which started on July 20, 2020 with case 139, with a total of 7115 confirmed cases and 125 deaths (Figure 3). As our country returns to some semblance of normalcy we have seen a relaxation of the lockdown restrictions and our Risk of Openness Index (previously 'Lockdown Rollback Checklist') indicates a favorable environment to

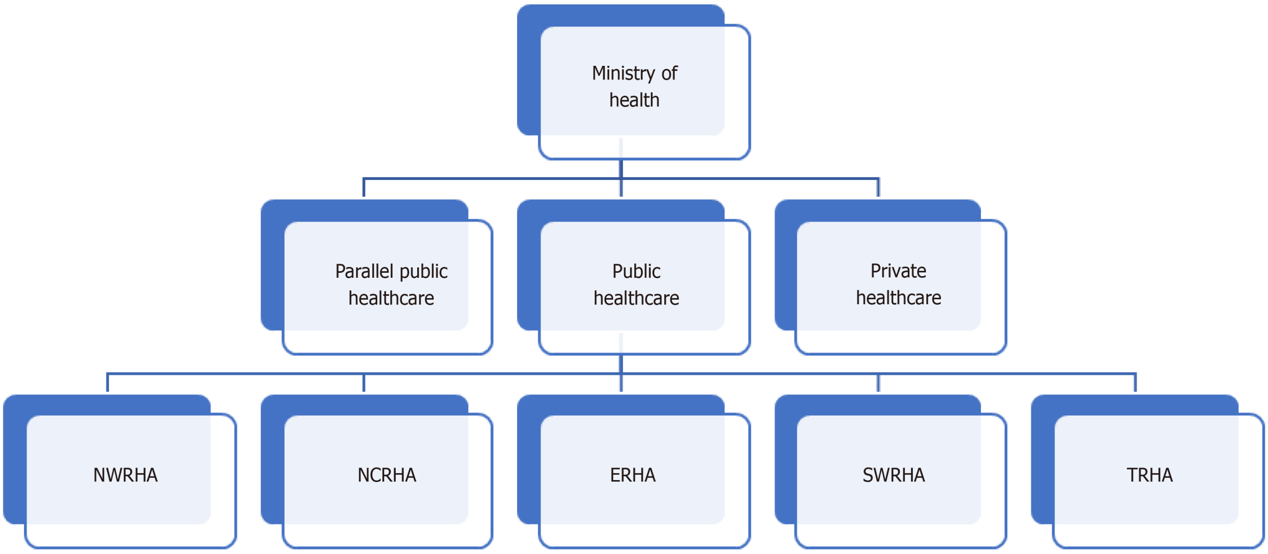

Figure 1 Organisation structure of the Trinidad and Tobago Healthcare System. NWRHA: North West regional health authority; NCRHA: North central regional health authority; ERHA: Eastern regional health authority; SWRHA: South West regional health authority; TRHA: Tobago regional health authority.

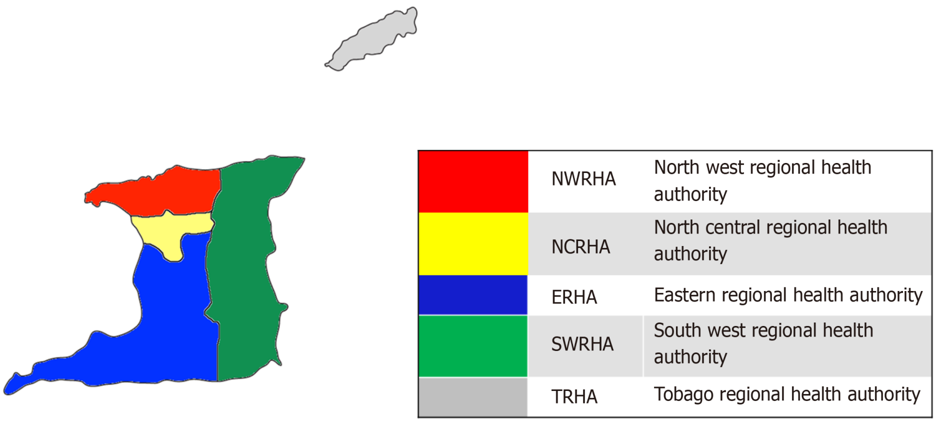

Figure 2 Map showing the geographic range of the Regional Health Authorities.

reopening[11].

Effects on public sector services

With the arrival of the first case of COVID-19 on the shores of Trinidad and Tobago, we noted a drop in clinic attendance as patients tended to avoid the hospital environment for fear of becoming infected. In addition, to reduce unnecessary crowding in the clinics, only patients requiring urgent consultation or follow up were given appointments. The patient medical records and referral letters were screened to identify such patients considered as high priority cases, which mostly consisted of patients with fractures, infections and cases of malignancy.

In accordance with public health recommendations, high visibility physical distancing signage was placed in the clinic waiting area and patients were required to wear face masks and wash their hands before being seen. Appointments in 20 min slots were also instituted to allow separation of persons by time. Only one family member was permitted to accompany a patient and children were not allowed in the clinic. Before entering the consultation room each patient had their temperature taken with an infrared scanner and medical personnel wore face masks and/or face shields during consultation. To further reduce patient traffic in the hospital, only essential imaging was requested and patients were encouraged to practice home based physical therapy. All non-urgent surgery was postponed and temporary measures such as

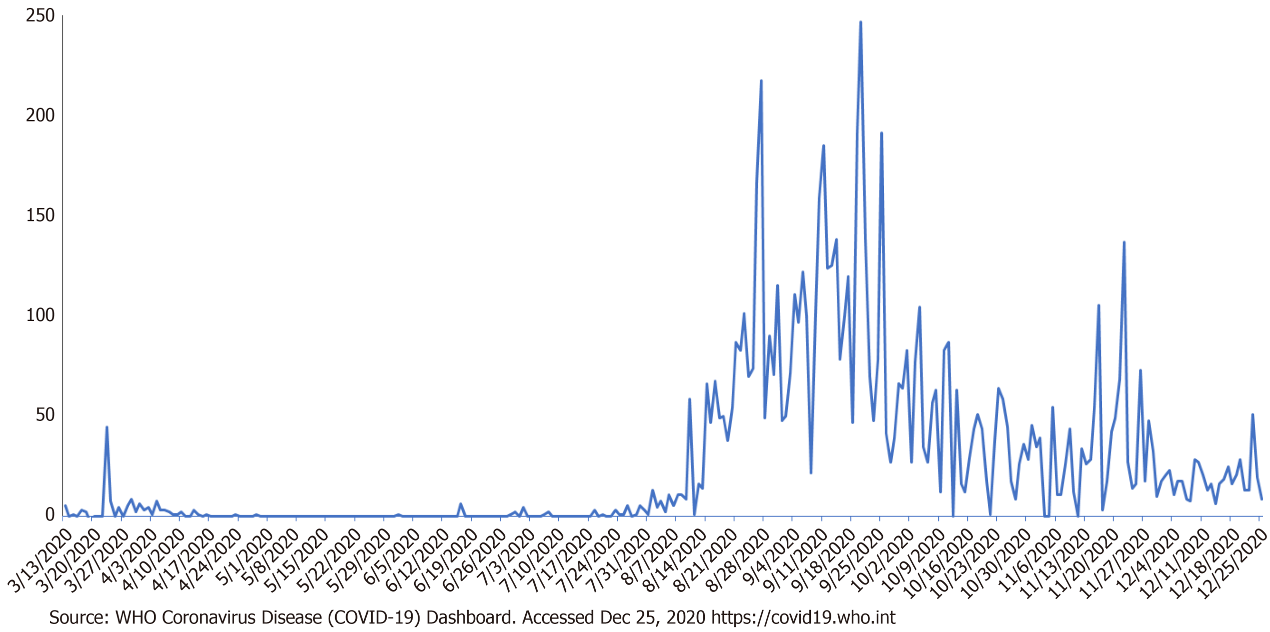

Figure 3 Daily confirmed cases of coronavirus disease 2019 in Trinidad and Tobago.

steroid injections and splints were used where applicable.

The national priority was to provide, at a minimum, basic orthopaedic services to the general community. Within the public sector the orthopaedic service is delivered by independently functioning teams. From the start, cross infection between teams of surgeons was identified as a major threat with the potential to destabilise our clinical infrastructure. To reduce risk we avoided unnecessary interaction between staff members of different teams, using electronic methods of communication *e.g.*, WhatsApp® for patient handovers and cancelling several departmental meetings including grand rounds and journal club presentations.

In the first wave of the pandemic, large numbers of COVID-19 positive cases and limited supplies of personal protective equipment (PPE) made it difficult to maintain the surgical services. To conserve scarce resources the Minister of Health in consultation with the Chief Medical Officer announced a temporary halt to all elective surgery in public hospitals on March 15, 2020[12]. To facilitate urgent and emergency cases, many surgeons purchased their PPE for use within the public hospital.

We are presently coming out of the second wave which has been characterised by community spread and rising mortality. To protect the healthcare workers, all patients, except those requiring immediate life-saving measures, must have a negative COVID-19 reverse transcriptase polymerase chain reaction (RT-PCR) test before undergoing surgery. Elective surgery has resumed although many lists have been cancelled due to a delay in obtaining tests results.

Effects on private sector services

The effect of the pandemic on the private sector differed from the public sector in several ways. Most private clinics continued to function with patients being reassured that safety measures were in place. Outdoor hand washing facilities, the provision of hand sanitiser and face masks for patients and staff were some of the additional preventative measures implemented in the private sector. Overcrowding in the waiting area was managed by having patients remain in their vehicles until the doctor was ready to see them. Despite this, doctors' practices reported low attendance rates with many appointments being cancelled.

As opposed to the public sector, there was a noticeable increase in the use of digital technology. Many practices took the opportunity to transition to a paperless office system, including the use of electronic payment to reduce interpersonal contact. Telemedicine for medical consultation was used infrequently, except by physical therapists where there has been early and wide adoption of the technology. A significant barrier to broader usage is the unavailability of a confidential and secure platform as well as an agreed billing and reimbursement method from payers[13].

With the predicted fall in revenue caused by the pandemic, many private hospitals introduced measures to preserve their financial viability. Critically, patient welfare was the priority, and hospital administrators established major safety precautions to encourage confidence in the private health care system. This strategy has been successfully used in cardiac surgery at one of the private hospitals in Trinidad[14]. Additionally, many surgical procedures were transitioned to the outpatient setting, with savings to both the patient and hospital while maintaining surgical volume. Furthermore, the widescale digital transformation has improved billing and administrative processes, which is anticipated to result in future cost savings. A surprising but welcome source of additional revenue has come from an increase in both laboratory tests and imaging studies as the public seeks to remain healthy in the face of a deadly pandemic. Despite all these challenges, at the time of writing, no private hospitals have closed.

Most private hospitals derive the majority of their income from surgery, and unlike the situation in the public sector, elective surgery was encouraged. Initially, limited supplies of PPE in private hospitals led to some innovative methods to preserve stocks and protect staff. This included the use of industrial protective face shields and "double masking", in which two face masks were used in combination: a standard surgical mask over an N95 respirator mask to protect the latter from becoming soiled with blood during surgery (Figure 4).

To maintain confidence in the private sector, compulsory COVID-19 PCR tests before elective surgery was implemented very early, with the use of dedicated testing facilities and staff (Figures 5 and 6). Emergency cases are admitted only after a negative COVID-19 immunoglobulin (Ig) G/IgM antibody test and isolated from other inpatients. Unless urgent surgical intervention is required, these patients must also have a negative COVID-19 RT-PCR test preoperatively. Although the additional testing is both inconvenient and expensive, it has been well received by most patients who recognise the need for these safety measures.

Although several doctors have contracted COVID-19, to date there are no reports of COVID-19 related deaths amongst orthopaedic surgeons or COVID-19 related deaths or complications following orthopaedic surgery.

Orthopaedic education during COVID-19

The University of the West Indies (UWI) is one of only two regional universities in the world and is currently ranked by the Times Higher Education as the Caribbean's leading university[15]. The medical school of the Faculty of Medical Sciences (FMS) provides training for over 200 medical students who were affected by the pandemic. The FMS moved swiftly in response to the pandemic, ensuring that their teaching staff was well equipped to work in the new normal of online education, with workshops and webinars conducted by the Centre for Medical Sciences Education and the Centre for Excellence in Teaching and Learning.

The four-week undergraduate orthopaedic clerkship has been reorganised into a two-week online course which focuses on the acquisition of core knowledge using didactic lectures, problem-based learning and group discussion. E-learning has been shown to be an enjoyable and effective method of teaching in some studies[16]. The method is however novel to medical education at UWI, specifically orthopaedics and is currently the subject of a study proposal which would give greater insight into its usefulness. (UWI Campus Research Ethics Committee Application CREC-SA.0511/09/2020). The online component is to be complemented by a two-week face-to-face clinically oriented course which began on November 8, 2020, in step with national conditions allowing for a safe return to the clinical setting.

Resident education has been significantly affected by the pandemic. The June/July 2020 exit examination has been postponed and the enrolment of new residents deferred until 2021. Teaching has continued online with the use of Zoom® following the suspension of face-to-face teaching. Of great concern is the diluted clinical exposure caused by a reduction in elective surgery and low outpatient clinic attendance. Additionally, the trauma burden from motor vehicle accidents and sports injuries is significantly reduced, a phenomenon likely related to the population being required to limit outdoor activity.

The FMS understands its pivotal role in supporting the healthcare workforce of Trinidad and Tobago and has had to weigh this with its obligation to provide a safe working environment for students. Continuous dialogue with stakeholders has produced a blueprint for the resumption of clinical teaching; the document which has the support of the Minister of Health has been granted an exception from the national mandate to suspend all teaching until 2021.

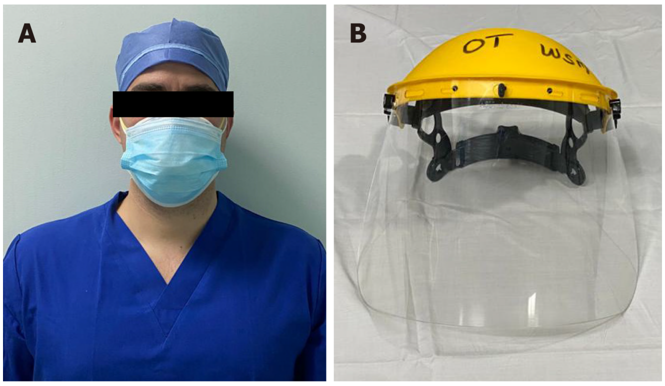

Figure 4 A standard surgical mask over an N95 respirator mask to protect the latter from becoming soiled with blood during surgery. A: Double masking technique in which a standard surgical mask is used over a N95 respirator mask to avoid blood contamination of the latter; B: A face shield designed for agricultural purposes being used in the operating theatre.

Figure 5 Coronavirus disease 2019 screening station.

Figure 6 Drive thru coronavirus disease 2019 screening and swabbing station.

The caribbean association of orthopaedic surgeons

This short report on the effects of the pandemic upon the orthopaedic services of Trinidad and Tobago would be incomplete without mentioning The Caribbean Association of Orthopaedic Surgeons (TCOS). The association was founded in 2007 following an informal gathering of orthopaedic surgeons from the region, dubbed an “Orthopaedic Lime”. Used in this context “lime”, is a Trinidadian phrase meaning: to hang out or socialise in an informal relaxing environment especially with friends[17]. The executive of TCOS lost no time in responding to the pandemic. The discussion of clinical cases and the scientific concepts were promptly migrated to a social media platform. This rapidly developed into the hosting of monthly Clinical Symposia *via* Zoom, and a larger two-day event is planned for November 2020. These virtual meetings have been well attended, providing both educational opportunities as well as a space for mental restitution. The connection with colleagues, socialization and sharing of experiences, are essential activities for mental wellbeing, providing a much-needed respite during these difficult times.

CONCLUSION

The COVID-19 pandemic has had an unprecedented effect upon the practice of orthopaedic surgery in Trinidad and Tobago. Amid the overwhelming negative impact of the pandemic, several noteworthy transformations have emerged. The rapid adoption of digital technologies in the workplace has improved efficiency, reduced waste and increased patient access to affordable healthcare. Similarly, the transition to online teaching has led to more consistent resident attendance and greater participation in discussion groups.

Surgeons have united in a spirit of teamwork and camaraderie as they face this novel viral threat. Hitherto unseen leadership qualities have emerged, with many examples of surgeons acting selflessly with courage, compassion and empathy. This COVID-19 pandemic will not last forever, but the role that we, as orthopaedic surgeons have played in facing the enemy will in perpetuity be part of our legacy.

Work safe, stay safe.

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MINIREVIEWS

Slacklining: An explanatory multi-dimensional model considering classical mechanics, biopsychosocial health and time

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Abstract

This paper aims to overcome slacklining's limited formulated explanatory models. Slacklining is an activity with increasing recreational use, but also has progressive adoption into prehabilitation and rehabilitation. Slacklining is achieved through self-learned strategies that optimize energy expenditure without conceding dynamic stability, during the neuromechanical action of balance retention on a tightened band. Evolved from rope-walking or 'Funambulus', slacklining has an extensive history, yet limited and only recent published research, particularly for clinical interventions and in-depth hypothesized multi-dimensional models describing the neuromechanical control strategies. These 'knowledge-gaps' can be overcome by providing an, explanatory model, that evolves and progresses existing standards, and explains the broader circumstances of slacklining's use. This model details the individual's capacity to employ control strategies that achieve stability, functional movement and progressive technical ability. The model considers contributing entities derived from: Self-learned control of movement patterns; subjected to classical mechanical forces governed by Newton's physical laws; influenced by biopsychosocial health factors; and within time's multi-faceted perspectives, including as a quantified unit and as a spatial and cortical experience. Consequently, specific patient and situational uses may be initiated within the framework of evidence based medicine that ensures a multi-tiered context of slacklining applications in movement, balance and stability. Further research is required to investigate and mathematically define this proposed model and potentially enable an improved

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understanding of human functional movement. This will include its application in other diverse constructed and mechanical applications in varied environments, automation levels, robotics, mechatronics and artificial-intelligence factors, including machine learning related to movement phenotypes and applications.

Key Words: Slacklining; Model; Human movement; Biopsychosocial; Time

Core Tip: Slacklining's is achieved through optimizing energy expenditure and dynamic stability, but limited explanatory models exist. These 'knowledge-gaps' are overcome through a new explanatory multi-dimensional model that considers entities from: self-learned movement patterns; classical mechanical forces governed by Newton's physical laws; biopsychosocial health; and time's multi-faceted perspectives as a quantified unit with spatial and cortical experience. Consequently, evidence-based situational uses will ensure a multi-tiered context for slacklining's applications in movement, balance and stability. Further research must consider diverse constructed and mechanical applications in varied environments, with automation levels, artificial-intelligence, and machine-learning related to movement phenotypes and applications.

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INTRODUCTION

Slacklining is a complex neuromechanical task where functional independence is achieved while dynamic stability is maintained from balance retention while treading on an unstable, three-dimensional, moveable, tightened webbing-band fixed at each end. This requires interactions between the individual's whole-body internal dynamics that drive the response to external environmental changes[1,2]. The individual adopts self-learned-strategies to ensure an optimal balance between energy expenditure and maintaining dynamic stability in the presence of perturbations[3,4]. Despite its extensive historical background[5], research into slacklining models that fully define the activity are limited[6], particularly in relation to a model's clinical rehabilitation implications and formulated explanations. This is predominantly due to incomplete descriptions of the neuromechanical control strategies not accounting for the biopsychosocial (BPS) health model or the multiplicities of time[7]. This leaves 'knowledge-gaps' that question areas of application extrapolation and detailed explanation and an expanded and evolved model that satisfies these requirements. The model must also have potential relevance to other diverse areas like construction and mechanical engineering in varied environments including automation, robotics and artificial-intelligence (AI) driven locomotion.

Consequently, the aims of this paper are to: summarize existing slacklining models; then expand and progress these to overcome existing 'knowledge-gaps' that explain the broad circumstances of use, through a multi-dimensional model (MDM); for the individual's capacity to employ control strategies that achieve functional movement and stability; and highlight potential applications to other diverse areas.

An overview of current models

Most models of self-balancing consider the duality of mathematical mechanical precision with supplementary neural control of sensory-motoric systems[3,8]. However, human motion strives to be a harmonious functional movement (HFM), 'the inter-relation of neural and muscular components to facilitate stable harmonized full-body functional movement'[9]. Most human movement models do not consider this need for full body HFM and are generally hypothesized about a stable or fixed base. This is inadequate for slacklining where the body is dynamically coupled with external changes and response actions[1]. Consequently, slacklining stability[6,10] and balance-control[11] is currently modelled as being achieved through: Self-learned patterns[12]; encompassing neuromechanical control strategies; within a 'saddle-shaped' interactive 3-dimensional (3D) task space that is concave horizontal-X for the slackline, and convex laterally-Y for shift, and vertically with sag-Z)[13]; with defined variables and significant degrees of freedom (DoF). These contribute *via* central nervous system (CNS) control[4] to specific movements[10] that amalgamate mobility and stability[9].

This use of classical mechanics acknowledges spatial orientation and subsequent corrective stabilization actions. This envisages a self-balancing mechanical model of an inverted pendulum (the person)[11], on a cart (the slackline), moving on an elliptical track[1] (the physical 3D space movement limitations), to a maximal distance from slackline contact[3], during instantaneous stability. Concurrently, the arms and trunk are decoupled from the stance leg/s by muscular co-contraction at the hips, but dynamically direct the vector forces that enable angular momentum control[6]. The forces are both pro-active and re-active to those of the slackline's 3D reciprocal forces at and through a point/s of fixed contact[3]. They form within the 'high-dimensional manifold' '… in which the subjects have to stay in order to maintain balance'[4].

However, this mechanical model has a 'knowledge gap' that requires evolution and expansion. It must acknowledge the framework of the BPS health model[14,15], and the multiplicity of possible time constructs[16,17].

Factors that necessitate change to existing classical mechanical models of slacklining

The summarized models of self-balance and HFM account for the available DoFs found with unpredictable dynamic movement on unstable 3D surfaces that consider both inter-segmental coordination and kinematic redundancy - summarised in a further article reviewing the literature and background to slacklining as "an integrated mathematical mechanical precision model, bound by classical mechanics equations in parity with sensory and motoric neural controls, that approximates a dynamic 'saddle-like' phase-space, high-dimensional manifold characterized by two internal competing manifolds of convergent and divergent motion".

The resultant "knowledge gap" arises from the lack of additional perspectives on HFM that involves complex actions and unstable surfaces[18]. These perspectives include: The BPS health model, accounting for physical, mental and social circumstances[14]; and the multiple perspectives of time from the basic neurophysiological effects of aging such as neuro-motoric delay, through to concepts inspired by a qualitative understanding of relativity-theory. Time must be considered and reflected as a physical continuum with epistemological relevance[19], how it relates to individual momentary status accounting concurrently for past experience and future intentions, the transience of 'this' moment, and its' interposition between external physical mechanical time and temporal internal or cortical time. By considering slacklining as a representative highly skilled and complex activity, as compared to quiet-standing, the proposed MDM can encompass both current and potential HFM situations involving equilibrium and self-balance, and their application to other diverse fields.

OVERLYING BIO-PSYCHO-SOCIAL INFLUENCE: A FURTHER DIMENSION

The BPS health model was proposed in 1977 being generally and widely preferred to the traditional 'bio-medical model' by virtue of its basic principles, that the individual's dimensional BPS triad reflects a holistic organism, not isolated organs[14,20]. Consequently, health, medical, and science practitioners are encouraged to adopt a holistic approach and account for individuality in personality, emotion, social situations, and environmental conditions. This has ensured greater emphasis on an empathetic and compassionate 'person-centered diagnostic approach'[20]; however, this has not fully penetrated basic science research and theory, yet.

The BPS factors contribute as a consequence of their context, setting, and the individual's social interaction support networks[15]. With slacklining, this can include prior experience, for example: Biologically - a beginner *vs* an expert; psychologically - positively for enjoyment, or negatively from an experienced injury when participating; and socially - the physical/psychological setting when participating[2,7]. This BPS approach incorporates the reason for participating. This may be obligatory rehabilitation within a clinical setting[7,21,22], or a high-performance training institute[23], at a height or a very low line-tension which accentuate the challenge, or recreationally with friends[5]. These BPS influences cast additional layers of control over the physical activity and its governance by physical laws that are not addressed in existing models. These contributors will influence subsequent learned movement patterns, so that no individual/s will adopt exactly the same movement and balance strategy at any given time point[8,9].

Criticisms of the BPS model predominate in four areas: (1) It is neither a scientific or a philosophical model; (2) Provides no answers on how a condition/disease is expressed by the three BPS components interactions; (3) Has no guidelines on when it should be applied; and (4) Recommends no definitive therapies and interventions. Noted disadvantages are that because it is multi-faceted it is complicated, making it problematic for education. It assigns no responsibilities, making it difficult to coordinate. It lacks concise theoretical framework related to content and how it functions[15]. But, the BPS health model enables more effective management! It connects science and humanism by facilitating collaborations between clinicians, patients, their families, and social support systems. Consequently, it remains a valued approach offering beneficial clinical, educational, and research services, while concurrently contributing to health and medicine policy and practice formation[15].

This multi-faceted BPS approach has evolved through the introduction of: semiotics - the language allowing the description of relationships between individuals and environments; and constructivism - how organisms perceive their environments. These explain the lack of uniformity in individual reaction to any defined physical or chemical stimulus. Stimuli are "... imprinted with a meaning [and] designated as a sign (that has no actual representation) ..." with the imprinting dependent on the individual's holistic "… motives, relationship needs, metabolic conditions, thoughts, and fantasies"[20]. Effectively, individuals construct their own environment and the imprinted meaning on the receptors "encompasses the individuals' unconscious, preconscious, and conscious memories in the implicit-, the working-, and the autobiographic - memory"[20]. Consequently, the two-link mechanistic model of cause and effect gains a third 'interpretation' stage: (1) *Cause* - the 'carrier' stimulates the receptors with a sign; (2) *Interpretation* - the 'interpretant' (the psycho-biological system developing during an individual's ontogenesis) which imprints this stimulated receptor with a meaning, or imprinted mark, prompts the organism to interpret the sign; and (3) Effect - the 'effect mark ... impregnates" the individual's environment[20].

The BPS model encompasses both the circumstances of 'emotional reactions' and 'somatic symptoms' as it is inclusive of the individual and their existing health status. It accounts for any affecting conditions by virtue of its paradigm's six specific supporting aspects[14]: (1) Illness based on biological changes indicate disease potential, not current circumstances; (2) Establishing relationships between physiological status and clinical presentation, both behavioral and psycho-social; (3) Living conditions significantly influence when conditions are reported and how they vary; (4) Psycho-social factors critically influence when and if individual's allow themselves and others to view them as sick; (5) "Rational treatment" directed at biological abnormality will not restore optimal status even when the condition is alleviated and correction documented; and (6) Provider's behavior and relationship with the individual influences the therapeutic outcome both positively and negatively.

Including BPS health as a dimensional input considers the 'individual' in any HFM and self-balance context. It creates an influence generally not accounted for, but required as it affects individual patterned responses as expanded upon below.

Biological contributors

The BPS model *biological* contributors to HFM provide insight into movement variability within and between individual/s, with many aspects well documented for 200 years, and some for 2000 years, consequently relevant historical references are provided. Biological attributes are specifically applicable in the presence of irregular inputs, both internal (ageing, fear, pain, …), and external (weather conditions, indoors *vs* outdoors, unstable surface contact, reason/motivation for training, fun, or rehabilitation …). These inputs cause physiological, sensory, and motor processing interactions[24], with specific biological relevance to nervous system processing, neuroplasticity, and 'reflex inhibition' or 'inhibition of reflexes' related to muscle activation.

Nervous system processing

There are significant variations in tissue-specific neural conductive paths[19] and subsequent delays that affect response times[18]. The CNS receives detected changes in position and orientation, and reacts in an integrated manner that maintains functional balance-control through a closed-loop feedback system with varied constraints on the sensory integration process, including "sensory weighting"[24]. Changes in motor activity or movement occur after nervous system processing[12], being primordially protective or survival responses designated to prevent injury in the presence of threat by facilitating the least detrimental choice. This is achieved through behavioral organization of 'action' or 'inhibition of action'[25]. The individual's response will vary in size and duration as a function of the input and individual experience[12]. Subsequent changes then input to the CNS feedback-loop as multiple sensory signals, body awareness, or environmental factors that add processing, further adaptation and changes to the initial movements. These are facilitated, inhibited, or further altered ... and the loop continues[26], but complexity will increase delays[6,8] unless the signals are 'packaged' as single unit from learned response[24]. However, a finite neural delay is required and determined by the brain's 'time available processing'[27] which is optimized during complex integrated neuro-motoric control, like slacklining. The CNS allocates 'weights' to each sensory system's incoming signals, to ensure each contribution is comparatively represented[28]; and employs 'muscle synergies', that combine muscle groups responses as a common neural signal that simplifies motor-control[29]. Altered movements are essential in the early protective phase of recovery and rehabilitation, but if not modified appropriately through learned-control they lead to mal-adaptation[12]. Slacklining, as a learned activity, is an explicit example and can only occur through HFM, which when achieved can override or modify the maladaptive movements.

Inhibition of reflexes and muscle activation

There is a duality in the term 'reflex inhibition' which describes two separate but independent centrally mediated phenomena: The 'inhibition of a spinal reflex' at the spinal level *i.e.*, the stretch and Hoffman reflex (H-reflex); and 'a reflex body response that causes inhibition to occur' at the central level thereby affecting muscle activation[30,31], essentially causing arthrogenic muscle inhibition (AMI)[32,33]. Both actions are reduced during slacklining due to refined or regressed levels of down regulation[7,34] from learned regulatory control of the external stimuli[23,35]. This is likely from increased striatal-network efficiency[36] from the hippocampus and other 'primitive' brain areas[18] leading to pre-synaptic inhibition in supraspinal centers. These predominantly affect reflex inhibition driven movement control[37] leading to neuroplastic change[38].

The ability to both 'compensate for' and 'coordinate with' these sensory-motoric induced physical delays and their variability[27] is influenced by integrated interplay[39]. This includes "visual prediction" and motor planning, where each retains some semi-autonomous compensatory control, but ostensibly under CNS hierarchical influence[18]. These changes remain in constant flux dependent on the individual's life status circumstances. Since motoric activity changes occur subsequent to CNS processing, this provides the initial opportunity for individual adaptation to afferent input, and any adaptation to movement patterns previously used. Changes in movement are essential aspects of response and experience. Their prediction cannot be only through physiological, sensory or motor considerations[26].

Other biological considerations include normal ageing and pathological declines in the body's mechanical structures[8,40] and neural system[41] and age-associated contrasts between early and later age learning, absorption and capacity. This includes cortical, subcortical[27], and neocortical tissue[38] plus limbic hippocampal-striatal representations and information processing; all of which contribute to memory and spatial learning fluctuations and age-deteriorations[41]. There is also the variable rise and ebb in white matter microstructure associated with cognition[42]. These aspects are further compounded by the mental state, such as deterioration with dementia, traumatic brain injury (TBI), Alzheimer's and Parkinson's disease[43]. They in turn contrast with the BPS health model perspectives, such as emotion, motivation and experience[15].

Neuroplasticity

Neuroplasticity is vital to this MDM of slacklining as neural tissue adaptive changes can be virtually instantaneous[44,45] or occur rapidly after a complex balance-task, like slacklining[27,46]. Neuroplastic changes can also be sustained for weeks or even years[47] being task-specific[23] and functionally transferable to activities of daily living (ADL)[48].

Anatomically, neuroplastic change occurs in different cerebral structures at variable rates. The duration of sustained change depends on the tissue and cellular components[45]. The triggered changes are activity-driven, rapid, and specific to dynamically regulated white matter (primarily myelinated axons which form the connections between cortico-cortical and cortico-subcortical regions and is critical for prefrontal cortex functioning)[40], and gray matter (primarily densely packed neuronal cell bodies, dendrites, and synapses)[49]. However, this dichotomous classification is overly simplistic as myelin in both the white and gray matter is derived from the neuroglial cells of oligodendrocytes developing from oligodendrocyte precursor cells (OPCs). To fully appreciate how dynamic myelination influences overall nervous system function during a complex whole-body activity, like slacklining, a circuit-level approach is required with integrating analysis of myelin dynamics and direct measurement of circuit function[45]. The measurable macro-level changes found with neuroplasticity, that indicate a re-sculpturing of brain structure, occur from increased underlying cellular and systems level cross-talk[36].

Neuroplastic-specific research of such changes has predominantly been on simple balance-based challenges (single-leg and tandem-standing), or dynamic (balance boards and moveable platforms)[50]. However, the balance-task difficulty for such activities is notably lower than that required to achieve and maintain a stable position when slacklining, which requires complex physical, neurological and whole body involvement[35]. Consequently, it can be extrapolated that changes found in simple and dynamic balance tasks will also be found in the more complex balance-task of slacklining[51]. The determined neuroplastic change can be latently reflected as both sensori-motor homunculus smudging[52] and as global concurrent functional change[48].

In considering the neurophysiological basis for neuroplastic change the white matter myelin support and insulate the axons and can alter their cell numbers, length, and penetration extent into the surrounding tissue[40]. They can be either modified through remodeling in situ or regenerated[49]. These include variable changes[45] to composition[38], distribution, and sheath[40]; the nodes of Ranvier size, length and spacing[53] which influence conduction velocity and by consequence reaction time. The gray matter neuroglial cells undergo multiple area morphological changes that include the fronto-parietal regions[47]; the limbic system from the hippocampal and para-hippocampus[46,50]; brain visual areas, lingual and fusiform gyri[26,48]; putamen and caudate nuclei that form the corpus and dorsal striatum; the cingulate gyrus and the precuneus in the superior parietal lobe and the supra-marginal gyrus[47]. Consequently, with slacklining, training-induced neuroplastic brain-tissue changes are specifically demonstrated by both structural and functional magnetic resonance imaging (fMRI)[47].

Such functional and morphological changes in brain structure subsequent to a complex balance oriented motor-learning task, like slacklining, has training-effects that result in activation and alteration of the primary motor cortex (M1), pre-motor cortex (PMC), supplementary motor cortex (SMA), cerebellum, and subcortical structures[26,54]. Connectivity reduces between other brain areas and the striatum during the training period, effectively increasing striatal network efficiency[47]. It is recognised that the fronto-parietal brain networks are responsible for coding acquired motor skills, but this appears to be a two-stage process[55]. Immediately post balance-training, functional connectivity is increased, then latently after several weeks structural changes that are induced by training can be visualized under both structural and fMRI. The task subsequently changes both the functional resting-state networks and the corresponding sub-cortical and cortical brain structures with time-related performance improvements[55]. Dynamic balance motor-training sessions initiate fronto-parietal network functional connectivity increases with the white matter after 1-wk[23] which continues consistently with micro-structural alterations over 6-wk with repeated training. In contrast, grey matter alterations and functional connectivity changes in prefrontal and supplementary-motor areas peaks at 3-wk[55].

Further, at the gross structural brain-tissue level, rapid and specific M1 gray matter changes triggered by balance-specific motor learning are visualized by MRI and diffusion tensor imaging (DTI). This includes increased cortical thickness from 1-session and is independent of resting cerebral blood-flow changes and repetitive leg use[50]. At the tissue and cellular level, neuronal processes re-modeling occurs at the pre-synaptic terminals that form synapses with dendritic spines. The gray matter induced changes include the SMA/pre-SMA, that reflect total dendritic spine alterations. Hence, both gray and white matter changes occur in the left anterior prefrontal lobe[56] from anatomical and functional connections *via* the cingulum bundle causing structural brain plasticity change across the entire cerebrum. This indicates large-scale networks comprising interconnected regions are positively affected leading to functional adaptation[55]. This strong systems level correlation between training-induced functional and structural brain plasticity changes suggests intrinsic brain activity has functional relevance for human brain morphological adaptations[55].

The exact time-scales accompanying structural remodeling and neuroplastic changes from high-demand balance training are not definitive[44]. The neural tissue cellular rearrangement and alteration occurs locally but at varying time-frames from activity specific stimulus[47]. The changes remain in flux, responding to variable internal[49] and external functional stimuli[42,50] that requires adopting new neural and motor sequences[57]. They are induced and maintained instantaneously, rapid short-term (hours-days) to medium-term (days-weeks), or long term (months-years).

Instantaneous neuroplastic initiation of cerebral change is instigated by sensori-motor[4,44] and psycho-social inputs[46]. These are assimilated by constant neural system adaptation[40] to provide solutions through new and modified pathways[45]. With challenging balance and postural tasks like slacklining, supraspinal sites exhibit pre-synaptic inhibition rather than post-synaptic actions as a predominant adaptation[26]. This is partially driven by corticospinal excitability from muscle and joint feedback that accentuates CNS modulation and corticospinal drive. This overrides pre-synaptic inhibition and enables a counteraction to the α-motoneuron inhibition[58].

With spinal 'reflex inhibition' the Ia afferent excitation is not fully transmitted to post-synaptic α-motoneurons which allows subsequent 'inhibition of the spinal reflex' to occur at the spinal level, including the stretch and H-reflex[51]; and a reduction in the reflex size without affecting the supraspinal input to the α-motoneuron pool. This reduced reflex size, without concurrent change to the background muscular activity, indicates modified spinal processing of afferent information[26].

Conversely, with AMI, trauma causing peripheral nociceptive afferent inputs to the CNS inhibits the α-motoneuron pool as a form of self-protection that deactivates local and stabilizing muscles, *e.g.*, quadriceps and multifidus[33]. With ongoing neural inhibition the CNS is prevented from fully activating affected muscles[58], which if sustained becomes detrimental[12]. Consequently, this form of 'reflex inhibition' is 'inhibition that occurs as a reflex body response' at the central level, and is a negative adaptation, where the down-regulation effect must be inhibited to restore normal function[37]. This instantaneous neuroplastic change is postulated to occur by reduced neurotransmitter release from central inhibition, which enables the Ia afferent excitation to be fully transmitted to post-synaptic α-motoneurons. This minimizes neural signal output reduction that maximizes normal supra-spinal input to the α-motoneuron pool which enables muscle activation that is otherwise dormant or 'reflex inhibited' from central influence[31], but does not affect 'disuse atrophy'[33,59].

Rapid short to medium-term neuroplastic change subsequently, occurs when the brain adopts new procedural rule sequences, or memorizes cascades of new reactions or events[44]. This includes: Specific memory and spatial orientation and mapping interpretation tasks, as with expert navigation[60]; and motor processing with complex movements, like slacklining[4,50]. These changes are in two formats: (1) Measurable neural tissue cellular rearrangement, and (2) Cellular remodeling as occurs with oligodendrocytes and OPCs[49]. They occur within hours of task performance due to the necessity to achieve activities with hippocampal formation-dependent non-spatial memory components[48] that require spatial separation of the vestibular and visual processes, as non-visual-dependent spatial orientation[44]. The spinal reflex reactions are strong in the initial learning stages, which creates instability that prevents control, *e.g.*, slacklining has uncontrolled ankle reciprocal agonist-antagonist cyclic contraction to eversion-inversion. With slackline training, learned activity has positive functional adaptation from centrally induced 'reflex inhibition' from reduced pre-synaptic neurotransmitter release[39] that dampens and overrides spinal reflexes.

Consequently, motor learning through complex balance training triggers neuroplastic 'rapid and specific gray matter changes in M1'[50] exhibited as selective brain-volume changes[60] and shown on MRI and DTI[43]. This includes microstructural changes in the limbic system (hippocampus and para-hippocampus)[44] and balance-control motor cortical effector representations of the trunk and lower limb that cause the noted increased cortical thickness. Further, they appear not to be isolated to high-level complex movement tasks, however the degree of change and its duration of retention is[50].

Longer term change results from motor learning and adopting automated task behavior[54]. The white matter myelin has increased conduction speed through new and remodeled oligodendrocytes and OPCs[45], including increasing cell size and length, and the size of and distance between nodes of Ranvier[53]. For the gray matter, the motor cortex changes at multiple areas, including the effector representations primarily responsible for the trunk and lower limb[50], with increased cortical thickness and sensori-motor homunculus smudging[52]. It is also postulated that changes are due to neuronal size, dendritic or axonal arborization, or neurogenesis[60]. There is also reduced cortex excitability[26] with subsequently, reduced spinal reflex excitability from spinal reflex processing of afferent inputs, including the H-reflex and stretch reflex[51,61]. At the macro-level, change favors: A smaller anterior hippocampal volume supported by associated reduction in the parieto-insular vestibular cortex; concurrent enlarged posterior hippocampal formation volumes and increased brain visual areas;

and enlarged lingual and fusiform gyri from increased visual cue usage[48]. During a training period, decreased gray matter connectivity can be shown[57] between the caudate nuclei and caudal anterior cingulate gyrus, precuneus in the superior parietal lobe, supra-marginal gyrus, and between the putamen and SMA and the supra-marginal gyrus[47].

Psycho-social contributors to the bio-psycho-social effect/dimension

Psychological contributors affect an individual's purpose for performing an activity and include expectations and self-motivation, daily life experiences, personal interactions, and stress. The social aspects include personal enjoyment, human social/technical interaction, rehabilitation, performance, and adjunct training[20]. Other important psycho-social factors include poor recovery expectations, pre-traumatic and post-traumatic psychological symptoms[15], and age related change[42].

Stress occurs within the context of occupational activities of work-load requirements, multi-tasking, hazards or negative customers, for example with taxi drivers, first responders and military personnel[60]. Other considerations are fatigue and sleep deprivation as with jet lag or work/life-stress related activities. These produce spatial cognitive deficits and temporal lobe atrophy from both gray and white matter differences, such as regional and total volume and neuroplastic change[45], that parallel biological causes.

In the gray matter new spatial memory and volume acquisition is influenced, particularly the anterior hippocampus, that affects processing ability[43,45]. This plays a key role in slackline performance and progression within settings that are contextual, declarative, and episodic. Further, the hippocampus role in vegetative and autonomic functioning affects the secretion of multi-adrenocorticotropic hormone[62]. These levels are determined by an intricate interaction and feedback system involving the hypothalamus, pituitary and adrenal (HPA) axis, all of which are directly affected by the stress response. The HPA axis is driven primarily by neural mechanisms causing glucocorticoids (GCs) secretion. These regulate hippocampal synaptic plasticity, gene expression and neuronal metabolism, which redirects' energy resources to meet real or anticipated demand within multiple organ systems[62]. These GCs cause cortisol elevation that is detectable in the plasma and saliva which, if prolonged or chronically elevated, is associated with reductions in hippocampal volume affecting spatial and hippocampal-dependent learning and memory task capacity. All forms of repeated or sustained BPS stress can lead to increased GCs and cortisol, with resultant negative hippocampus effects on learning, memory, and modified or inhibited functional activity task performance capacity. Structurally, the stress leads to hippocampus remodeling through three actions: hormonal influences (particularly estrogen in females), dendrite atrophy in the Cornu-Ammonis region, and suppression of the adjacent dentate gyrus neurogenesis of granule neurons in the hippocampus[62].

In the white matter, 'hyper-intensities' (WMH) can be critical as these indicate reduced tissue integrity associated with reductions in cognitive domains[42]. In particular, WMH affect executive function and attention, including working memory, mental flexibility, fluency, planning, set shifting, inhibition, and distinctive cognitive processes. These reduction effects are prominent with ageing and age-related disorders such as medial temporal lobe atrophy (MTA). For functional performance activities like slacklining, this significant MTA negativity reduces active ability as both MTA and periventricular hyper-intensities predict performance inhibition independently[42].

These vulnerable regions affect global reactions to repeated stress, trauma, and ageing[36]. This in-turn affects capacity and progression in learning and achievement of balance activities, with slacklining as an example[50]. Consequently, each individual's circumstance will vary on each occasion of each activity due to progression/regression within their given situation; where each are in-turn affected by their level of motivation, mental functioning, and cognitive status at the time. This is definitive in explaining why psycho-social factors must be accounted for in any model of HFM, particularly with complex balance tasks like slacklining. The BPS model of health explains this phenomenon in terms of factors associated with recovery that are not biomedical[15,20].

TIME MULTIPLICITY: A CRITICAL DIMENSION OF THE MODEL

Overview of the influence of time

The multiplicity of 'time' is an integral dimension in any hypothetical human functional model that explains slacklining. The 'spatial' aspect of time remains implicit within the diverse biological movements that define slacklining. Our focus is the fundamental aspect of an identity between space and time, which facilitates consideration of a multiplicity of times. Although a unique time and a unique space may be defined by physicists for communication within social groups, in this paper the multiplicities of time are considered, and how they, each and together, are critical in affecting the MDM.

As a species, humanity has contemplated the transience of time from the perspectives of philosophers to scientists, but rarely from that of health professionals when considering movement and rehabilitation. The relevance is that time does not exist alone as an invisible substance that encapsulates everything[16], rather it has a multiplicity of forms that must be considered separately, yet concurrently integrated to explain and understand slacklining as an example of complex HFM.

Both time and space are inseparable 'movement relations', as designated and encouraged by the theory of relativity. Similarly, we contrast spatial relations with temporal relations, or immobility relations with mobility. From the psychological perspective of the individual's internal-cortical time, for a human subject moving in space, future events feel closer than past events that occurred in similar time durations[63]. This asymmetry is a consequence of future events approaching, whereas past events recede and provide apparent differences in the subjective experience of movement through time. This is mirrored in the physical experience of movement through space. However, if the experience is experimentally reversed, then past-future asymmetry is eliminated[63]. This may indicate that during slacklining, as a complex and dynamic functional movement, the concepts of relativity theory may qualitatively apply, though conditional on being viewed from a new perspective. The quantitative assessment of this effect requires knowing the "spatial velocity of the future progression", that takes the place of light velocity in the Lorentz transformation (a linear transformation of one coordinate system to another which is moving at constant speed relative to the other).

However, in hypothesizing a MDM of movement, the separate entities must be acknowledged and considered, yet integrated as a whole that encompasses the achievement of the final action, that of stable HFM. With the development of relativity theory, partially as a consequence of the determination of electromagnetism, the need to understand the deeper connection between space and time variables appeared. The role of different observers in relation to moving reference frames was stressed, together with the loss of absolute space and time[64]. Subsequently, when extending the inspiration of relativity theory, emphasis has been placed on the constructed and conventional characteristics of time, and on the equally legitimate properties of the duality of external-physical clocks and an individual's internal-cortical experienced time/s. This will help resolve the issues of time perception and its potential multiplicities, and how they are to be considered within this proposed MDM of slacklining[16,17].

The relevance of 'external-physical' time and 'internal-cortical' times

A duality of time is the first manifestation of *multiplicity,* being an integrated reflection of the individuals given spatial and cortical recognition[16,65]. Here, '*external-physical'* time, often considered as 'true time', is that computed by physicist's clocks, and 'estimated' by human subjects. '*Internal-cortical'* time is that constructed within the brain and referred to as 'perceived' time[66]. Experiments show that internal times have a direct relationship with neural connections and reflexes that provide the subsequent human pre-emptive and causative physical reactions. These include cortical integration and musculoskeletal responses that occur within quantifiable time frames. These were first measured in the 1850s[67] being described as 'psycho-physiological time'[18], and demonstrated to vary dependent on the stimulus itself. Sound or touch propagated a neural interval of 150 ms compared to light at 200-250 ms, while other physical stimuli required longer durations, but all within the range of 100 ms-5 s[19]. The early research also considered 'internal time' as a metaphysical contemplation[67]; but stipulated a distinction between durations requiring significant computational neural processing time that occurred "unconsciously ... before precepts' emerge", and that this did not imply that neural substrates were unrelated to consciousness[18].

Relevance of neuronal conduction and processing within times perspective

A further consideration of differentials between 'external' and 'internal' is neural transmission systems' physiological limitations. As time-varying events occur in a physical state there are concurrent delays in the registered instantaneous *vs* the external state, with discrepancies between the two perspectives[18]. This is complicated further by the discreteness of the level of stimulation which determines the time delays for both neural delay and response, as there is a time differential between stimulation and a change in the target site's neural activity[18]. Furthermore, the individual's BPS status will influence the perspectives of both cortical and external time through current levels of excitation and preparedness due to motivation, social and psychologically influenced behavioral perspectives. Consequently, neuronal conduction and processing occurs in three distinct orders of duration on the external-physical time continuum; but do not epistemologically hold the same status: (1) < 100 ms, is 'instantaneity' and without 'time'; (2) 100 ms-5 s, is the 'present'; and (3) > 5 s, involves memory and duration estimation[19]. Within each perceived category separate subgroups are identified. Within 'instantaneity', 20 ms is the threshold for perceived succession or continuous presence, and approximately 40 ms is the minimum latency for reflex behaviors requiring only the spinal cord, *e.g.*, tendon-jerk responses. By contrast, learned motor 'voluntary response' with longer neural pathways are approximately 100-120 ms[67]. Lastly, 'choice response' behaviors involve additional cortical processing and slow to approximately 200-350 ms.

Consequently, simple reaction time is directly related to the delays in the single neurons or neural chains input-output actions, as variations depend on both the cell type and the modality of transmission-transduction; *e.g.*, sound-burst reaction-time is shorter than light-flash[65]. For complex functional balance tasks like slacklining, concurrent brain tasks result in a distinction between task processing and achievement that occur concurrently but with different durations. The implications being that the brain cannot maintain the required global task of balance by means of 'set and forget', addressing joint stiffness by postural adjustment from visual inputs[28]. This leads to an integrated global system where task success is determined by processing, accounting for time multiplicities, and adapting physiologically. This happens through concurrent neuroplastic change, down-regulation modification from hippocampal dampening, and spatial mapping within a learned and time-sensitive-adaptive experienced environment. To further complicate time's multiplicity is normal and pathological human ageing on the brain[41]. In early age we absorb, develop, and learn quickly, in later age the hippocampal-striatal circuitry for memory and spatial learning deteriorates[41].

Accordingly, the multiplicity of time is reflected in the learning and conducting of a complex balance task like slacklining by: the biological neuronal delay, the physical external time elapsed during the task, the perceived cortical time of the slackliner, and the process delays of choice action responses. Additional examples of time-multiplicity may also occur when temporal goals are set (*e.g.*, remain on the slackline for > 10 s); or when subjects receive instantaneous or delayed feedback during the elapsed-time standing on the slackline. The induced improvements in balance performance acquired during training are associated directly with increased striatal network efficiency[50]. These can be demonstrated on MRI, where connectivity between the striatum and other brain areas is decreased at varying rates[47] to enable the dampening process through increased reaction speed and selectively reduced input from multiple brain functional performance contributors.

Immediate relevance of time's multiplicity to slackline task performance

To remain stable and in balance, like slacklining, an individual either reverts to or progresses from a prior successfully learned strategy[6]. They employ learned control techniques that have become achieved movement patterns[68] that occur on multiple body-response time-scales[1]. However, on each new attempt to maintain an existing or progress to a higher level of competence, the integrated body-action occurs with the advantage of additional knowledge and experience[2,34], accompanied by accrued training[69], and the existing social structure determining why they perform this task[7]. Further, deviation from the stable upright position requires input from the three sensory contributors, each with different conduction latent time delays: (1) Proprioception *via* the joints; (2) Vision *via* the eyes; and (3) Vestibular *via* the labyrinthus[24]. These facilitate self-balance against gravity's inertial and ground-born vibration effects on head movements, particularly if vision is impeded. This provides at least six DoF: Three in the X, Y, and Z planes from the head's linear acceleration and static displacement giving translational motion sensed by the 'otolith organs'; and three from body rotation related to the X,Y, Z axes giving roll, pitch, and yaw as rotational motion sensed by the 'semicircular canals'. These inputs occur within the subsequent physical time delays present in the human sensory[39] and motoric[27] neural pathways. The delays limit the achievement of stabilization[51] but are minimized by having input from three separate systems 'packaged'[24] which enables responses to be assessed and adjusted based on how these inputs contribute to the 'total balance system'[28]. The subsequent physical time delay is differentially present at the levels of neural conduction[40], central processing[1], and motor response[27]. This causes a difference between what is experienced and what was intended[65,66].

Changes in motor activity or responsive movement patterns occur after CNS processing, by which time the reactionary response needed will be different to that produced post-processing[12], and that which is experienced[66]. A further confounding contributor of 'packaged' information is task complexity. This encroaches on time's multiplicity as actions in the sensory systems support each other through a feedback loop that provides' the signaling for the control task/s'[6]. As tasks become more complicated[8], *e.g.*, slacklining compared to quiet standing[13], delay increases within the system leading to greater disparity between the reactionary time measure and the time experience. This disparity is amplified by the increasing differences that task complexity causes between the intention (future), the actualized (current experienced), and the reflective (past) responses the individual attempts to assimilate and integrate[4]. Consequently, the brain continuously receives functional input that instigates change[44], constantly adapts, and provides new and modified paths[45].

These pathways will influence the multiplicity of measured time. The adopted strategy selected for HFM as an intended strategy will not be replicated exactly. This means that slacklining as a learned activity will be: maintained by a minimum level of practice, progresses only with further appropriate practice, and regresses with none[69]. Hence, as the individual seeks to repeat a positive or successful 'time-experience', they employ a retrospective time point intended to be imposed on a future time point, that will then become the current measurable time point from the physical perspective[16] and the experience[65]. This leads to the new adopted strategy and will in-turn become a new time point from which they will progress, or attempt to prevent further regression, to regain and progress their previous successful time-experience strategy. However, as each time point is reached, it is no longer simply a current-measurable physical property, but one that is transformed to an 'experience'.

This 'integrated experience' then fluctuates at the CNS and physical 3D level between: Transitionary perspectives of anticipatory and preparatory actions; reflection on both positive and negative effective intentions; and the existing current moment of experience[9]. During this 'current moment' it is recognized that time, as a context, is different and that this 'current moment' is perceived to change[17]. Time is reflected as a physical measure[16] to that which the individual has achieved as the experienced entity, and which is and always was intended to be replicated, regressed or progressed[19].

When the BPS health model was introduced[14] it highlighted time's importance within multiple perspectives, *e.g.*, "at all 'times' in history". As such, "time is not discovered, it is constructed"[16], as the brain, being the focal source of the human entity, "does not process information, but creates it"[70]. The brain constantly learns by enquiry and examination of the consequences and outcomes of action-based interactions, to test the hypotheses within its environment. This is achieved through control of the body as it explores and seeks, rather than simply acting as a coding device for information-absorption[70]. Over time, the brain can foretell the likely consequences of its actions through cognition, as experience ensures our systems are calibrated, which enables past actions to acquire meaning. Information and experience is assimilated to become the present, and construct the future, through the ability to 'disengage from … sensors and actuators'[70]. This cognitive loop replicates and parallels the precise physiological, neural, and mechanical-versus-control feedback loops which are influenced by our age-time physical and mental state. These existing models, described by infinite-dimensional mathematical differential-equations whose analysis ensures balance and stability, are governed by the essential limitations of sensory-motoric reflex delays[8]. The consideration of the multiplicity of time provides an overlaid encompassing dimension, and an enhanced paradigm within which any model of movement must be considered. This is particularly so for complex functional actions like slacklining, and by consequence, several time parameters may intervene in the equations.

CONSEQUENCES OF THE POINT OF VIEW PRESENTED

Slacklining facilitates a maintenance or improvement in balance-control that is explained by existing mathematical manifold models[1,4,6]. These models describe an expanding manifold, where a higher available range of motion is present before the manifold edges are reached[4], and balance is lost. With repeated training, individual learning facilitates an expansion of these manifold edges[1]; though to a finite limit which appears to be in the order of 10 cm laterally from the foot/feet for beginner and intermediate slackliners[3], but may be greater for expert level slackliners[4]. Consequently, balance stability is specifically discussed within existing models as a functional relation to the slackliner's contact point with the line; which enables the existing models manifold to be expanded in the future.

As control improves, the reactionary forces of the slackline[4] represents a unique dimensional contributor that pushes back against the weight and force of the slackliner[6]. This reaction force will reciprocate and remain incompatible with the slackline until a point of stabilisation is again reached. Further, this must also coincide with the individual's cortical and cerebral inputs, including those from the hippocampus[46,48], as well as the motivational and emotional centers[15]. These neurological aspects represent further dimensional contributors that have both preparatory and responsive actions that will assist closure of the manifold to a stable model, once all dimensional factors are equal and in harmony. This will represent a point of complete stability that is likely to last only briefly, till the imbalance of forces reoccurs and a state of entropy ensues. This is initiated by the combination of the individual's internal reactionary forces and the external forces of the environment that include the slacklines stored kinetic energy. However, the expert slackliner can prolong this period of equilibrium and exhibit a greater capacity to achieve and maintain stability and HFM.

To fully comprehend this proposed MDM, BPS health is considered along with each dimensional contributor. Within the three planes of movement, simple physics is accounted for within a physical, topographical, ordinary equivalent space. From the dimensional perspectives of forces and action-reaction resulting from the individual's physical interactions with the slackline and the environment, these are explained by classical mechanics. However, indirectly these recognized contributing forces are constrained by components of the BPS health model, and concurrently subjected to the multiplicity of time. Each force action is generated by the individual through the process of voluntary and involuntary muscular activity. It is a consequence of a balance reaction that is controlled from the three CNS levels, peripheral, spinal, and central. The central contributor includes cortical and cerebral inputs at the conscious and subconscious level[43], and the concurrent variations in motor cortex neural recruitment and neuroplastic changes[52].

The balance overlay affecting the dimensional input within the BPS health model entails that the biological, psychological, and social experiences of life perspectives are integral to HFM. The necessity of the given situation at hand, namely 'not falling over', is in itself a primordial imperative postural behavior[25] determined by postural orientation and postural equilibrium[71]. These inputs directly affect the dimensional forces generated and reciprocated to ensure that slacklining is achieved, and overlies the physical aspects of motion, function, and action or action-inhibition[25]. The sensory information is packaged and integrated[28], with or without a finite neural delay from time available processing[27] following input from the somatosensory, vestibular, and visual systems[24]. This in-turn determines the physical load perspectives and a muscular action at all levels of the body, employing muscle synergies as required to simplify motor-control[29], and achieve the necessary forces to retain balance and achieve HFM[50].

However, these loads are themselves determined by the goals of the movement task at hand and the context of the environment it is in[71], the fight-flight-freeze response[25], amusement[5] or physical endeavour[61]; and the skill and age of the individual[72]. These perspectives of the individual's goals and expectations are also affected by their prior life experience. This in-turn leads to both physical as well as emotional and psychological determined experience[20]. They are also affected by the multi-dimensional aspects of time in relation to space[16], perceived position[24], the stage of learning[4], and the individuals' position related to the anticipatory neurological reaction. These anticipatory postural adjustments maintain postural stability by compensating for destabilizing forces associated with moving a limb[69]. When the anticipatory movements align with the physical movement requirement and the psychological anticipatory experience related requirements, then the point of stability is facilitated. Consequently, the retention of balance on the webbing band to achieve slacklining is an integrated response of multi-dimensional inputs that is determined from: The amount of cognitive processing necessary for postural control, as established by the complexity of the task at hand, and the capability of the individual to provide the control (Table 1).

Table 1 Summary table of the proposed concept-model

Additional dimensionality		Multiple levels	Description
Time multiplicity: physical/external versus cortical/internal. These can include: (1) Biological neuronal delay; (2) Learning; (3) Process delays of choice; (4) Action responses; (5) Physical external time elapsed; (6) Perceived cortical time; (7) Temporal goal setting; and (8) Instant feedback	Biopsychosocial constraints, these can include: (1) Motivation; (2) Attitude; (3) Context; (4) Experience/Skill (neuroplasticity); (5) Fatigue; (6) Muscle properties; (7) Injury; and (8) Age	4: Neural activity	The manifold of different muscle activity strategies leading to HFM slacklining are the result of a complex integration of top-down control loops, bottom-up reflexes, neural latencies, inhibition loops *etc.*
		3: Muscle activity	Various muscle activation strategies can be used to control the multi-DoF joint kinematics and stay within the manifold of level 2 (co-contraction to control joint stiffness, agonist/antagonist tuning)
		2: Multi-DoF joint kinematics	Keeping within the manifold of level 1 can be attained through multiple solutions of joint kinematic strategies (abundant movement system). Different positions and orientations of the segments of the extremities and trunk can give the same CoM coordinates; vice versa the same point in the CoM phase space can be obtained through various joint kinematics. The (infinite) set of joint kinematic strategies form a manifold themselves within a high-dimensional topographical space
		1: CoM phase space	At the whole-body level there is > 6D phase space for CoM (position, orientation and velocity relative to the base of support, limbs and diverse body parts) contains a manifold in which the objective of slacklining (level 0) is achieved. There are physical limits to the extent the CoM can deviate from the base of support and to the velocities that can be counteracted. Higher velocities can be counteracted in regions of the manifold where deviation from the base of support is small
		0: HFM slacklining	The basic objective of slacklining is harmonious functional movement on a tightened rope: smooth dynamic stability

The slacklining multi-dimensional model presented above illustrates: the two added dimensions of 'time multiplicity' and 'biopsychosocial constraints', in the left 2-columns in descending hierarchical order; and the subsequent multiple levels at which these influence the body's response are presented in the 5-Rows and read from bottom to top in ascending hierarchical order. MDM: Multi-dimensional model (of slacklining); HFM: Harmonious functional movement; CoM: Centre of mass; DoF: Degrees of freedom.

FURTHER RESEARCH DIRECTIONS

Future research should investigate this slacklining MDM as a high-dimension mathematical manifold that details and discusses the multiple proposed contributing dimensions/constructs. There should include specific model applications that enable an improved understanding of HFM, stability, and balance-control. This may provide new/evolved evidence based recreational, performance, and rehabilitation slacklining applications and techniques as well as general stability-balance models. The MDM role in areas requiring development and utilization of stability, such as applications for machine learning for identifying pattern recognition of movement phenotypes. These applications may also extend to prostheses, mechanized automation, altered gravitational environments, robotics, mechatronics, and AI driven locomotion.

CONCLUSION

The successful strategy an individual employs to achieve slacklining is optimally explained by a hypothesized MDM. The strategy encompasses self-learned movement patterns that involve active and reactive generated forces that are integrated with gravity and the slackline's elastic reactive properties, governed by classical mechanics, occurring within a 3D defined space. These actions are subject to the BPS health model that integrates biological criteria, under psychologically experienced and motivated influences, affected by socially determined inputs. Concurrently, the multiplicity of time pervades and integrates all contributors as a measurable unit and integrated spatial and cortical experience. Dynamic stability is transitory and momentary, and acquired through the integration of all dimensions. It is higher in those with greater skill, but always returns towards entropy with movement away from, back to, and only momentarily crossing the point of fully integrated stability, a duration that lasts longer as skill increases. This multi-tiered context facilitates multiple slacklining applications in movement, balance and stability. Further research is required to investigate this proposed model and potentially enable an improved understanding of HFM and its application in other diverse constructed and mechanical applications, varied environments and automation, robotic, mechatronics and AI factors.

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MINIREVIEWS

Dual antibiotic loaded bone cement in patients at high infection risks in arthroplasty: Rationale of use for prophylaxis and scientific evidence

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Abstract

In view of the demographic changes and projected increase of arthroplasty procedures worldwide, the number of prosthetic joint infection cases will naturally grow. Therefore, in order to counteract this trend more rigid rules and a stricter implementation of effective preventive strategies is of highest importance. In the absence of a "miracle weapon" priorities should lie in evidence-based measures including preoperative optimization of patients at higher infection risks, the fulfilment of strict hygiene rules in the operating theatre and an effective antibiotic prophylaxis regimen. Instead of a "one size fits all" philosophy, it has been proposed to adjust the antibiotic prophylaxis protocol to major infection risks taking into account important patient- and procedure-related risk factors. A stronger focus on the local application mode *via* use of high dose dual antibiotic-loaded bone cement in such risk situations may have its advantages and is easy to apply in the theatre. The more potent antimicrobial growth inhibition *in vitro* and the strong reduction of the prosthetic joint infection rate in risk for infection patients with aid of dual antibiotic-loaded bone cement in clinical studies align

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with this hypothesis.

Key Words: Prosthetic joint infection; Antibiotic-loaded bone cement; Single low dose antibiotic-loaded bone cement; Dual high dose antibiotic-loaded bone cement; Antibiotic prophylaxis; Risk-for-infection patients

Core Tip: The objective of an effective antibiotic prophylaxis in arthroplasty may be best achieved through the combination of a systemic and local application route *via* antibiotic-loaded bone cement. Based on the observation of strong synergistic effects in antibiotic elution and antimicrobial efficacy of dual antibiotic-loaded bone cements, the hypothesis of a clinically more meaningful prophylaxis has been tested against gentamicin-only containing bone cements. Evidence is provided that this easy-to-apply strategy might be successful, if important comorbidities or procedure-related factors predispose patients to higher infection risks than usual.

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INTRODUCTION

Prosthetic joint infection (PJI) is one of the most dreadful complications of arthroplasty. Effective prophylactic strategies are essential to reduce the incidence of these difficult to treat and burdensome infections. The mode of prophylactic use of antibiotic-loaded bone cement (ALBC) is a frequent surgical practice in cemented hip and knee replacement. The idea behind delivering antibiotics directly into the vulnerable joint compartment is that local concentrations well above the minimum inhibitory concentration of the pathogen can be achieved without exposing the patient to major risks of side effects. With this mechanism ALBC may form an additional antimicrobial frontline *in situ* and complement the routine systemic antibiotic prophylaxis. The combined systemic and local antibiotic administration may be even more important in situations where the efficacy of the systemic prophylaxis is experiencing increasing limitations due to the spread of resistant bacteria to the commonly used perioperative antibiotics cefazolin or cefuroxime[1,2]. The Scandinavian registries and, most recently, the National Registry of United Kingdom have demonstrated that the additional use of ALBC reduces the revision risk in cemented hip and knee replacement[3-6]. It can be further speculated that this effect is more significant if specific cement brands are analyzed due to different antibiotic elution capacities of the cement polymers in commercial ALBC brands[7,8].

In view of the demographic changes, arthroplasty surgeons today face the challenge to operate on an increasing number of older patients suffering from several major comorbidities. Numerous clinical studies have provided evidence that important patient-related disorders predispose patients to a higher operational risk of infections than on average[9-11]. This is also true for the more complex surgical procedures of revision arthroplasty which is frequently associated with longer operation times and a higher invasiveness leading to a PJI incidence of 5% and more[12]. Significantly increased infection rates of 4%-6% are also reported in the frail cohort of femoral neck fracture (FNF) patients on an emergency trauma track which does not leave time for preoperative health optimization strategies or for decolonization protocols of multi-drug resistant bacteria[13,14]. In order to counteract the higher infection risks in such patient cohorts, one may hypothesize that a more optimized and risk-adjusted antibiotic prophylaxis strategy may have a positive impact on the PJI incidence. This may include (1) modification of the routine perioperative antibiotic prophylaxis regimen by either extending the duration[15] or by adding a second antibiotic to the standard drug (*e.g.*, vancomycin or teicoplanin to a cephalosporin)[16] or (2) use of high dose local antibiotic combinations. Given the controversial outcomes regarding the first option and the substantial risks of side effects associated with prolonged systemic antibiotic exposure[17], a risk-adjusted strategy with dual ALBC might be a more attractive and "easy-to-apply" option in the theatre. The more potent antimicrobial growth inhibition found *in vitro* and the significantly reduced PJI rates in high infection risk patients receiving dual ALBC strongly argue for the latter option. This review summarizes the literature and evaluates the evidence from preclinical and clinical studies for the use of dual ALBC for PJI prevention in risk for infection patients and orthopaedic risk procedures. For that purpose, the PubMed and EMBASE literature databases were screened for publications pertaining to the clinical utilization of dual antibiotics in cement for infection prophylaxis. Use of dual ALBC in treatment of septic cases was excluded from the evaluation. Only four *in vitro* and five original clinical studies were identified which met the inclusion criteria. The latter were also stratified by level of clinical evidence (I-IV). The combination of gentamicin and clindamycin in commercial bone cement was the only referenced dual ALBC in these clinical studies. To the best of our knowledge there are no clinical outcome studies published which have compared the PJI rate in hand-made (theatre-admixed) dual ALBC *vs* single ALBC.

COMMERCIALLY PREMIXED *VS* HAND-MIXED DUAL ALBC

There are several Food and Drug Administration and European Medicines Agency approved ALBC which are available as "ready-to-use" commercial products. According to their antibiotic contents they can be grouped in single low dose ALBC [*e.g.*, impregnated with either 0.5 g or 1 g of gentamicin or loaded with 1 g of tobramycin in 40 g polymethyl methacrylate (PMMA) powder] or in dual high dose ALBC (*e.g.*, impregnated with 1 g of gentamicin and 1 g of clindamycin or loaded with 0.5 g of gentamicin and 2 g of vancomycin). In addition, there is widespread non-standardized, off-label and surgeon-directed use involving hand-mixing various antibiotics into bone cement. Reasons for this practice are economic considerations, lack of availability of specific ALBC, limited local regulatory approval or need for specific customized solutions in septic revision arthroplasty[18]. However, manual admixture of antibiotics into bone cement has raised some concerns with regards to unknown elution kinetics, toxicity, efficacy and mechanical stability of such in-theatre made ALBC[18]. The latter aspect is particularly important if the cement is intended for fixation. In fact, the manual addition of higher amounts of some antibiotics in powder- or in liquid-form has been shown to affect the fatigue strength of PMMA prompting fears of premature aseptic loosening of the joint[19]. It should also be noted that some antibiotics are not stable at the bone cement curing temperature (*e.g.*, many beta-lactam antibiotics) or chemically interfere with the polymerization process (*e.g.*, rifampicin)[20]. Given these uncertainties, the majority of surgeons still prefer the use of commercial single or dual ALBC for prosthesis fixation.

STRONGER ANTIMICROBIAL ACTIVITY WITH THE DUAL ALBC COPAL GENTAMICIN + CLINDAMYCIN *IN VITRO*

Gentamicin is the most frequently used antibiotic for impregnating bone cement because of its broad and concentration-dependent bactericidal effect, its relatively good elution in comparison to other antibiotics and its ability to withstand the high temperatures reached during polymerization of the bone cement[21]. Its antimicrobial spectrum covers non-gentamicin resistant gram-positive staphylococci, enterococci and several gram-negative bacilli[22]. Clindamycin is also an attractive antibiotic for local delivery which shares several features of gentamicin, but shows in addition a potent antimicrobial activity against intraosteoblastic *Staphylococcus aureus*[23]. Its spectrum overlaps with gentamicin on staphylococci and furthermore covers non-clindamycin resistant streptococci and anaerobic bacteria[24]. In combination, both antibiotics may target up to 90% of all pathogens typically found in PJI[25,26]. Given these antibiotic properties it is therefore not surprising that a dual ALBC bone cement using these antibiotics has been developed. This bone cement COPAL G+C (gentamicin + clindamycin) (Heraeus-Medical GmbH, Wehrheim, Germany) is simultaneously loaded with 1.68 g of gentamicin sulfate (= 1 g of active gentamicin) and 1.18 g of clindamycin hydrochloride (= 1 g of active clindamycin) within the polymer basis of the successful PALACOS bone cement. Soon after the commercialization of COPAL G+C, Kuehn *et al*[7] and Neut *et al*[27] compared the antibiotic elution from this product with several single antibiotic loaded low dose cement brands on the market in two independent studies. It was found that COPAL G+C exhibited a much stronger synergistic release of both antibiotics exceeding that of gentamicin alone in single ALBC by a factor of at least 10[7,27].

Ensing *et al*[28] then combined these elution experiments with antimicrobial growth inhibition tests comparing the dual high dose COPAL G+C and the single low dose PALACOS R+G cement (containing 0.5 g of gentamicin). For that purpose, antibiotic-containing eluates from bone cement samples were collected at different time points and spotted onto agar plates which had been priorly inoculated either with a gentamicin-sensitive *Staphylococcus aureus* or with a gentamicin-resistant coagulase-negative *Staphylococcus epidermidis* strain. Both bacterial test strains were originally derived from PJI patients. COPAL G+C was observed to inhibit bacterial growth much more strongly when compared to PALACOS R+G. In more detail, the single low dose ALBC was effective in inhibiting growth of the gentamicin-sensitive *Staphylococcus aureus* for a period of 72 h of elution. However, the G+C containing cement yielded a stronger and more prolonged bacterial inhibition for at least 28 d, which was the entire duration of the experiment. In case of the gentamicin-resistant *Staphylococcus epidermidis* strain PALACOS R+G was not able to inhibit the bacteria while COPAL G+C prevented growth of these bacteria at all times after elution.

Cara *et al*[29] expanded on these studies and compared the inhibitory effect on staphylococcal biofilm formation of plain cement (no antibiotic) with the three ready-to-use commercial ALBC brands PALACOS R+G, COPAL G+C and COPAL G+V (the latter contains a combination of 0.5 g gentamicin and 2 g vancomycin, Heraeus Medical GmbH, Wehrheim, Germany). In total, ten different strains of *Staphylococcus aureus* and *Staphylococcus epidermidis*, some with specific resistance to gentamicin, were analyzed. It was observed that all the tested ALBC can inhibit biofilm formation of methicillin-susceptible staphylococci (without antibiotic resistances) up to day 9 (end of observation period). However, the inhibition of the dual ALBC brands at day 9 appeared more potent and sustained than that of the single ALBC product (Figure 1A). Strong antimicrobial effect of all 3 ALBC - at least up to day 3 - was also evident for methicillin-resistant staphylococci if they were still susceptible to gentamicin. However, a strong difference could be noticed for such strains which were highly resistant to gentamicin. In these cases, only the dual loaded products were able to exert a potent anti-biofilm activity with a tendency of even stronger and longer lasting inhibition for the G+C combination (Figure 1B). The most reliable and most sustained inhibition effect of the G+C combination against gentamicin-resistant coagulase-negative staphylococci is of important clinical relevance since regular antibiotic surveillance data from several countries point to an increasing gentamicin resistance level of these bacteria[30].

LOWER PJI RATE WITH DUAL ALBC (COPAL G+C) - HEMIARTHROPLASTY IN FNF PATIENTS

These promising *in vitro* observations with dual ALBC prompted surgeons at the Northumbria NHS Trust hospitals in the United Kingdom to test the hypothesis of a clinically more meaningful infection prophylaxis with COPAL G+C in the setting of a randomized clinical trial. For this they chose the particularly frail patient cohort of FNF patients known to suffer from higher infection risks. The study comprised of 848 patients with intracapsular fractures who were treated with cemented hemiarthroplasty according to the United Kingdom trauma guidelines. It was found that the primary study endpoint, incidence of deep surgical site infections (SSI), was significantly lower in the intervention group receiving the dual ALBC COPAL G+C (1.1% deep SSI rate) compared to the standard group receiving the single low dose ALBC PALACOS R+G (3.5% deep SSI rate, P = 0.041, evidence level I, Figure 2)[31]. If also considering the number of superficial SSI occurring in both groups, the difference was even more significant (1.7% in the intervention group *vs* 5.3% in control group). Tyas *et al*[32] later extended the patient number from this randomized study and analyzed 1941 FNF-patients in the same way. The lower PJI rate in the dual ALBC group was maintained (1.2% *vs* 3.4%). Savage *et al*[33] independently reported a PJI rate of 0% in the dual ALBC FNF-patient cohort *vs* 2.9% in the single ALBC group. This study compared bone cements from two different manufacturers in a mixed prospective and retrospective study design (n = 206), (evidence level II).

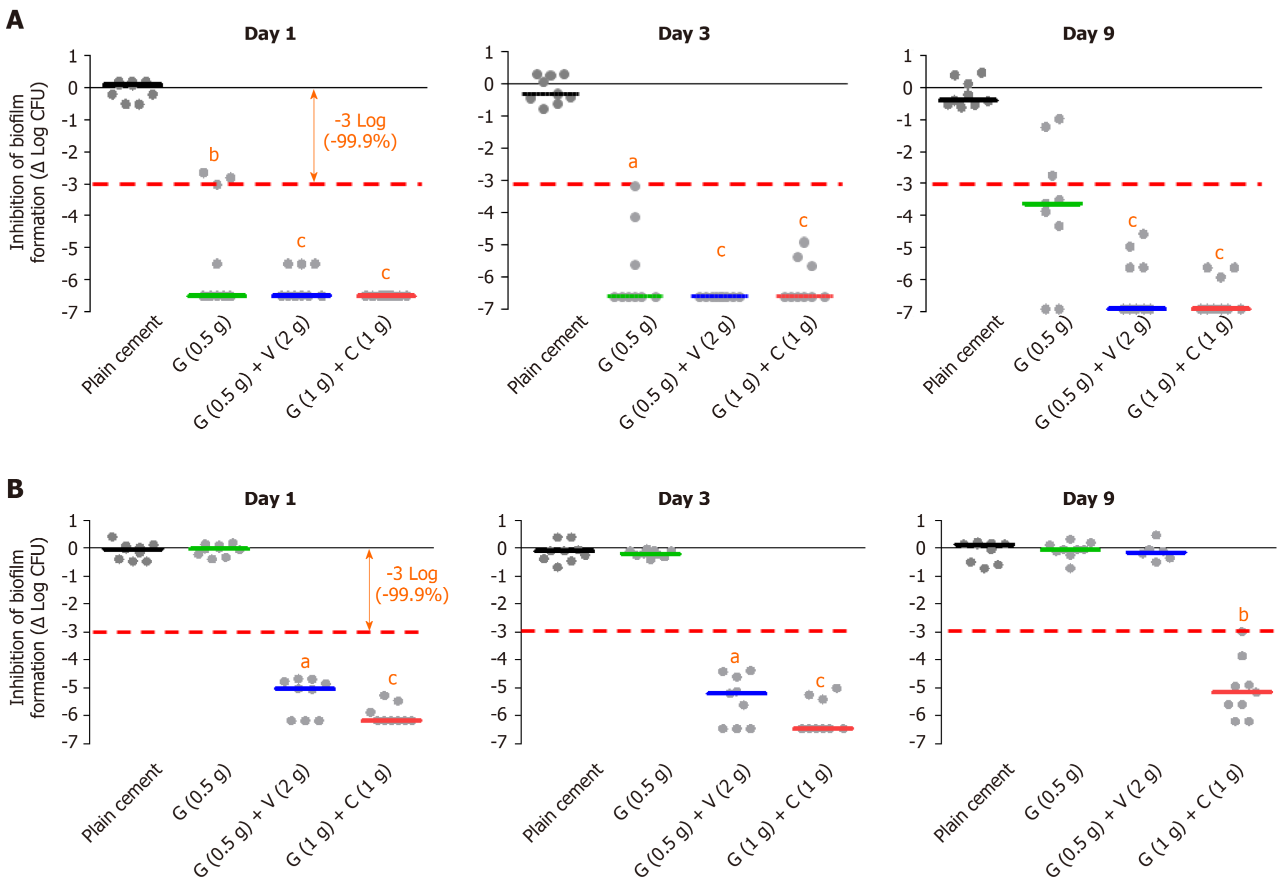


Figure 1 *In vitro* biofilm inhibition experiments with different bone cement types (plain, single and dual antibiotic-loaded bone cement). A: Prophylactic anti-biofilm effect of three different antibiotic-loaded bone cements against a gentamicin and methicillin-susceptible *Staphyloccus aureus* strain at day 1, day 3 and day 9 on basis of three independent experiments; B: Prophylactic anti-biofilm effect of three different antibiotic-loaded bone cements against a gentamicin- and methicillin-resistant *Staphylococcus epidermidis* strain on basis of three independent experiments. $^{a}P < 0.05$, $^{b}P < 0.01$, or $^{c}P < 0.001$ respectively in comparison with PALACOS R (cement without antibiotic). G: Gentamicin; C: Clindamycin; V: Vancomycin.

Concerns that the use of a dual antibiotic loaded cement with higher drug content may trigger more antibiotic-mediated side effects in these fragile patient cohorts could not be confirmed. In fact, the comparison of complications including renal failure or percentage of *Clostridium difficile* infections did not reveal differences between the standard and intervention group[31]. There was even a statistically significant decrease in the need for critical care treatment in the COPAL G+C group (0.5% *vs* 4.7%) reflecting the clinical impact of the much lower PJI rate in the intervention group receiving dual ALBC[31].

LOWER PJI RATE WITH DUAL ALBC (COPAL G+C) - ASEPTIC KNEE REVISION ARTHROPLASTY

Inspired by the promising results from the FNF studies, Sanz-Ruiz *et al*[34] tested the study hypothesis of a more potent infection prophylaxis with the dual ALBC COPAL G+C in the field of aseptic revision knee arthroplasty. All septic and oncologic revision causes were excluded in this study. On basis of 246 patients analyzed in this retrospective study no case of PJI was observed in the COPAL G+C group compared to six cases occurring in the PALACOS R+G group (PJI rate = 4.1%, *P* = 0.035, evidence level III). The use of the dual ALBC in all patients undergoing aseptic revision arthroplasty was further found to be cost-effective despite the additional cost of dual ALBC. A hospital saving of approximately 1200 € per patient was calculated due to 3.9 avoided PJI cases per 100 aseptic knee revision patients[34].

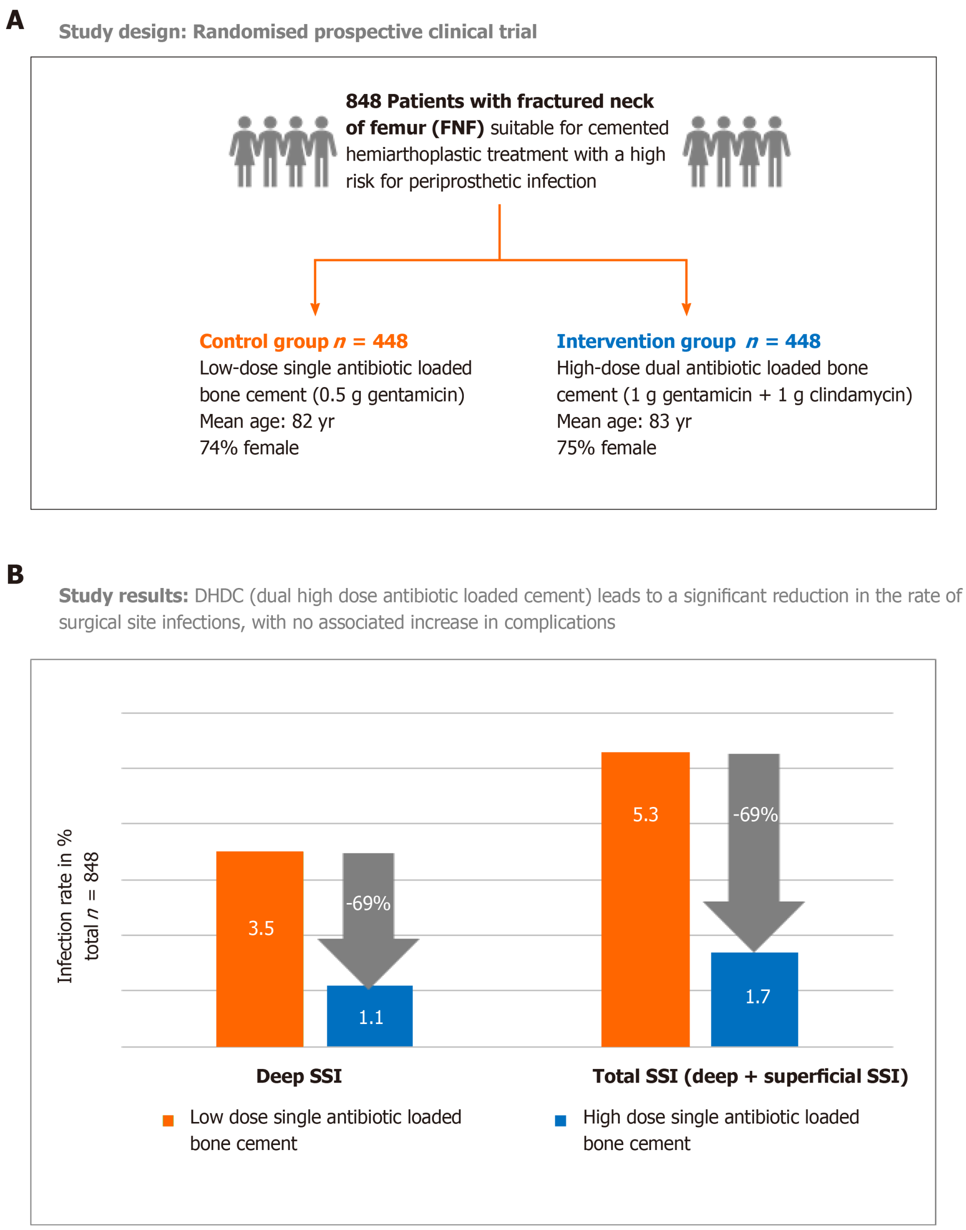


Figure 2 Randomized clinical trial in femoral neck fracture patients comparing prosthetic joint infection rate in low dose single antibiotic loaded bone cement group with high dose dual antibiotic loaded bone cement group. A: Study design, 848 patients were randomised to receive either hemiprostheses cemented with a low dose single antibiotic-loaded bone cement (PALACOS R + gentamicin = control group) or with a high dose dual antibiotic-loaded bone cement (COPAL gentamicin + clindamycin = intervention group); B: Study results: Primary endpoint was the deep surgical site infection rate (SSI) in the observation period of ≥ 1 yr in each group. Secondary endpoint was the rate of superficial SSI. For the calculation of the total SSI, both deep and superficial SSI cases in each group were combined. SSI: Surgical site infection.

LOWER PJI RATE WITH DUAL ALBC (COPAL G+C) - RISK FOR INFECTION PATIENTS IN PRIMARY ARTHROPLASTY

Sanz-Ruiz and Berberich[35] further analyzed the infection rate in presumed risk for infection patients by comparing the influence of single ALBC *vs* dual ALBC on the PJI incidence after primary cemented joint replacement. Patients were defined as risk for infection individuals if they presented a combination of at least two or three major risk factors for total hip arthroplasty and total knee arthroplasty, respectively, using a simple scoring system. The risk algorithm included specific patient-related comorbidities (*e.g.*, severe anemia, severe obesity, diabetes mellitus, chronic immunosuppression) and further general risk factors (*e.g.*, hip-fractures or prior arthroplasty surgeries)[35]. The study analyzed 2551 patients and found a trend towards fewer PJI cases in the dual ALBC (COPAL G+C) group containing exclusively patients at higher infection risk compared to the mixed risk profile (low and high risk) in the single ALBC (PALACOS R+G) group (PJI rate 2.45% *vs* 3.7%) (level of evidence

III/IV). This was a particularly interesting observation as one would expect an even higher PJI incidence in the higher infection risk cohort of patients. Further studies are needed to confirm whether this trend to fewer PJI cases in presumed risk for infection patients can be generalized on a broader basis for dual ALBC.

LOWER RATE OF RE-REVISIONS WITH DUAL ALBC IN SPACER AND/OR FIXATION CEMENT FOR REVISION PROSTHESIS - SEPTIC REVISION ARTHROPLASTY

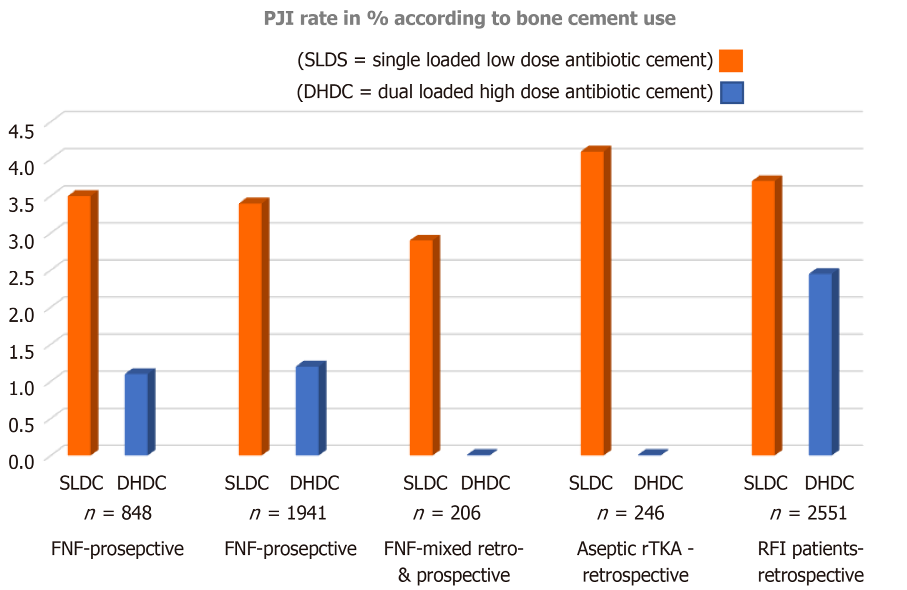
For many surgeons it is common clinical practice to use ALBC for the manufacture of block or articulating spacers in staged PJI treatment protocols and/or for the fixation of the revision prosthesis. Such ALBC spacers are meant to prevent bacterial recolonization of the foreign body and assist in the successful eradication of the infected joint in combination with systemic antibiotics. In order to increase the depot effect of the local antibiotics and to counteract the risk of antibiotic resistances in septic cases, the use of combinations of local antibiotics has been suggested[36]. The selection of antibiotics should be based on the antibiogram of the PJI organisms found after culture of synovial fluid and tissue biopsies. Vancomycin is the most common antibiotic added to aminoglycoside-containing single ALBC either in form of commercial dual ALBC brands or manually admixed in the theatre. The rationale of its use is to further target gentamicin-resistant methicillin-resistant *Staphylococcus aureus* (MRSA) and methicillin-resistant *Staphylococcus epidermidis* (MRSE). pathogens which are frequent in some regions, such as the United States[37]. Although several questions remain regarding optimal dosage for the possible therapeutic effects on biofilm-bacteria and/or contribution to renal injury if admixing large amounts of antibiotics into cement[18,36], its contribution to successful infection eradication appears conclusive[38]. Wouthuyzen-Bakker *et al*[39] have recently demonstrated on a large number of PJI cases to which extent the addition of vancomycin into the cement spacer influences the amount of growth-positive cultures taken at reimplantation of the revision prosthesis. The rate of unsterile biopsies dropped from 21.7% to 9.5% if combinations of vancomycin and gentamicin in the cement were used instead of aminoglycoside monotherapy spacers. On a single bacteria level, the strongest antimicrobial effect by such dual ALBC spacers was evident for coagulase-negative staphylococci (reduction of growth-positive samples from 13.3% to 2.5%).

Abdelaziz *et al*[40] have also provided evidence that the strategy of using the broad spectrum dual ALBC COPAL G+C (with or without additional admixing of vancomycin or ofloxacin) led to complete cure of PJI in one-stage treatment protocols. At five years follow-up, no patient required a repeated revision arthroplasty with exchange of the cemented prosthesis because of either infection or loosening. This was particularly remarkable as 33% of the included PJI cases in this study were caused by polymicrobial infections.

CONCLUSION

The current literature including *in vitro* and *in vivo* studies supports the additional benefits of dual ALBC, with synergy of drug elution and improved antibacterial activity on a wide range of pathogens related to orthopedic infections. While its therapeutic efficacy on mature biofilm-bacteria is still not entirely clear, more and more data have now demonstrated that it may confer better protection from infection in particularly vulnerable patients or in higher risk procedures (see Figure 3 for summary of clinical evidence). However, this conclusion is based on a mix of prospective and retrospective cohort studies, the latter with a lower evidence level and inherent limitations with regard to possible study bias and higher risk of confounding factors. A generalization of the observed effect of a stronger antibiotic prophylaxis by dual ALBC may also be problematic given that the ready-to-use brands of bone cements differ in their antibiotic elution properties as well as in the nature and amount of pre-mixed antibiotics.

The idea of an infection risk-adapted antibiotic prophylaxis strategy may be one interesting option among other preoperative optimization protocols to decrease the burden of PJI. In addition to the use of dual ALBC this can also be achieved by temporary or permanent antibacterial implant coatings including surface modifications with silver ions or manual spreading of a fast-resorbable, antibiotic-



Ref.	Sprowson *et al*[31] 2016	Tyas *et al*[32] 2018	Savage *et al*[33] 2019	Sanz-Ruiz *et al*[34] 2020	Sanz-Ruiz *et al*[35] 2020
Indication and study design	Femur fracture, randomized prospective trial	Femur fracture, randomized prospective trial	Femur fracture, retro-& prospective study	Aseptic rTKA, retrospective study	Primary TKA & THA (RFI-patients), retrospective study
Number of patients included	*n* = 848	*n* = 1941	*n* = 206	*n* = 246	*n* = 2551
Study arms	SLDC *vs* DHDC	SLDC *vs* DHDC	SLDC *vs* DHDC	SLDC *vs* DHDC	SLDC *vs* DHDC
Evidence level	level I	level I	level II	level III	level III/IV
PJI rate in %	**3.5 *vs* 1.1**	**3.4 *vs* 1.2**	**2.9 *vs* 0**	**4.1 *vs* 0**	**3.7 *vs* 2.45**

Figure 3 Overview of published clinical study results comparing prosthetic joint infection rate in patients in single low dose cement and dual high dose cement group across different indications. The table below lists the main study authors, indication and study design, number of patients included, evidence level of clinical study and prosthetic joint infection rate in % in both study groups. PJI: Prosthetic joint infection; SLDC: Single low dose cement = PALACOS R+G (containing 0.5 g of gentamicin); DHDC: Dual high dose cement = COPAL G+C (gentamicin + clindamycin); FNF: Femoral neck fracture; rTKA: Revision total knee arthroplasty; RFI: Risk for infection; THA: Total hip arthroplasty.

loaded hydrogel[41]. Both strategies have been shown to reduce early post-surgical infections in uncemented implants in orthopedic surgery. Further studies are needed to truly elucidate the effect of dual ALBC and other local antibiotic delivery systems for infection prevention and to weigh possible benefits against potential adverse effects and costs.

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MINIREVIEWS

Advantages of preoperative planning using computed tomography scan for treatment of malleolar ankle fractures

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Abstract

Malleolar ankle fractures have been classified using plain radiographs, and there is no consensus regarding the role of computed tomography (CT) scans in preoperative planning. We analyzed critical aspects, such as limits of standard radiographs, types of injury, classification methods and cost/benefit evaluations. CT scans allow a 3D analysis of the fracture to be obtained and consequently assess the indication for surgical procedure, surgical access and the type of fixation devices required. This exam is useful for detecting lesions that may go unnoticed on radiographs and will help surgeons to clarify the pathoanatomy of ankle fractures. According to Arbeitsgemeinschaft fur Osteosynthesefragen/ Orthopaedic Trauma Association (AO/OTA) classification, CT scan is recommended in medial malleolar fractures with vertical rim, type 44B fractures with posterior malleolar involvement and all type 44C fractures (according to AO/OTA). Also Tillaux-Chaput fractures (43-B1 according to AO/OTA), malleolar fractures in the presence of distal tibial fractures (43 according to AO/OTA) and distal tibia fractures in adolescents should be studied with CT scans.

Key Words: Computed tomography scan; Malleolar fractures; Planning; Trauma; Imaging

Core Tip: Computed tomography scan is recommended in medial malleolar fractures with vertical rim, type 44B fractures [according to Arbeitsgemeinschaft fur

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Osteosynthesefragen/Orthopaedic Trauma Association (AO/OTA) classification] with posterior malleolar involvement. All type 44C fractures (according to AO/OTA), Tillaux-Chaput fractures (43-B1 according to AO/OTA), malleolar fractures in the presence of distal tibial fractures (43 according to AO/OTA) and distal tibia fractures in adolescents should be studied with computed tomography scans.

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INTRODUCTION

Ankle fractures represent 10.2% of all fractures[1] and are the most common fractures of the lower extremity after proximal femur fractures[2]. The incidence number is approximately 1000 out of 1000000 people per year[3] with higher rates reported in the European literature[3,4]. Single malleolar fractures are the most frequent followed by bimalleolar fractures (25% of ankle fractures) and trimalleolar fractures (5%-10%)[5].

Isolated posterior malleolar fractures are rare[6] because they are usually associated with other bone or ligament injuries[7]. Ankle syndesmosis injury occurs in 10%-13% of cases, and 20% of cases require surgical treatment[8,9]. Malleolar fractures, in some cases, are associated with tibial pilon injuries[10-13].

The Arbeitsgemeinschaft fur Osteosynthesefragen/Orthopaedic Trauma Association (AO/OTA) fracture and dislocation classification is one of the most used classifications. Malleolar segments are categorized as 44 and are based on the direction of the fracture lines and of the fracture degree of comminution (A-C)[14]. This classification is based on standard plain radiographs, although often this diagnostic assessment can underestimate the nature, extent and severity of the injury because of the complex three-dimensional anatomy of the joint[15].

Compute tomography (CT) scan is used in some cases in order to obtain a 3D analysis of the fracture and to consequently assess the indication for the surgical procedure, surgical access and type of fixation devices required. The anatomical reduction of fractures demonstrated higher functionality and improved long-term outcomes[16].

However, approximately one-third of patients aged 10-21 years with bimalleolar and trimalleolar fractures presented clinical signs of post-traumatic arthritis, and more than 97% showed pathological radiological findings[17-19]. Possible causes are due to minor inconsistencies, axial malalignment and syndesmosis instability. This study aims to identify the cases in which a CT scan is recommended in order to avoid or reduce the risk of long-term complications.

CRITICAL ASPECTS

Plain radiographs

Radiological assessment, usually performed in the emergency room, presents noncanonical projections because of patient pain or the presence of immobilization devices[2,16]. Furthermore, it is subject to the variable accuracy of the action and the scarce penetration of the radiations. Therefore, it is difficult to determine if the diagnostic assessment is adequate to perform a surgical fixation procedure with satisfying results. CT scan study does not replace an adequate plain radiograph study. Instead, it can provide precious information regarding the assessment of the fracture lines pattern and the number of fragments.

High-energy injuries

CT is fundamental to determine if surgical treatment is required due to the increase of the energy of the injury, which consequently increases the possibility of associated dislocations as well as complex injuries secondary to rotation flexion. Kumar *et al*[16] reported that in ankle fracture cases the increase of malleolar involvement and the increase of the severity of the injury led to a different type of treatment strategy (that is surgical procedure) after CT scan study was performed. Hence, the presence of occult fractures and complex fracture lines is more likely in such injuries. The severity of the fracture is predictive of the increased risk of intra-articular abnormality[20,21], and in such cases preoperative CT scan assessment could identify additional lesions and mobile bodies requiring surgical treatment. The global change of the management plan rate was 23.2%, which was comparable with another retrospective study[2].

Classification methods

The most used classifications in the literature are AO/OTA, Weber or Lauge-Hansen classifications and are all based on standard plain radiographs. Clinical studies report that such classifications are not correlated with the fracture mechanism[22,23] and are not predictive of the sequence of bone and ligament injuries like CT, magnetic resonance imaging and surgical exploration are[24,25].

Cost/benefit analysis

Currently, CT scan studies represent the standard of care for all lower extremity joint fractures, especially acetabular fractures[26], femoral head fractures[27], distal femur fractures[28], tibial plateau fractures[29], tibial pilon fractures[30], talar fractures[31], calcaneal fractures[32], metatarsal fractures[33] and tarsometatarsal fractures[34]. Therefore, the CT scan study is by definition higher and larger than radiological analysis, although it is not assumed that it is required in all types of malleolar fractures[2].

CT requires higher costs, timing and exposure to radiation. Medical facilities are unfortunately more sensitive to cost and timing containment due to the constant increase of the demand for services; for this reason, it is essential to determine when a CT scan assessment is required. Radiation exposure is a sensitive aspect, particularly in pediatric patients. It was reported that the actual dose of an ankle CT scan study (0.07 mSv) was low and equivalent to a plain radiograph with anterior-posterior planes of the chest[35]. This value is ten times lower than the required dose of a CT scan study of the chest, abdomen and pelvis. It could be further reduced by limiting the exposed body segment or using a cone-beam CT scan and other protocols without the risk of losing essential information[36-38].

ADVANTAGES OF CT ANALYSIS

The advantages of using CT in the preoperative planning of malleolar fractures are: more accurate planning to determine the conservative/surgical approach and the type of fixation device required (and this is the major advantage because of the long-term results in spite of the surgical treatment[17-19]); the identification of unknown lesions in order to obtain a more accurate prognosis, including the detection of tibial pilon fractures; and more diffuse use of CT in the preoperative planning could clarify some unresolved biomechanical aspects regarding the relationship between the mechanism of injury and the pattern of fracture.

The most used classification, among the studies regarding the use of CT in the preoperative planning is the Danis Weber–AO classification, limited only to the three main categories: infrasyndesmotic (44-A according to AO/OTA classification), transsyndesmotic (44-B according to AO/OTA classification) and suprasyndesmotic (44-C according to AO/OTA classification). However, there is no absolute consensus among the authors[2,16,39]. This classification is attractive for clinicians because it is simple. The disadvantage of this system is that it does not incorporate a staging system to allow the degree of injuries falling only under one heading in terms of severity[40].

In our opinion this system is extremely simple and does not allow the differentiation of significant varieties within each group. Therefore, we reassessed the published system in order to determine a more detailed algorithm specifically referring to the Danis Weber subclassifications.

In our revision of the literature, the Lauge-Hansen classification was useful and significant in the evaluation of the importance of CT in the preoperative planning[7,41]. The classification is based on the rise of the mechanic forces, and there is a direct correlation between the increase of the energy of the injury and the usefulness of the preoperative CT study[2].

Infrasyndesmotic fractures (44-A according to AO/OTA classification)

Isolated lateral malleolar fractures [type 44-A1; Lauge-Hansen supination adduction (SA) stage I] and isolated medial malleolar fractures (type 44-A2.1/2; Lauge-Hansen SA stage II) are largely caused by injuries with no associated lesions. The use of CT is not recommended in this type of case. In a retrospective study[2] of 100 patients, no significant changes were noted regarding the treatment option (only 1 patient out of 24 cases of infrasyndesmotic fractures) following a CT scan study compared to the plain radiograph analysis[2].

The vertical medial malleolar fracture (Lauge-Hansen SA stage II) represents a particular condition because a medial tibial pilon injury can occur in the case of persistent energy of injury in adduction[11,42]. This type of lesion was described in 61% of SA stage II in the retrospective study conducted on 120 patients by Alluri *et al*[43]. In such cases, CT is recommended because the ideal treatment should provide the specific approach with elevation and bone grafting to significantly improve the prognosis[44]. In our opinion, the angulation of the line of fracture increases or decreases the suspected rate of tibial pilon injuries.

The above described subjects regarding the study of medial malleolus can be applied to bimalleolar fractures type 44-A2.3 (Lauge-Hansen stage II). In fracture type 44-A3 with a medial malleolus involvement associated with part of the posterior malleolus, a CT scan study is always recommended.

The importance of the preoperative CT scan study in the case of posterior malleolus fractures is documented by numerous publications in the literature. In fact, classifications based on CT scan studies have been proposed[13,45,46]. CT images allow the identification of impacted fracture fragments not visualized with conventional plain radiographs and with possible changes to the preoperative planning.

Black *et al*[2] and Magid *et al*[47] demonstrated that the use of CT scan study varies between 24.0% and 38.7% of the treatment planning compared to simple plain radiographs in cases of trimalleolar fracture[2,47]. Donohoe *et al*[48] and Palmanovich *et al*[49] reported that CT scan images increased the diagnostic accuracy and the intraobserver and interobserver agreement compared to conventional radiographs[48,49]. Furthermore, Evers *et al*[50] showed that in 25.1% of cases (430/1710), the planning was revised after CT scan study was performed with an increase of surgical indications and fixation device technique[50].

Transsyndesmotic fractures (44-B according to AO/OTA classification)

In transsyndesmotic fractures of isolated fibular fractures (type 44-B1 and B2) or bimalleolar fractures, the preoperative CT scan study does not significantly change the surgical treatment option[11,51]. This could be related to the fact that the standard radiographs are sufficient to adequately detect this type of fracture.

This assumption cannot be applied to transsyndesmotic fracture of posterior malleolar fracture (type 44-B3). In this case the study of posterior malleolus, as in fractures type 44-A3, cannot be based only on plain radiographs (Figures 1-3).

Suprasyndesmotic fractures (44-C according to AO/OTA classification)

In suprasyndesmotic fractures, despite the degree of fracture (C1, C2, C3 Lauge-Hansen PER stage 1-4), CT is always recommended. This study allows the evaluation of the syndesmosis and the possible involvement of the Tillaux-Chaput fragment[52,53]. Plain radiographs are not sufficient for syndesmosis evaluation because of the extreme variability among the individuals[54,55], whereas axial CT scan images allow a correct diagnosis as well as a determination of the best direction of the transsyndesmotic screw placement.

Tillaux-Chaput fractures (43-B1 according to AO/OTA classification) and malleolar fractures in the presence of distal tibial fractures (43 according to AO/OTA classification)

Conventional plain radiographs did not detect the Tillaux-Chaput fragment, which is more frequently present in fractures type B and C according to AO/OTA classification, in the studies conducted by Black *et al*[2] and Kumar *et al*[16]. This suggests an absolute advantage of the use of CT in fractures involving the anterior tibial tubercle[44] or in suspected cases considering the above-mentioned posterior malleolus fractures. The fixation of the anterolateral fragments re-establishes the anterior incisure and provides the stability of the anterior syndesmosis[56] (Figures 4 and 5).

The presence of occult fractures of the medial malleolus in fractures of the distal shaft of the tibia are described by some authors[57-60]. In the study by Jung *et al*[57], 89% of

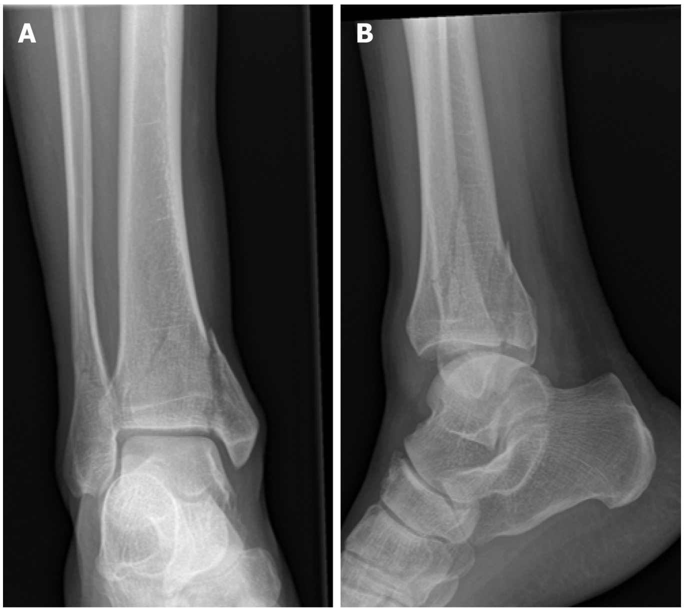

Figure 1 Transsyndesmotic fracture (44-B3). A: Anteroposterior; B: Lateral view.

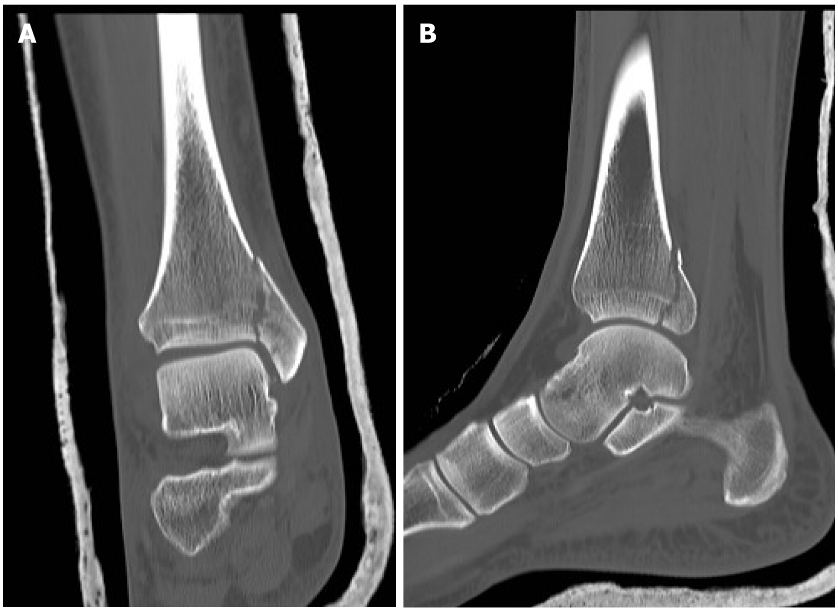

Figure 2 Computed tomography scans of the coronal plane and sagittal plane allow detection for the best screws direction. A: Coronal plane; B: Sagittal plane.

patients with distal tibia spiral fracture (type 43 according to AO/OTA) associated with malleolar fracture underwent surgical fixation. The importance of the preoperative identification derives from the risk of intraoperative decomposition during a surgical procedure of nailing with a consequent increase of surgical difficulties and duration of surgical treatment.

CT is additionally recommended in distal fracture of the leg because the line of fracture (even closed fracture) involves the epiphyseal/malleolar regions.

Malleolar ankle fractures in adolescents

The preoperative CT scan study represents the gold standard in malleolar ankle fractures in adolescents. Plain radiographs tend to underestimate this type of fracture. It is noted that consolidating fractures of the distal tibia present some features because the ossification of the growing cartilage is medial-lateral and posterolateral. This implies extraordinarily complex patterns of fractures (*i.e.* triplane fractures) and only with axial, sagittal and coronal planes is it possible to obtain adequate treatment

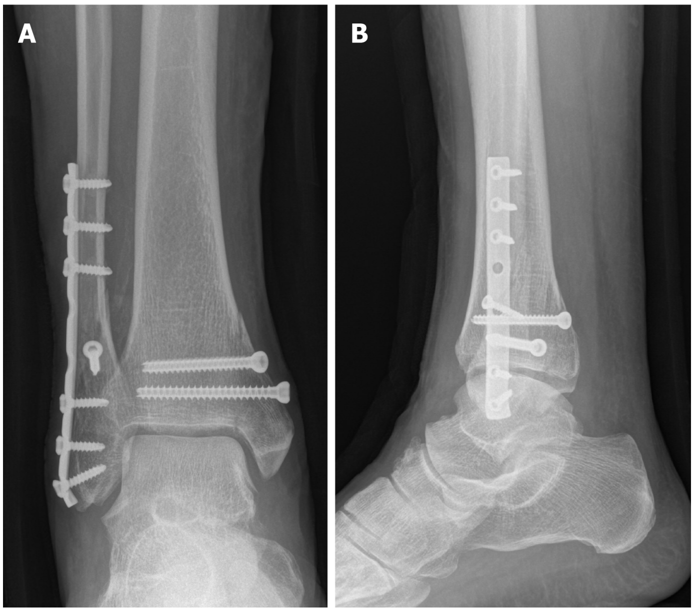

Figure 3 Postoperative X-rays in the anteroposterior and lateral view. Fractures treated with plate and screw fixation. A: Anteroposterior view; B: Lateral view.

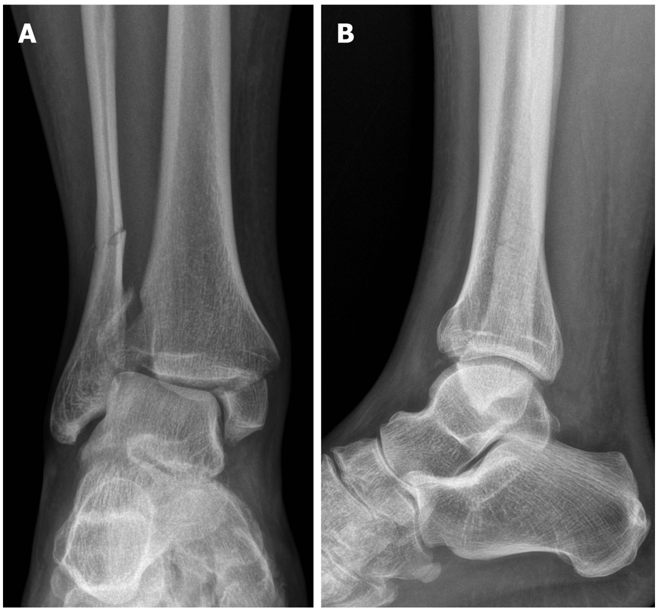

Figure 4 Suprasyndesmotic fracture (44-C2). A: Anteroposterior; B: Lateral view.

planning[11,61] (Figures 6-8).

CONCLUSION

The aim of malleolar fracture treatment is the anatomical reduction of the articular surfaces and of the syndesmosis. The use of CT in the preoperative planning could improve the clinical outcomes and reduce the risk of intraoperative difficulty and surgical duration in vertical medial malleolar fractures, in fractures type 44B with posterior malleolus involvement and in fractures type 44C. A CT scan study is mandatory in cases of Tillaux-Chaput fracture, malleolar fractures associated with the distal third of the leg and in adolescent patients. Additional large-scale clinical studies with cost/benefit analysis are required to confirm this hypothesis.

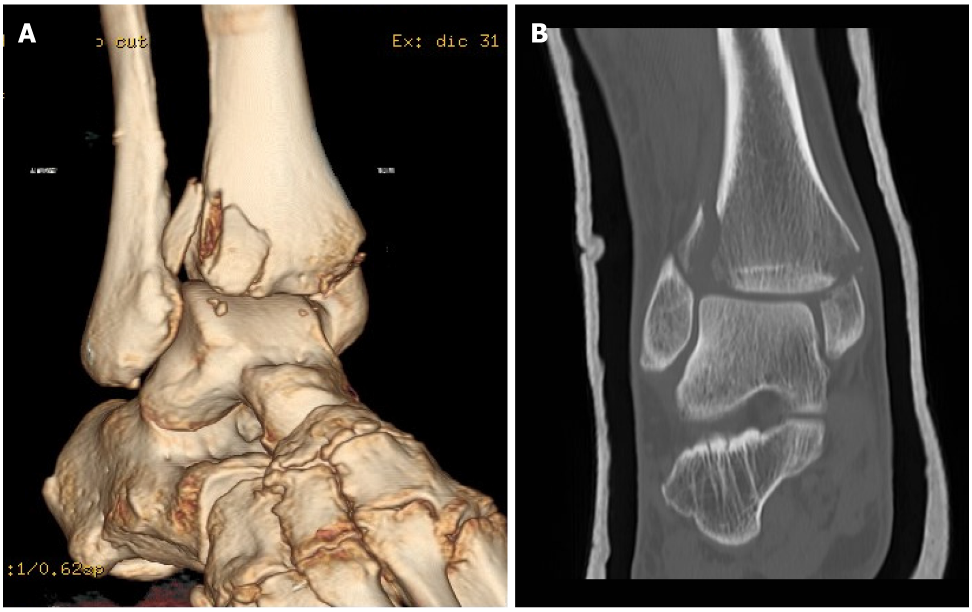

Figure 5 Computed tomography scans shows the involvement of the Tillaux-Chaput fragment. A and B: Tillaux-Chaput fragment.

Figure 6 Ankle fracture in adolescent. A: Anteroposterior view; B: Lateral view.

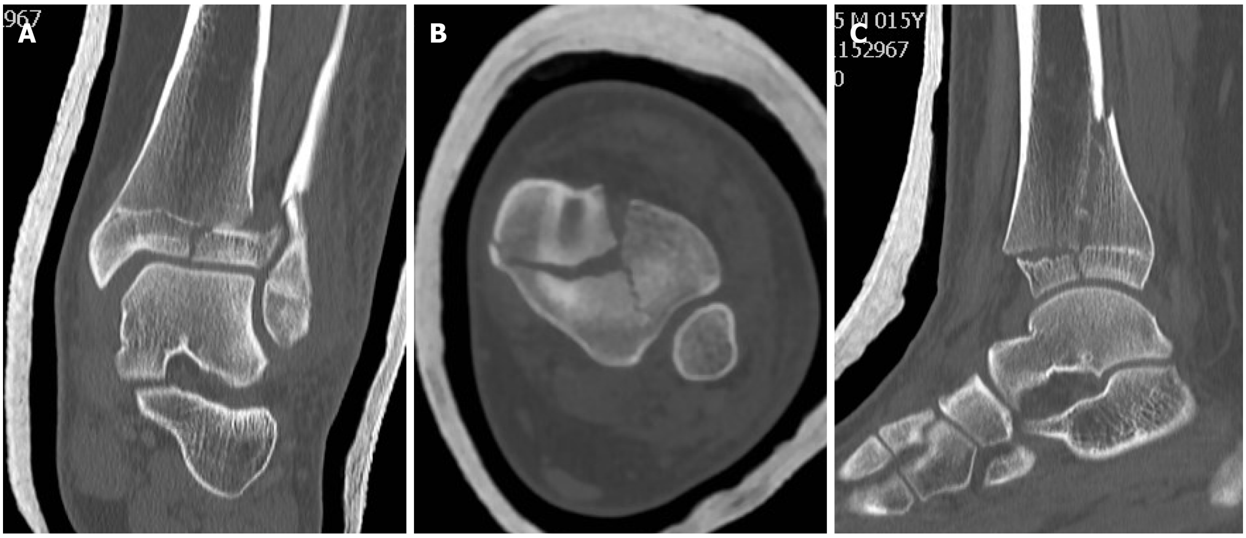

Figure 7 Computed tomography scan shows a triplane fracture. A: Coronal plane; B: Axial plane; C: Sagittal plane.

Figure 8 Postoperative X-rays in the anteroposterior view. Fractures treated with screws.

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ORIGINAL ARTICLE

Retrospective Study

Proximal tibial osteotomy for genu varum: Radiological evaluation of deformity correction with a plate *vs* external fixator

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Abstract

BACKGROUND

High tibial osteotomy (HTO) is a well-known procedure for the correction of knee varus. The purpose of this study was to compare the radiological results and accuracy of deformity correction performed using two different techniques: acute opening wedge correction using a plate and gradual correction with a monolateral external fixator.

AIM

To compare of the radiological results of two different techniques: acute opening wedge correction (a plate and screw) and gradual correction (external fixator).

METHODS

A total of 43 patients with plates and 36 patients with external fixators were included. All patients had moderate uniplanar varus deformities. We measured radiographic parameters, including the mechanical axis deviation (MAD), medial proximal tibial angle (MPTA), Caton-Deschamps Index (CDI), posterior proximal tibial angle, and joint line obliquity angle (JLOA). The accuracy of MAD correction was calculated based on a correction goal of neutral or overcorrection for medial compartment arthritis.

RESULTS

Demographics including age, body mass index, sex, and preoperative deformities were similar between the groups. The MAD significantly improved from 23.6 mm medial to the midline (SD = 8.2 mm) to 6.9 mm lateral to the midline (SD = 5.4 mm) (P < 0.001). The accuracy of MAD correction did not differ between the groups and was 96.1% (SD = 8.1%) in the plate group and 98.2% (SD = 5.2%) in the external fixator group (P = 0.18). The MPTA significantly improved from 83.9° (SD = 2.9°) to 90.9° (SD = 3.3°) (P < 0.001), and the change was similar between the groups. Differences were noted in patella height, with a CDI change of -19.2% (SD

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= 13.7%) and 3.1% (SD = 8.0%) for the plate and external fixator groups, respectively (P < 0.001). The change in JLOA was 1.6 degrees (SD = 1.1 degrees) and 0.9 degrees (SD = 0.9 degrees) for the plate and external fixator groups, respectively (P = 0.04).

CONCLUSION

Reliable correction of moderate varus alignment was achieved with both the acute opening wedge technique with a plate and the gradual monolateral external fixator technique. The patellar height decreased with the open wedge plate technique. Joint line obliquity decreased to a greater degree with the open wedge plate technique, perhaps as a result of medial collateral ligament release. The appropriate technique should be selected based on surgeon and patient preferences; however, external fixation may be a better choice when the preservation of patellar height is deemed important.

Key Words: High tibial osteotomy; External fixator; Gradual correction; Plate and screw; Genu varum; Radiological

Core Tip: Open wedge high tibial osteotomy with plate and screw fixation is feasible and an appealing operation for surgeons. Overcorrection or under correction of the deformity leads to the persistence of pain. Patellar height changes affect patients with patellofemoral injuries. With the external fixator technique, the residual deformity can be corrected after surgery, and patellar height changes can be prevented. This is a retrospective study that was conducted to compare the accuracy and radiological outcomes of monolateral external fixation and internal fixation for proximal tibial varus deformity correction.

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INTRODUCTION

High tibial osteotomy (HTO) is a well-known procedure for the correction of knee deformities. This operation was introduced by Jackson in 1958 for the treatment of knee osteoarthritis (OA)[1]. In genu varum deformities, the load is transferred to the medial compartment of the knee, thus leading to the progression of medial compartment deterioration. HTO realigns the mechanical axis of the lower extremity, and this realignment decreases the load on the medial compartment and slows the progression of OA[2,3].

An abnormal biomechanical axis of the lower extremity not only causes damage to the cartilage of the knee but also affects the outcome of knee ligament reconstruction surgery. The degree of pain relief experienced after varus deformity correction depends on the accuracy of deformity correction. Inaccurate correction may cause pain to persist[4].

There are different techniques for genu varum knee deformity correction, including gradual correction with monolateral external fixation and acute opening wedge correction with internal fixation. HTO with monolateral external frame fixation is a minimal incision technique where the fibula and lateral cortex of the tibia are left intact during the osteotomy[5]. Gradual distraction of the medial cortex is performed with hinging on the intact lateral cortex, leading to realignment.

HTO with internal fixation and acute deformity correction may be performed with different approaches. Closing wedge HTO (CWHTO) and opening wedge HTO (OWHTO) are the two most well-known techniques for knee deformity correction. With OWHTO, patellar height changes can occur, which may adversely affect the patellofemoral cartilage[2,6]. Changes in the posterior tibial slope (PTS) are another possible problem of OWHTO[7-11]. Although CWHTO does not seem to affect the posterior slope, achieving an accurate correction is more difficult with CWHTO than with OWHTO, and there is an increased risk for peroneal nerve injury[12,13]. There is no consensus on which technique is superior.

In this study, we compared OWHTO with a plate to gradual correction with a monolateral fixator in a group of patients with moderate varus deformities of less than 10 degrees. In our practice, complex deformities (greater than 11 degrees or multiplanar deformities) are usually approached with a hexapod frame. The radiological outcome data included the accuracy of coronal plane realignment and the effect on patella height and posterior slope.

MATERIALS AND METHODS

This study was a retrospective, nonrandomized study (level III). The study was reviewed and approved by our institutional review board. We identified 79 consecutive patients who underwent genu varum deformity correction surgery either by internal fixation with opening wedge correction (43 patients) or a monolateral external fixator (36 patients). The inclusion criteria were patients who required less than 11 degrees of correction, patients aged 18 years or older, and patients who did not have an accompanying femoral deformity. Patients with Blount disease and those undergoing revision surgery were excluded from the study. All the surgeries were performed by the senior authors. The different approach for similar patients represents an evolution of practice with a move away from external fixation to OWHTO with a locked plate.

We used the Kellgren-Lawrence classification (KL) system for OA[14]. The severity of arthritis was graded by X-ray as follows (KL): 0, no narrowing of the joint space or reactive changes; 1, doubtful narrowing of the joint space with possible osteophyte formation; 2, possible narrowing of the joint space with definite osteophyte formation; 3, definite narrowing of the joint space, moderate osteophyte formation, some sclerosis, and possible deformity of the bony ends; and 4, large osteophyte formation, severe narrowing of the joint space with marked sclerosis, and definite deformity of bone ends.

Our goal was to correct the mechanical axis in the patients without OA (KL ≤ 2) to normal anatomical alignment and to overcorrect the axis to 10 mm valgus in the patients with OA (KL > 2)[15].

Each patient obtained a bilateral hip-to-ankle X-ray, anteroposterior (AP) view of the knee, and lateral view of the knee both before surgery and six months after surgery. mechanical axis deviation (MAD) and medial proximal tibial angle (MPTA) measurements were performed before and six months after the operation to evaluate the status of deformity correction in the coronal plane. The other radiological parameters used for the evaluation included posterior proximal tibial angle (PPTA), and joint line obliquity angle (JLOA).

To quantify MAD, we measured the distance of the mechanical axis (center-of-hip to center-of-ankle line) from the center of the tibial plateau either laterally or medially. The lateral knee X-ray was used to measure the patellar height. We used the Caton-Deschamps Index (CDI) to evaluate the patella height before and 6 mo after the surgery (Figure 1). On the lateral view, the CDI was calculated as the distance from the upper part of the tibial plateau to the inferior pole of the patella divided by the length of the patella from the upper pole to the lower pole (Figure 1). All the measurements were performed by limb reconstruction fellowship-trained surgeons.

We measured PPTA to evaluate the PTS in the lateral view before and 6 mo after the surgery. We drew a line from the center of the diameter of the tibia in the lateral view and a line tangent to the tibial plateau. The angle between these lines was the PTS.

Surgical technique

Acute genu varum deformity correction using OWHTO and plate and screw fixation was performed through an incision over the medial surface of the proximal tibia. After incising the pes anserine insertion over the tibia, the superficial fibers of the medial collateral ligament (MCL) were released from the tibia. An oblique wire was inserted from the medial cortex toward the head of the fibula 1.5 cm distal to the lateral tibial plateau. The osteotomy was done along the wire making sure to leave the lateral cortex intact. The posterior half of the osteotomy ended near the tibial tuberosity. This region was connected to the anterior half of the osteotomy, which was performed in an

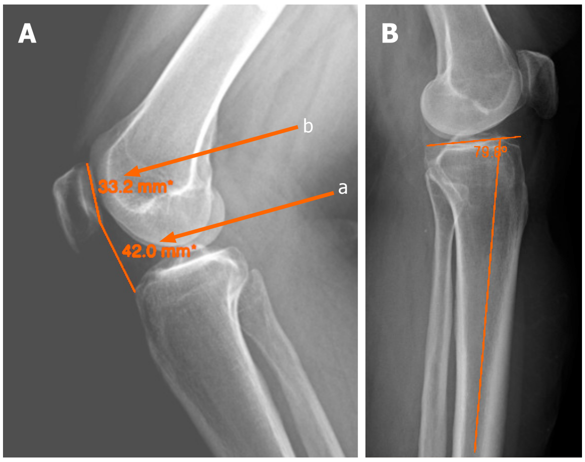

Figure 1 Knee X-ray images. A: Caton-Deschamps Index (a/b) for evaluation of the patella height; B: Posterior proximal tibial angle.

oblique fashion below the tibial tuberosity and continued to the anterior cortex of the proximal tibia. The lateral cortex was left intact, and the cut was stopped 1 cm medial to the lateral cortex. A laminar spreader was used in the posterior part of the osteotomy site to retract the two parts, stretching the soft tissue for several minutes and gradually opening the gap to achieve the preplanned measurement. A metal trial was inserted with a base height matching the preoperative plan. Care was taken to ensure that the opening wedge height was equal between the anterior and posterior parts to avoid unintentional flexion. The alignment of the lower extremity was confirmed during the surgery with a long rod from the hip to the ankle and C-arm fluoroscopy. A tri-cortical allograft was then inserted into the gap after the trial wedge was removed. The graft was not tapped into the osteotomy site to avoid graft fracture. The osteotomy site was then fixed with the plate and screws consisting of four 5-mm locking screws in the proximal segment and three to four locking and nonlocking 4.5- to 5-mm screws in the distal segment. The remaining space in the opening wedge was filled with freeze-dried allograft chips and demineralized bone matrix putty. In the postoperative follow-up period, the OWHTO patients were evaluated in the clinic 2 wk and 6 wk after surgery, and monthly thereafter for 6 mo after surgery (Figure 2). The patients were non weight bearing for 6 wk after surgery and then they were transferred to the partial weight bearing.

Gradual genu varum deformity correction with a monolateral external fixator procedure was performed through a small incision over the medial surface of the tibia just below the tibial tubercle. A monolateral frame external fixator with a hinge at the osteotomy level was placed over the medial side of the tibia and connected to the bone with two half-pins proximally and three half-pins distally. The hinge was carefully oriented in the coronal plane. The fixator was positioned parallel to the tibia in the sagittal plane to avoid unintentional flexion during distraction. The 6 mm pins were made of stainless steel and covered with hydroxyapatite. An osteotomy in the tibia was made with multidirectional drilling in a direction perpendicular to the axis of the tibia. A narrow osteotome was used to complete the osteotomy at the medial side. The lateral cortex and fibula remained intact. Distraction at the osteotomy site was started 7 d after the surgery with a rate of 0.25 mm four times a day. Adjustment was evaluated by X-ray 1 wk after starting the distraction, and the distraction gap was reassessed by the senior authors. After the adjustment schedule was completed, a new hip-to-ankle X-ray was taken for the final alignment measurement. For patients with residual malalignment, a new schedule was created to continue correction; this process was continued until the intended final result was achieved.

The patients were non weight bearing for 2 wk after surgery, and then transferred to the partial weight bearing. These patients were evaluated in the clinic every month until frame removal. After frame removal, they were seen 6 mo after surgery (Figure 3).

RESULTS

There were 43 patients in the plate and screw group and 36 patients in the external

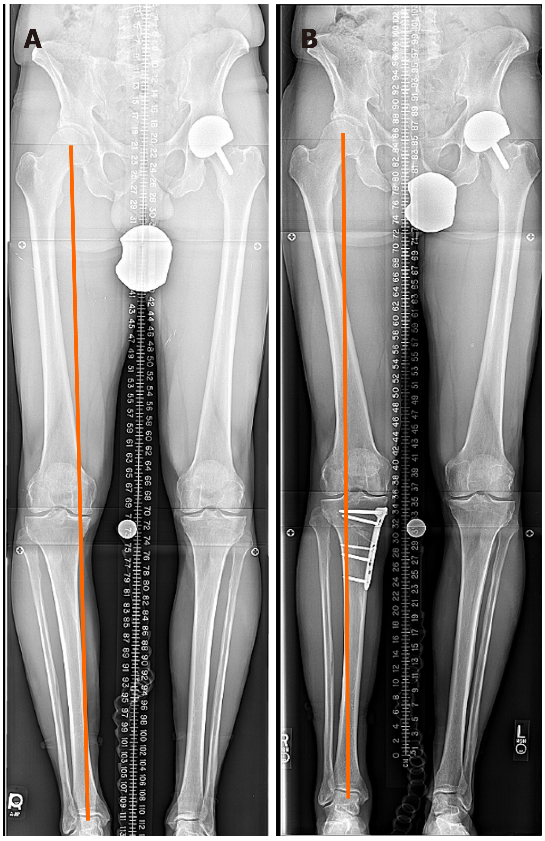

Figure 2 High tibial osteotomy with plate and screws. A: Pre-operation; B: Post-operation.

fixator group, and these groups were further subdivided based on whether the intraoperative correction goal was neutral alignment or overcorrection.

Age, body mass index, and sex were similar between the plate and external fixator groups (Table 1). We also compared the subgroups of each arm of this study as well as the subgroups within each arm (Table 2). The intra-arm comparison demonstrated several significant results, leading us to conclude that subgrouping and intergroup comparisons were appropriate.

For the MAD measurements, we included 40 patients in the plate and screw group and 36 patients in the external fixator group. In all the patients who underwent plate and screw fixation, the mechanical axis was transferred from the medial side to the lateral side. The patients who underwent external fixation were divided into two subgroups. In the external fixator group with an overcorrection goal, the mechanical axis of 1 of the 13 cases remained on the medial side. In the external fixator group with a neutral goal, the mechanical axis of all the cases shifted to the lateral side or neutral position (Table 3).

Among all patients, the MAD significantly improved from 23.6 mm medial to the midline (SD = 8.2 mm) to 6.9 mm lateral to the midline (SD = 5.4 mm) (P < 0.001, results not shown in the table). The mean MAD before surgery in the plate and screw group with a neutral goal was 24.5 mm medially and 4.3 mm laterally after surgery (Table 3). In the plate and screw group with an overcorrected goal, the MAD was 25.9 mm medially preoperatively and 12.7 mm laterally postoperatively. For the external fixator group, the patients with a neutral goal had an average MAD of 21.3 mm medially preoperatively and 3.5 mm postoperatively (no medial *vs* lateral because average of absolute value). The overcorrected subgroup of patients with external fixators had 23.0 mm of medial MAD before surgery with 9.5 mm after. The results between the two groups were not significantly different.

Among all patients, the MPTA significantly improved from 83.9° (SD = 2.9°) to 90.9° (SD = 3.3°) (P < 0.001, results not shown in the table). The changes in MPTA between the plate and screw patients *vs* the external fixator patients were not significantly different between the subgroups (Table 4). The plate and screw patients' MPTA increased 6.8 degrees in the neutral group compared to 5.7 degrees in the external fixator's neutral group. For the respective overcorrected subgroups, these changes were 9.6 degrees and 6.2 degrees.

Table 1 Patients demographic

Demographics	Plate and screw (n = 43)		External fixator (n = 36)		P value
	n	Mean (range)	n	Mean (range)	
Age (yr)	43	46.3 (19-68)	36	42.1 (24-67)	0.14
BMI (kg/m^2)	39	26.0 (18.7-35.0)	11	30.0 (20.3-39.1)	0.08
Sex (female)	43	32.6%	36	47.2%	0.16

BMI: Body mass index.

Table 2 Patients demographic

Demographics	Plate and screw (n = 43)				External fixator (n = 36)				P value			
	N[1] (n = 25)		O (n = 18)		N (n = 23)		O (n = 13)		N *vs* N	O *vs* O	N *vs* O (plate and screw)	N *vs* O (ex fix)
	n	Mean (range)	n	Mean (range)	n	Mean (range)	n	Mean (range)				
Age (yr)	25	41.7 (19-68)	18	52.7 (32-67)	23	39.9 (24-55)	13	46.1 (30-67)	0.61	0.12	< 0.01	0.11
BMI (kg/m^2)	23	24.1 (18.7-33.5)	16	28.8 (22.4-35.0)	8	27.6 (20.3-39.1)	3	36.4 (33.1-38.4)	0.15	0.03	< 0.001	0.01
Sex (female)	25	36.0%	18	27.8%	23	47.8%	13	46.2%	0.41	0.25	0.57	0.92

[1]In this table and all subsequent ones. T: Total group; N: Neutral goal; O: Overcorrected; BMI: Body mass index.

Table 3 Mechanical axis deviation changes

MAD	Plate and screw		External fixator		P value	
	N	O	N	O	N *vs* N	O *vs* O
	Mean (range)	Mean (range)	Mean (range)	Mean (range)		
MAD pre-op (mm)	24.5 med (14 med to 42 med)	25.9 med (11 med to 37 med)	21.3 med (9 med to 42 med)	23.0 med (11 med to 42 med)	0.15	0.38
MAD post-op (mm)	4.3 lat (1 lat to 13 lat)	12.7 lat (3 lat to 20 lat)	3.5 (7 med to 10 lat)	9.5 (5 med to 20 lat)	0.40	0.08

MAD: Mechanical axis deviation; N: Neutral goal; O: Overcorrected; op: Operation.

Table 4 Medial proximal tibial angle changes

MPTA	Plate and screw		External fixator		P value	
	N	O	N	O	N *vs* N	O *vs* O
	Mean (range)	Mean (range)	Mean (range)	Mean (range)		
ΔMPTA (degree)	6.8 (0-13)	9.6 (3-14)	5.7 (2-10)	6.2 (-4 to 15)	0.25	0.05

MPTA: Medial proximal tibial angle; N: Neutral goal; O: Overcorrected.

To determine the accuracy of correction, we first defined the error. The error of the correction was calculated as a ratio. The acceptable range from the MAD goal was considered 5 mm. The numerator was the distance from the limits of the acceptable range: 5 mm medial to 5 mm lateral for the neutral goal and 5 mm lateral to 15 mm lateral for the overcorrected goal (15). The denominator was the difference between the MAD preoperatively and the median of the acceptable MAD range postoperatively: 0

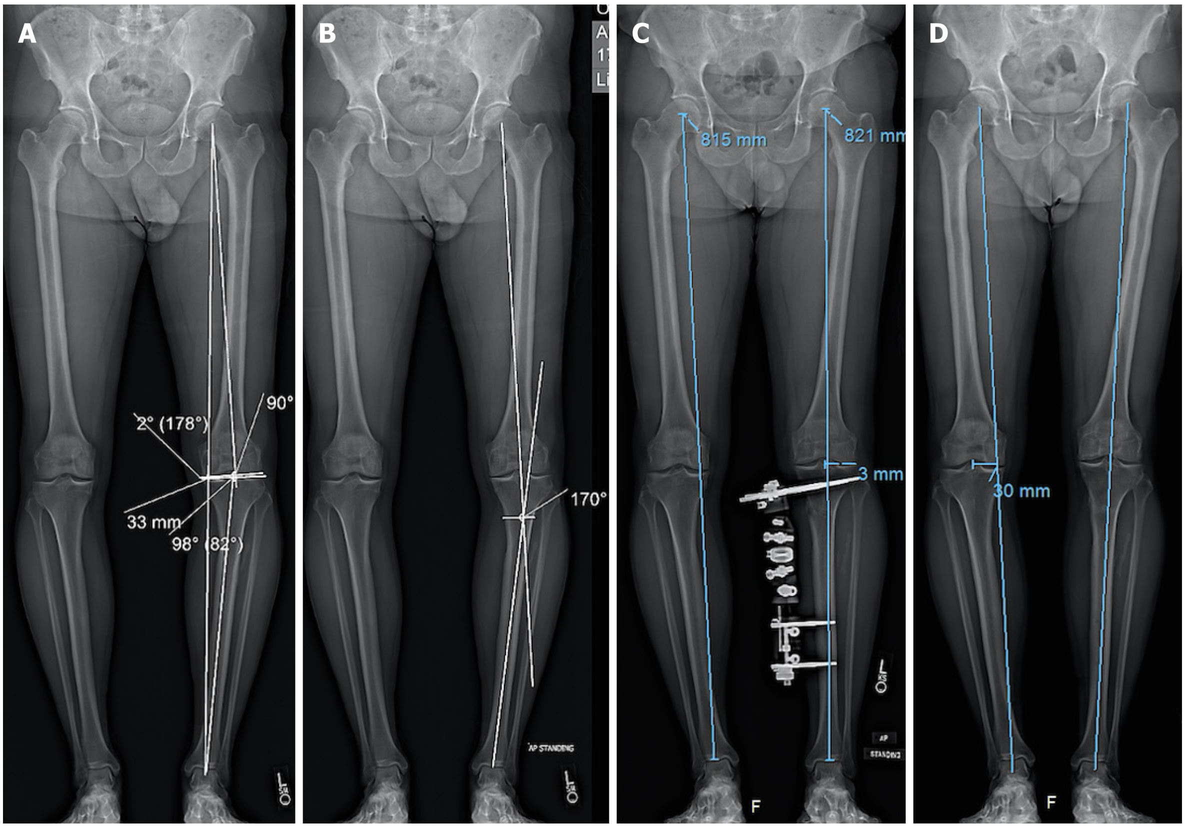

Figure 3 High tibial osteotomy with external fixator. A and B: Before correction medial proximal tibial angle: 82, joint line obliquity angle: 2, mechanical axis deviation: 33 mm, lateral distal femoral angle: 90; C: After correction with external fixator; D: After removal of external fixator.

mm in the neutral subgroup *vs* 10 mm lateral in the overcorrection subgroup. The accuracy for each patient was calculated by subtracting the error from 1[5,16,17].

The accuracy was quite high for every subgroup (Table 5). There were no statistically significant differences between the two arms' respective subgroups.

The mean preoperative CDI for the patients in the plate and screw group was 1.1, and that for the patients in the external fixator group was 1.0 (Table 6). This difference was not statistically significant. The postoperative measurements were 0.9 for the plate and screw group and 1.1 for the external fixator group, which was statistically significant. The absolute changes for the two groups were a decrease of 0.2 and an increase of 0.02 respectively for the two groups, and the percent changes were a decrease of 19.2% and an increase of 3.1%. These differences were statistically significant.

The average change of the plate and screw patients' PPTA was a decrease of 3.3 degrees *vs* a mean decrease of 1.7 degrees of external fixator patients' change in PPTA (Table 7). The percent changes were -4.1% *vs* -2.0%. None of these results were statistically significant.

The mean absolute value of the change in JLOA preoperatively to postoperatively was an increase of 1.6 degrees for the plate and screw group and a 0.9 degree increase for the external fixator group (Table 8). This difference was statistically significant.

There was a major complication in the external fixator group with one patient with loss of reduction and collapse in the regenerated bone at the osteotomy site after the removal of the external fixator. Subsequent open reduction and internal fixation with plates and screws were performed for this patient. Some of the patients in the external fixation group had discharge and superficial infections around the half-pin that were successfully treated with oral antibiotics. There were no cases of neurovascular injury, neuropraxia, nonunion, deep infection, or osteomyelitis in either group. There was no significant change in knee range of motion in either group at the last follow-up as compared to the pre-operative baseline measurement.

Table 5 Accuracy of mechanical axis deviation correction

Accuracy	Plate and screw			External fixator			*P* value		
	T	N	O	Total	N	O	T *vs* T	N *vs* N	O *vs* O
	Mean (range)	Mean (range)	Mean (range)	Mean (range)	Mean (range)	Mean (range)			
Accuracy (%)	96.1 (60 to 100)	94.8 (60 to 100)	97.7 (87 to 100)	98.2 (79 to 100)	98.2 (82 to 100)	98.2 (79 to 100)	0.18	0.17	0.82

T: Total group; N: Neutral goal; O: Overcorrected.

Table 6 Changes in Caton-Deschamps Index

CDI	Plate and screw	External fixator	*P* value
	Mean (range)	Mean (range)	
CDI pre-op (unitless)	1.1 (0.7-1.6)	1.0 (0.8-2.1)	0.77
CDI post-op (unitless)	0.9 (0.4-1.1)	1.1 (0.8-1.9)	0.01
ΔCDI (unitless)	-0.2 (-0.5 to 0.2)	0.02 (-0.2 to 0.2)	< 0.001
%ΔCDI (%)	-19.2 (-47.0 to 21.9)	3.1 (-8.1 to 25.0)	< 0.001

CDI: Caton-Deschamps Index.

Table 7 Posterior proximal tibial angle changes

PPTA	Plate and screw	External fixator	*P* value
	Mean (range)	Mean (range)	
ΔPPTA (degree)	-3.3 (-9 to 1)	-1.7 (-11 to 4)	0.14
%ΔPPTA (%)	-4.1 (-11.3 to 1.3)	-2.0 (-12.8 to 5.1)	0.11

PPTA: Posterior proximal tibial angle.

Table 8 Joint line obliquity angle changes

JLOA	Plate and screw	External fixator	*P* value
	Mean (range)	Mean (range)	
ΔJLOA (degree)	1.6 (4 med to 3 lat)	0.9 (3 med to 2 lat)	0.04

JLOA: Joint line obliquity angle.

DISCUSSION

HTO is an appropriate procedure for genu varum deformity correction to correct MAD. The procedure alleviates pain in patients with OA of the medial compartment of the knee. In this study, we compared the results of acute correction with OWHTO to those of gradual correction with an external fixator for knee varus deformities. The reported indication for HTO surgery is varus alignment of the knee combined with any of the situations, such as medial compartment OA, medial compartment overloading (such as post medial meniscectomy), knee instability or osteochondral lesions[18].

The indications for HTO surgery in our study were a varus deformity greater than 5 degrees and knee pain. If there was radiographic medial joint space narrowing, then the goal was overcorrection. If there was no radiographic medial joint space narrowing, then the goal was neutral alignment.

Our results showed that while the re-alignment was substantial, there were not significant differences between the two groups in MAD and MPTA changes, and the accuracy of correction. The PPTA changed less in the external fixator group than the plate and screw group, but this change was not significant.

Patella baja may be a concern after OWHTO[19]. Patella baja causes anterior knee pain and crepitus[4,20]. Because of the transfer of the tibial tuberosity distally and laterally, the biomechanical axis of the patellofemoral joint changes after surgery[8]. One biomechanical study showed that OWHTO tilts the patella medially and increases the pressure over the lateral surface of the patella[21]. It has also been reported that the pressure over the patellar cartilage increases after OWHTO[6].

The literature has shown that there is a significant increase in patellofemoral joint pressure with genu varum knee deformity correction of more than five degrees[6]. Previous work has evaluated the effect of shortening the patellar height over the patellofemoral articular cartilage[7,22]. Researchers have demonstrated that shortening the patellar tendon after OWHTO accelerates the development of patellofemoral OA. Chondral lesions increased in long-term follow-up and likely causes anterior knee pain[23].

In our external fixator group, the patellar tendon height changed less than that in the plate group after surgery. The osteotomy performed in the external fixator group at the distal tibial tuberosity did not affect the patellar height. Additionally, when a varus deformity is gradually corrected, the soft tissue around the knee lengthens gradually, and the patellar tendon length does not change after varus deformity correction. For this reason, this technique may be preferred for genu varum deformity patients with OA of the patellofemoral joint. Also, the JLOA changed less in the external fixator group compared to the plate and screw group. Gradual correction of the deformity may allow the ligaments to stretch more slowly, having less of an effect on the JLOA. Additionally, the medial collateral ligament is released during the acute correction of OWHTO, which may decrease the JLOA. The clinical outcomes were similar between the two groups.

Correction of the knee genu varum deformity is important before anterior cruciate ligament (ACL) reconstruction[13]. The PTS is one of the factors that affects the outcome of ACL reconstruction. Increasing the PTS results in a transfer of the loading to the anterior part of the knee, and this overload may affect the outcome of ACL reconstruction surgery. OWHTO has been shown to increase the PTS[12,24]. Every 10-degree increase in the PTS causes a 6-mm translation of the anterior tibial load axis[4]. Our results show that there was a smaller change in the PTS in the external fixator group than in the OW group. However, the difference in PPTA change between the groups was not significant.

The results of some modifications of open wedge HTO have been reported. One study showed no differences in patellar height or PTS between an ascending *vs* descending OWHTO, a technique requiring leaving the tuberosity attached to the distal tibia or proximal tibia, respectively[23]. Some surgeons advise releasing the posterior soft tissue to prevent an increase in PTS[4]. Another study recommends against the release of the soft tissue and medial ligament[25]. In this biomechanical study, it was shown that cutting the anterior fiber of the MCL affects the stability of the medial side in HTO[25].

Evaluation of the changes in the MAD and MPTA in both groups showed there was no significant difference in correction of the genu varum deformity between the both groups. The accuracy of the correction was 96.1% (60%-100%) in the plate and screw group and 98.2% (79%-100%) in the external fixator group. Both techniques led to accurate genu varum deformity correction, and there was no significant difference between the two groups.

Undercorrection, or sometimes overcorrection, may compromise the outcome of genu varum deformity correction surgery[4]. Preoperative measurement planning is helpful to achieve optimal alignment correction. However, sometimes, the laxity around the knee that appears on weight-bearing X-rays is not as obvious when the patient is in the supine position intraoperatively[26]. With our external fixator technique, we have the opportunity to continually correct residual deformities after surgery, making it a helpful procedure in patients with soft tissue laxity in the knee. Additionally, because the external fixator allows gradual correction, the formation of bone is well controlled, the rate of lengthening can be adjusted, and nonunion or malunion can be prevented[16,17,27,28].

There are some limitations of our study. First, these operations were performed by experienced surgeons, which may affect the results of the operations and may have reduced the rate of complications after the operations. External fixator adjustments require experience and expertise; thus, these results may be hard to generalize to a large variety of practices. Second, this study is a retrospective study with a limited number of patients. As mentioned above, there were some demographic differences between some subgroups, and we evaluated the radiological outcomes of the two techniques. Future works would be helpful if they evaluate these results in a larger number of patients. Third, this study was a radiological comparison of the two techniques, and a study comparing the early and late clinical outcomes in both groups in a larger number of patients would be helpful to determine the clinical performance of these techniques. Fourth, our patients were confined to those with varus deformities of less than ten degrees. We suggest future studies evaluating patients with larger-degree varus deformity corrections.

CONCLUSION

Reliable degrees of correction of moderate varus alignment were achieved with both the acute opening wedge technique with a plate and the gradual monolateral external fixator technique in patients undergoing HTOs. The appropriate technique should be selected on the basis of the surgeon and patient preferences; however, external fixation may be a better choice when maintenance of patellar height is deemed important.

ARTICLE HIGHLIGHTS

Research background

High tibial osteotomy (HTO) for the correction of painful varus knee deformities is a known surgery. Different HTO techniques have been reported in the literature, including open and closed wedge osteotomies. In this study, the radiological efficacy of the gradual and acute correction of varus deformities with two different fixation methods (external fixator and plate screw) was evaluated.

Research motivation

We aimed to compare the radiological accuracy of the gradual correction of varus deformities with HTO with an external fixator and that of acute correction with a plate and screw.

Research objectives

The changes in radiological parameters (mechanical axis deviation, medial proximal tibial angle, posterior proximal tibial angle, joint line obliquity angle, Caton-Deschamps Index) were evaluated after both acute and gradual correction to determine the accuracy of correction achieved with the two techniques.

Research methods

Retrospective, nonrandomized study (level III).

Research results

Both acute correction (opening wedge and plate and screw) and gradual correction (external fixator) yield reliable degrees of correction of moderate varus alignment. The changes in the radiological parameters achieved with and accuracy of the two techniques are reasonable. There were changes in the patellar height after acute correction with a plate and screw.

Research conclusions

Both techniques (HTO with plate and screw and external fixator) are reliable for the correction of varus deformities, and external fixation may be a better choice when the preservation of patellar height is important.

Research perspectives

Studies with a larger number of patients and evaluations of the early and late clinical outcomes of both techniques are suggested.

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ORIGINAL ARTICLE

Prospective Study

Pain and function deteriorate in patients awaiting total joint arthroplasty that has been postponed due to the COVID-19 pandemic

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Abstract

BACKGROUND

Elective total joint arthroplasty (TJA) procedures have been postponed as part of the coronavirus disease 2019 (COVID-19) response to avert healthcare system collapse. Total hip arthroplasty (THA) and total knee arthroplasty (TKA) procedures comprise the highest volume of elective procedures performed at health care facilities worldwide.

AIM

To determine the demand for TJA despite the pandemic and the impact of surgery postponement on physical and mental health.

METHODS

We conducted a prospective cross-sectional telephonic interview-based study on patients awaiting THA and TKA at an academic institution in South Africa. The questionnaire consisted of four sections. The first section recorded baseline demographic data and medical co-morbidities, the length of time spent awaiting TJA, and the patients' desire to undergo elective surgery despite the COVID-19 pandemic. Section 2 and Section 3 assessed the patients' current physical and mental health, respectively, as a consequence of deferred surgical intervention. The last section established the patients' perception of the healthcare system's response to the COVID-19 pandemic and necessity to postpone elective surgery. Patients received counseling and education on the current state of surgery during the COVID-19 pandemic and associated risks. Thereafter, patients were once again asked about their desire to undergo TJA during the COVID-19 pandemic.

RESULTS

We included 185 patients (65.95% female; mean age: 50.28 years) awaiting TJA for a mean of 26.42 ± 30.1 mo. Overall, 88.65% of patients wanted TJA despite the COVID-19 pandemic. Patients awaiting TJA for 1-3 years were 3.3-fold more likely to want surgery than those waiting < 1 year (P < 0.000). Patients with comorbidities were 8.4-fold less likely to want TJA than those with no comorbidities (P = 0.013). After receiving education, the patients wanting TJA decreased to 54.05%. Patients who changed their opinion after education had less insight on the increased morbidity (P = 0.046) and mortality (P = 0.001) associated with COVID-19. Despite awaiting TJA for shorter period (24.7 ± 20.38 mo), patients who continued to demand TJA had greater pain (P < 0.000) and decreased function (P = 0.043) since TJA postponement.

CONCLUSION

There is deterioration in health for patients, who have had elective procedures postponed during the COVID-19 pandemic. Waiting lists should be prioritized for urgency with the re-initiation of elective surgery.

Key Words: Total hip arthroplasty; Total knee arthroplasty; Elective surgery; COVID-19; Waiting lists; Primary total joint arthroplasty

Core Tip: This was a prospective cross-sectional study of patients awaiting elective total joint arthroplasty (TJA) that was postponed during the coronavirus disease 2019 (COVID-19) pandemic. We investigated the demand for elective TJA, impact of surgery postponement on overall health, and the role of patient education regarding the healthcare system's response during the COVID-19 era. After receiving counseling about the peri-operative risks of COVID-19 infection, patients who continued to demand elective TJA had greater pain and decreased function compared to other patients, despite awaiting surgery for the shortest length of time. Waiting lists should be prioritized for urgency with the re-initiation of elective surgery.

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INTRODUCTION

The infectious disease caused by the novel severe acute respiratory syndrome coronavirus 2 virus (coronavirus disease 2019 [COVID-19]) was declared an international pandemic by the World Health Organization in March 2020[1-3]. In response, a moratorium was declared on the performance of elective surgery in many countries to avert healthcare system collapse, preserve equipment, and maintain resources and hospital capacity[4-8]. Approximately 28 million elective operations were cancelled or postponed worldwide during the peak 12 wk of this global pandemic[7,8]. Total hip arthroplasty (THA) and total knee arthroplasty (TKA) procedures comprise the highest volume of elective procedures performed at health care facilities worldwide[4,8]. A survey of the European Hip Society and the European Knee Associates from 40 different countries reported a near total shutdown of total joint arthroplasty (TJA) with 92.6% of primary TJA procedures being cancelled[7]. The demand for TJA is already high and waiting lists continue to rise with approximately 150000 elective procedures performed per month in the United States cancelled at some time due to the COVID-19 response[3,7,8]. The prolonged postponement of elective

TJA has had devastating economic implications on the healthcare system. It is estimated that the process of re-initiation of elective procedures following the COVID-19 pandemic in developing countries would result in an approximate loss of $700 billion[9].

In addition to the growing economic burden, patients awaiting surgery for more than 180 d have demonstrated increased risks for poor outcomes after TJA[10,11]. Patients with hip and knee osteoarthritis on extended waiting lists for surgery deteriorate with time on the pain and physical function on the Western Ontario McMasters Universities Osteoarthritis index scores and joint-specific Oxford scores[10,11]. Poor pre-operative baseline function is also associated with worse pain and functional outcomes up to 24 mo after TJA[10-12].

The aim of this study was to gain insight into patient perceptions in the setting of a waiting list for TJA at an academic institution in the COVID-19 era. Through a questionnaire-based telephone interview, we assessed patient demand for elective TJA and evaluated the impact of the postponement of TJA on function and mental health. Lastly, we assessed the effect of purposeful patient education and counseling about the reasoning behind postponement of elective surgery on patient demand for TJA[13].

MATERIALS AND METHODS

We conducted a prospective cross-sectional telephonic interview-based study of 227 patients awaiting TJA at a single, referral academic institution in Johannesburg, South Africa during the COVID-19. There were 118 patients and 109 patients planned for elective primary TKA and THA respectively, during this time who had their surgery postponed. Patients requiring emergency surgery for hip fractures, periprosthetic fractures, joint dislocation, or periprosthetic joint infections were excluded. Institutional review board ethics approval was obtained (M190528) before commencement of the study. Contact information was obtained for all patients from the institution's TJA waiting list. This waiting list generally operates on a first-in first-out basis with exceptions for cases that are deemed clinically urgent. The list has been used to capture data of patients who qualify for and consent to TJA. It is used to plan and prepare surgical lists and has been operational since 2004.

Interviews were conducted from 20 June to 10 July 2020, a full 6 wk after all elective surgery in both private and public hospitals in South Africa had been cancelled in response to the global COVID-19 pandemic as mandated by the South African Disaster Management Act. At the time of initiation of patient interviews, our institution had already made the decision to only revisit resumption of elective procedures after the 1st of October 2020, a period of 32 wk. Interviews were all conducted telephonically by two post-graduate orthopedic surgery students, and all interviews were recorded. The interviewers were fluent in all major South African language groups and all patients were, to the extent possible, interviewed in their first language. A single, standardized and structured questionnaire was used for all interviews, and all interviews were recorded. Patients were given the option to provide verbal voluntary consent or refusal to participate in the study after being informed of its purpose. The questionnaire consisted of four sections.

The first section recorded baseline demographic data including age, gender and medical co-morbidities including heart disease, diabetes mellitus and human immunodeficiency virus infection. The time that each patient had spent waiting for elective, primary TJA was calculated from the date the patient was first added to the waiting list until the date of suspension of all elective surgery lists, 20 March 2020. Lastly, we ascertained the patients desire to undergo elective TJA procedures despite the COVID-19 pandemic.

Section 2 assessed the patients current disease state as a consequence of the deferred surgical intervention. A 5-point Likert scale was used to determine the degree to which the patient felt the postponement of surgery had affected their pain, numerical rating scale (NRS) pain score, functionality and need for analgesia. Section 3 was an evaluation of mental health. Depressive symptoms including weight gain and loneliness were recorded. A 5-point Likert scale was used to evaluate the patients' anxiety regarding TJA during the COVID-19 pandemic.

Section 4 endeavored to establish the patients' perception of the healthcare system's response to the COVID-19 pandemic and necessity to postpone elective surgery. We assessed patients' knowledge of basic coronavirus transmission prevention measures such as the wearing of face masks, general hand hygiene, and social distancing. We attempted to assess the extent of insight that patients had regarding the response of the healthcare system to the COVID-19 pandemic. This included the patient's knowledge of infection control procedures that have been implemented to minimize disease spread. Thereafter, patients were counseled regarding the current state of surgery during the COVID-19 pandemic. Patients were educated on the introduction of routine testing for COVID-19 prior to admission and preclusion of visitors during their hospital stay. Patients were then counseled with respect to poor clinical outcomes in COVID-19 infected patients undergoing surgery including the possibility of death and the risk of contracting COVID-19 as an inpatient. Upon conclusion of this patient education patients were once again asked about their desire to undergo TJA during the COVID-19 pandemic.

Results were tabulated with mean and standard deviation calculated for integer variables. Chi-squared testing was used to compare relationships between categorical variables. Patient age and period awaiting TJA were categorized and responses were compared across sub-groups. Additional categorical variables that responses were compared across included comorbidities and demand for TJA despite COVID-19 pandemic both before and after patient education and counseling. Odds ratios (ORs) were calculated using logistics regression for binary outcomes. Statistical significance was set at $P < 0.05$. The statistical software used for analysis was *R* 4.0.2 for Windows Copyright (C) 1989, 1991 Free Software Foundation, Inc with interface *R* Studio Version 1.3.959.

RESULTS

Sample population and demographic data

There were 185 patients (81.5%) included in the study (Figure 1). The mean age was 50.28 years (range: 33-69) with 122 female patients (65.95%). There were 106 (57.3%) patients awaiting surgery for TKA and 79 (42.7%) for THA, respectively. The overall mean length of time for patients awaiting TJA was 26.42 mo (standard deviation [SD]: 30.1; range: 3-264 mo). The mean length of time for patients awaiting THA was 28.29 mo (SD: 34.87; range: 3-264 mo) and TKA was 25.03 mo (SD: 26.07; range: 4-200 mo), respectively. There were 126 patients (68.11%) with one or more comorbidities. Additional demographic details and results for the questionnaire are depicted in Table 1.

Patient demand for TJA

There were 164 patients (88.65%) who wished to undergo TJA and 21 patients (11.35%) that did not want elective TJA, respectively at the earliest opportunity despite the COVID-19 pandemic. Patients awaiting TJA for more than 3 years were 4.3-fold more likely to want surgery compared to those awaiting surgery for less than 1 year (OR > 3 years 6.15; < 1 year 1.41; $P = 0.029$). Patients awaiting TJA between 1 and 3 years were 3.3-fold more likely to want surgery compared to those awaiting surgery for less than 1 year (OR: 1-3 years 4.71; < 1 year 1.41; $P < 0.000$). Patients with more than one comorbidity were 8.4-fold less likely to want elective surgery during the pandemic compared to those with no comorbid conditions (OR > 1 comorbidity 0.24; no comorbidities 3.38; $P = 0.013$).

Pain and function since the postponement of surgery

There was increased joint pain experienced by 101 patients (55.49%) since the postponement of their TJA. The responses for pain and function were compared between patients that wanted TJA despite the COVID-19 pandemic to those who did not want surgery at the earliest opportunity (Table 2). Increased joint pain was experienced by 58.28% ($n = 95$) of patients that wanted TJA despite the COVID-19 pandemic compared to 31.58% ($n = 6$) of patients that did not want elective surgery at the earliest opportunity ($P = 0.037$). The mean NRS pain score overall was 7.37 (SD: 2.24; range: 0-10).

There were 123 patients (67.21%) who felt their functionality due to joint pain had decreased since the postponement of surgery. There were 73 (78.5%) patients between the age of 45 to 60 years who had decreased functionality since the postponement of surgery compared to 25 (46.3%) and 24 (68.6%) patients under 45 years and over 60 years of age, respectively ($P = 0.015$). There was decreased function for patients that wanted TJA compared to those who did not, demonstrated by significant differences in decreased functionality due to joint pain (70.99% *vs* 38.1%; $P = 0.002$) and decreased walking distance (50.3% *vs* 28.58%; $P = 0.034$) respectively.

Table 1 Coronavirus disease 2019 arthroplasty waiting list questionnaire response results

Section I: Demographic data	
Age in yr, mean ± SD	50.28 ± 8.9
Gender, *n* (%)	
Male	63 (34.05)
Female	122 (65.95)
TJA, *n* (%)	
TKA	106 (57.3)
THA	79 (42.7)
Awaiting TJA in mo, mean ± SD	26.42 ± 30.1
Number of comorbidities, *n* (%)	
0	59 (31.89)
1	95 (51.35)
2	29 (15.68)
3	2 (1.08)
Comorbidities, *n* (%)	
DM	27 (14.59)
HPT	89 (48.11)
TB	5 (2.70)
Cardiac disease	9 (4.86)
Asthma	12 (6.49)
Lung disease	5 (2.70)
HIV	18 (9.73)
Demand for TJA despite COVID-19 pandemic, *n* (%)	
Yes	163 (88.11)
No	22 (11.89)
Section II: Pain and function	
Joint pain since postponement of TJA, *n* (%)	
Decreased	23 (12.64)
Same	58 (31.87)
Increased	101 (55.49)
Access to pain medication, *n* (%)	
Yes	90 (72)
No	35 (28)
NRS pain score, mean ± SD	7.37 ± 2.24
Current state in comparison to before TJA postponement	*n* (%)
Functionality due to joint pain	
Much less	24 (13.11)
Less	99 (54.1)
Same	50 (27.32)
More	5 (2.73)
Much more	5 (2.73)
Walking distance	

Much less	30 (16.3)
Less	59 (32.07)
Same	88 (47.83)
More	6 (3.26)
Much more	1 (0.54)
Sitting	
Much less	18 (9.89)
Less	57 (31.32)
Same	101 (55.49)
More	6 (3.3)
Much more	0 (0)
Sleep	
Much less	25 (13.59)
Less	25 (13.59)
Same	104 (56.52)
More	20 (10.87)
Much more	10 (5.43)
Need for pain medication	
Much less	8 (4.57)
Less	12 (6.86)
Same	74 (42.29)
More	47 (26.86)
Much more	34 (19.43)
Section III: Mental health	*n* (%)
Weight change since TJA postponement	
Lost	33 (25.98)
Same	56 (44.09)
Gained	38 (29.92)
Feelings of isolation or loneliness	
Yes	59 (32.78)
No	121 (67.22)
Anxiety to get infected with COVID-19	
No	28 (15.3)
Minimal	20 (10.93)
Neutral	22 (12.02)
Moderate	47 (25.68)
Severe	66 (36.07)
Anxiety to spread COVID-19 to relatives	
No	28 (15.64)
Minimal	17 (9.5)
Neutral	14 (7.82)
Moderate	39 (21.79)
Severe	81 (45.25)

Anxiety about Finances due to COVID-19	
No	18 (10)
Minimal	20 (11.11)
Neutral	82 (45.56)
Moderate	40 (22.22)
Severe	20 (11.11)
Section IV: Insight	
Understanding of healthcare system response to COVID-19	*n* (%)
Aware no elective surgery	
Yes	137 (74.05)
No	48 (25.95)
Fair no elective surgery	
Yes	157 (84.86)
No	28 (15.14)
Important to delay elective surgery	
Yes	162 (87.57)
No	23 (12.43)
Knowledge of preventative measures	*n* (%)
Hand washing	
Yes	124 (67.03)
No	62 (32.97)
Social distancing	
Yes	124 (67.03)
No	62 (32.97)
Wearing mask in public	
Yes	123 (66.49)
No	63 (33.51)
Peri-operative patient considerations for COVID-19	*n* (%)
Routine pre-operative screening	
Yes	122 (89.1)
No	15 (10.9)
Increased morbidity if COVID-19 positive	
Yes	120 (88.9)
No	15 (11.1)
No visitors allowed	
Yes	114 (87)
No	17 (13)
Increased mortality if COVID-19 positive	
Yes	92 (67.2)
No	45 (32.8)
Patient education and counselling	
Still demand TJA despite COVID-19 pandemic	*n* (%)
Yes	100 (54.05)

No	85 (45.95)

COVID-19: Coronavirus disease 2019; DM: Diabetes mellitus; HIV: Human immunodeficiency virus; HPT: Hypertension; NRS: Numerical rating scale; SD: Standard deviation; TB: Tuberculosis; THA: Total hip arthroplasty; TJA: Total joint arthroplasty; TKA: Total knee arthroplasty.

Mental health during the COVID-19 pandemic

There were 113 patients (61.75%), who experienced increased anxiety about getting infected with COVID-19 should they get their elective TJA during this time. There were 120 patients (67.04%) who experienced increased anxiety about subsequently spreading COVID-19 to relatives. The responses for mental health were compared between patients that wanted TJA despite the COVID-19 pandemic to those who did not want surgery at the earliest opportunity (Table 3). The increased anxiety of getting infected with COVID-19 was found in 64.19% (n = 104) of patients who wanted TJA compared to 42.86% (n = 9) of patients that did not want surgery at the earliest opportunity (P = 0.013). Similarly, there was increased anxiety to spread COVID-19 to relatives for 110 patients (69.62%) that wanted TJA and 10 patients (47.62%) that did not want elective surgery, respectively (P = 0.016). There were no significant differences between patients when compared between age groups and presence of comorbidities.

Patient insight and impact of patient education

There were 162 patients (87.57%) that accepted the reasoning behind the delay of elective surgery in response to the COVID-19 pandemic. The detailed results for the assessment of patient insight are depicted in Table 1. After receiving patient education there were 100 patients (54.05%) that still wanted TJA despite the COVID-19 pandemic and 85 patients (45.95%) that did not want elective surgery at the earliest opportunity (Figure 2). Over half the patients (100 patients/54.05%) wanted TJA despite the COVID-19 pandemic (continued demand group) after counseling. There were 21 patients (11.35%) that opted out of surgery as the earliest opportunity despite COVID-19 (defer group) both before and after patient education. There were 64 patients (34.59%) that changed their opinion after receiving patient education (receptive group).

The receptive group previously wanted TJA despite the COVID-19 pandemic and subsequently opted out of elective surgery after receiving patient education. The results for questions regarding patient insight were compared between the continued demand group, the defer group and the receptive group (Table 3). The importance to delay elective surgery was recognized 81.97% of the receptive group compared to 91.4% and 100% of the continued demand and defer groups, respectively (P < 0.000). Similarly, 76.67% of the receptive group were aware of the increased risks associated with COVID-19 if infected peri-operatively, compared to 91.75% and 100% of patients from the continued demand and defer groups, respectively (P = 0.046). There were 44 patients (73.33%) from the receptive group that understood there would be no visitors allowed to see them in hospital after surgery compared to 85 (91.75%) and 20 (95.24%) patients from the continued demand and defer groups, respectively (P = 0.018). Lastly, 43.33% of the receptive group were aware of the increased risks for death associated with COVID-19 compared to 77% and 85.71% of patients from the continued demand and defer groups, respectively (P = 0.001).

Continued demand for TJA despite the COVID-19 pandemic

The patient characteristics and perception of pain and function since the postponement of TJA was of interest regarding the continued demand group. The results for questions regarding pain and function were compared between the continued demand group, the defer group and the receptive group (Tables 4 and 5). Patients in the continued demand group were awaiting TJA for a mean period of 24.7 mo (SD: 20.38, range: 3-132 mo). The mean length of time for patients awaiting TJA in the Defer group was 25.32 mo (SD: 40.54, range: 4-200 mo) and in the receptive group was 28.91 mo (SD: 37.82, range: 4-264 mo), respectively. Increased joint pain was experienced by 60.61% of the continued demand group compared to 33.33% and 53.12% of defer and receptive groups, respectively (P = 0.035). The mean NRS pain score for the continued demand group was 7.68 (SD: 2.14; range: 2-10) compared to 5.9 (SD: 3.2; range: 0-10) and 7.24 (SD: 1.8; range: 2-10) for defer and receptive groups, respectively (P < 0.000). There was decreased functionality due to joint pain for 75.51% of the continued demand group since the postponement of surgery compared to 50% and 60.94% of

Table 2 Pain and function responses compared between patients that wanted total joint arthroplasty despite the coronavirus disease 2019 pandemic (Yes) to patients that did not want elective surgery as soon as possible (No)[1]

Current state in comparison to before TJA postponement	Want TJA despite COVID-19 pandemic		*P* value
Function	Yes, *n* (%)	No, *n* (%)	
Functionality due to joint pain			0.002
Much less	26 (16.05)	0 (0)	
Less	89 (54.94)	8 (38.1)	
Same	42 (25.93)	8 (38.1)	
More	2 (1.23)	4 (19.05)	
Much more	3 (1.85)	1 (4.76)	
Walking distance			0.034
Much less	27 (16.56)	3 (14.29)	
Less	55 (33.74)	3 (14.29)	
Same	77 (47.24)	11 (52.38)	
More	3 (1.84)	4 (19.05)	
Much more	1 (0.61)	0 (0)	
Sitting			0.63
Much less	15 (9.2)	3 (15.97)	
Less	53 (32.52)	4 (21.05)	
Same	90 (55.21)	11 (57.89)	
More	5 (3.07)	1 (5.26)	
Sleep			0.572
Much less	21 (12.88)	4 (19.05)	
Less	21 (12.88)	4 (19.05)	
Same	94 (57.67)	10 (47.62)	
More	19 (11.66)	1 (4.76)	
Much more	8 (4.91)	2 (9.52)	
Pain	Yes, *n* (%)	No, *n* (%)	
Joint pain			0.037
Decreased	20 (12.27)	3 (15.79)	
Same	48 (29.45)	10 (52.63)	
Increased	95 (58.28)	6 (31.58)	
Access to pain medication			0.714
No	30 (27.03)	5 (35.71)	
Yes	81 (72.97)	9 (64.29)	
Need for pain medication			0.05
Much less	6 (3.87)	2 (10)	
Less	8 (5.16)	4 (20)	
Same	65 (41.94)	9 (45)	
More	44 (28.39)	3 (15)	
Much more	32 (20.65)	2 (10)	
	Yes, mean (± SD)	No, mean (± SD)	*P* value

NRS pain score	7.54 ± 2.02	3.09 ± 3.27	< 0.000

[1]Yes (n = 164); No (n = 21). COVID-19: Coronavirus disease 2019; NRS: Numerical rating scale; SD: Standard deviation; TJA: Total joint arthroplasty.

Table 3 Mental health responses compared between patients that wanted total joint arthroplasty despite the coronavirus disease 2019 pandemic (Yes) to patients that did not want elective surgery as soon as possible (No)[1]

Mental health responses	Want TJA despite COVID-19 Pandemic, *n* (%)		*P* value
	Yes	No	
Weight change since TJA postponement			0.423
Lost	30 (27.03)	3 (18.75)	
Same	50 (45.05)	6 (37.50)	
Gained	31 (27.93)	7 (43.75)	
Feelings of isolation or loneliness			0.89
Yes	51 (32.48)	8 (34.78)	
No	106 (67.52)	15 (65.22)	
Anxiety to get infected with COVID-19			0.133
No	15.43	14.29	
Minimal	10.49	14.29	
Neutral	9.88	28.57	
Moderate	26.54	19.05	
Severe	37.65	23.81	
Anxiety to spread COVID-19 to relatives			0.016
No	26 (16.46)	2 (9.52)	
Minimal	13 (8.23)	4 (19.05)	
Neutral	9 (5.7)	5 (23.81)	
Moderate	35 (22.15)	4 (19.05)	
Severe	75 (47.47)	6 (28.57)	
Anxiety about finances due to COVID-19			0.785
No	16 (10.06)	2 (9.52)	
Minimal	36 (22.64)	4 (19.05)	
Neutral	70 (44.03)	12 (57.14)	
Moderate	19 (11.95)	1 (4.76)	
Severe	18 (11.23)	2 (9.52)	

[1]Yes (n = 164); No (n = 21). COVID-19: Coronavirus disease 2019; TJA: Total joint arthroplasty.

patients in the defer and receptive groups, respectively (P = 0.043).

DISCUSSION

In our study, 88.65% of patients awaiting TJA wanted elective surgery as soon as possible despite the current COVID-19 pandemic. Similarly, a study by Brown *et al*[14] in the united states demonstrated that almost 90% of patients wanted to reschedule elective TJA as soon as possible. A study conducted in the United Kingdom found that only 56.8% of patients for TJA wanted their elective surgery as soon as possible[15]. Additionally, Brown *et al*[14] reported that 85% of patients agreed with the decision to cancel elective surgery in response to the COVID-19 pandemic in the united states.

Table 4 Pain and function responses compared between the continued demand group, defer group and receptive group[1]

Current function in comparison to before TJA postponement	Continued demand group, *n* (%)	Defer group, *n* (%)	Receptive group, *n* (%)	*P* value
Functionality due to joint pain				0.043
Much less	15 (15.31)	0 (0)	9 (14.06)	
Less	59 (60.20)	10 (50)	30 (46.88)	
Same	19 (19.39)	6 (30)	24 (37.5)	
More	2 (2.04)	3 (15)	0 (0)	
Much more	3 (3.06)	1 (5)	1 (1.56)	
Walking distance				0.118
Much less	21 (21.21)	2 (10)	7 (10.94)	
Less	29 (29.29)	4 (20)	25 (39.06)	
Same	46 (46.46)	11 (55)	31 (48.44)	
More	2 (2.02)	3 (15)	1 (1.56)	
Much more	1 (1.01)	0 (0)	0 (0)	
Sitting				0.518
Much less	12 (12.12)	2 (11.11)	4 (6.25)	
Less	29 (29.29)	4 (22.22)	23 (35.94)	
Same	53 (53.54)	11 (61.11)	37 (57.81)	
More	5 (5.05)	1 (5.56)	0 (0)	
Sleep				0.643
Much less	13 (13.13)	3 (15)	9 (14.06)	
Less	15 (15.15)	4 (20)	6 (9.38)	
Same	50 (50.51)	10 (50)	43 (67.19)	
More	14 (14.14)	1 (5)	5 (7.81)	
Much more	7 (7.07)	2 (10)	1 (1.56)	
Current pain in comparison to before TJA postponement	Continued demand group, *n* (%)	Defer group, *n* (%)	Receptive group, *n* (%)	*P* value
Joint pain				0.035
Decreased	10 (10.10)	3 (16.67)	10 (15.62)	
Same	29 (29.29)	9 (50)	20 (31.25)	
Increased	60 (60.61)	6 (33.33)	34 (53.12)	
Access to pain medication				0.792
No	19	5	11	
Yes	51	9	30	
Need for pain medication				0.068
Much less	5 (5.26)	2 (10.53)	1 (1.67)	
Less	7 (7.37)	4 (21.05)	1 (1.67)	
Same	34 (35.79)	9 (47.37)	31 (51.67)	
More	26 (27.37)	3 (15.79)	17 (28.33)	
Much more	23 (24.21)	1 (5.26)	10 (16.67)	
NRS pain score, mean (± SD)	Continued demand group	Defer group	Receptive group	*P* value
	7.68 ± 2.14	5.9 ± 3.2	7.24 ± 1.8	< 0.000

[1]Continued demand (*n* = 100); Defer (*n* = 21); Receptive (*n* = 64). NRS: Numerical rating scale; SD: Standard deviation; TJA: Total joint arthroplasty.

Table 5 Responses for Insight Perception Regarding coronavirus disease 2019 compared between the continued demand group, defer group and receptive group[1]

Insight responses	Continued demand group, *n* (%)	Defer group, *n* (%)	Receptive group, *n* (%)	*P* value
Healthcare system response to COVID-19				
Aware no elective surgery				0.951
Yes	73 (74.49)	15 (75)	48 (75)	
No	25 (25.51)	5 (25)	16 (25)	
Fair no elective surgery				0.710
Yes	82 (82.83)	17 (85)	57 (89.06)	
No	17 (17.17)	3 (15)	7 (10.94)	
Important to delay elective surgery				< 0.000
Yes	85 (91.4)	21 (100)	50 (81.97)	
No	8 (8.6)	0 (0)	11 (18.03)	
Knowledge of preventative measures				
Hand washing				0.441
Yes	69 (69.70)	14 (66.67)	41 (64.06)	
No	30 (30.30)	7 (33.33)	23 (35.94)	
Social distancing				0.441
Yes	69 (69.70)	14 (66.67)	41 (64.06)	
No	30 (30.30)	7 (33.33)	23 (35.94)	
Wearing mask in publicYes	68 (68.69)	14 (66.67)	41 (64.06)	0.489
No	31 (31.31)	7 (33.33)	23 (35.94)	
Peri-operative patient considerations for COVID-19				
Routine pre-operative screening				0.016
Yes	94 (94)	18 (85.71)	44 (73.33)	
No	6 (6)	3 (14.29)	16 (26.67)	
Increased morbidity if COVID-19 positive				0.046
Yes	89 (91.75)	21 (100)	46 (76.67)	
No	8 (8.25)	0 (0)	14 (23.33)	
No visitors allowed				0.018
Yes	85 (91.4)	18 (85.71)	44 (73.33)	
No	8 (8.6)	3 (14.29)	16 (26.67)	
Increased mortality if COVID-19 positive				0.001
Yes	77 (77)	18 (85.71)	26 (43.33)	
No	23 (23)	2 (14.29)	34 (56.67)	

[1]Continued demand (*n* = 100); Defer (*n* = 21); Receptive (*n* = 64). COVID-19: Coronavirus disease 2019.

This is reflected in our study of a sub-Saharan Africa population with 87.57% of patients accepting the need to delay elective TJA procedures. There is a demonstrated need to postpone elective surgery, particularly in high-risk patients and re-initiation

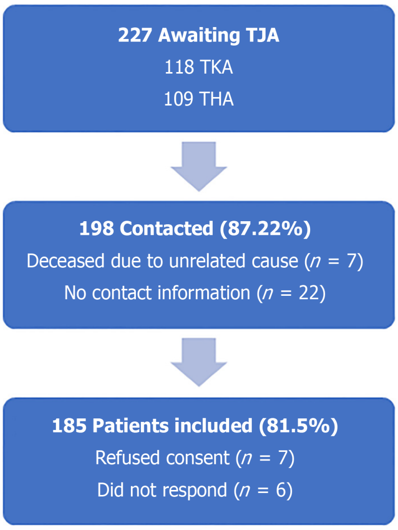

Figure 1 Flowchart of the study cohort. THA: Total hip arthroplasty; TJA: Total joint arthroplasty; TKA: Total knee arthroplasty.

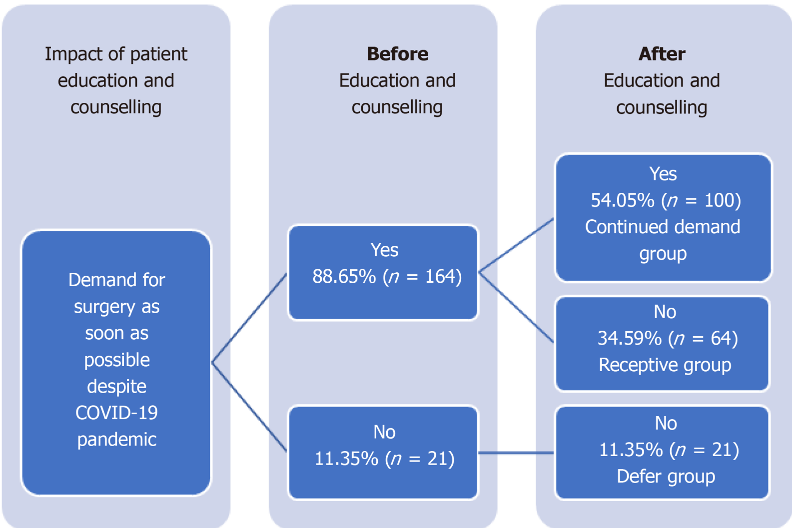

Figure 2 Patient demand for total joint arthroplasty before and after receiving education and counseling. COVID-19: Coronavirus disease 2019.

should be careful and gradual.

Patients with comorbidities, particularly those with cardiac diseases, hypertension and diabetes mellitus, have increased risks for morbidity and mortality if infected with COVID-19[16,17]. In our study, patients with comorbidities were 8.45-fold less likely to want elective surgery at the earliest opportunity compared to those with no comorbid conditions (P = 0.0128). Similarly, Chang *et al*[15] reported that patients classified ASA I (60.5%) and ASA II (60.0%) were more likely to agree to undergo earlier elective TJA after the COVID-19 pandemic compared to ASA III (44.4%) and ASA IV (0%) patients (P = 0.01). A multicenter study by Kayani *et al*[16] assessed the impact of COVID-19 infection on peri-operative outcomes for patients undergoing surgical treatment for hip fractures. COVID-19 positive patients had increased post-operative mortality rates (P < 0.001), increased risk of post-operative complications (P < 0.001) and more critical care unit admissions (P < 0.001) compared to COVID-19 negative patients[16]. Furthermore, COVID-19 positive patients with greater than 3 comorbidities had a significantly higher risk for mortality compared to those with no comorbidities (P < 0.001)[16].

The waiting period for elective TJA is high in our sub-Saharan setting when compared to other reported rates worldwide. In our study, the mean length of time for patients awaiting THA was 28.29 mo and 25.03 mo for TKA. In 2018, the average median worldwide waiting time for elective THA was 113 d (range: 50-282 d) and 189 d (range: 45-839 d) for TKA with wide variation, across countries[18]. Initially, longer waiting period was associated with increased patient demand for elective surgery at the earliest opportunity despite the COVID-19 pandemic in our study. Patients awaiting TJA for between 1 and 3 years were 3.34-fold more likely to want elective surgery at the earliest possibility compared to those awaiting surgery for less than 1 year (P < 0.000). A systematic review including 15 studies of patients awaiting TJA for osteoarthritis was conducted to assess the impact of wait times on pain and functional status[19]. There was a mean waiting period between 42-399 d with strong evidence that pain and WOMAC score did not deteriorate for patients waiting less than 180 d[19]. Similarly, a multicenter study with a mean wait time of 5.07 mo by Vergara *et al*[20] observed that patients waiting less than 3 mo had a greater likelihood of achieving successful post-operative outcomes on the WOMAC scale and the 36-item short form survey scores. Furthermore, a multicenter study including 7151 patients found that longer waiting periods were significantly associated with a lower Oxford Hip Score at 12-mo follow-up after THA[21]. Patients waiting 12 and 24 mo had a post-operative mean difference of 2.6 and 4.2 Oxford Hip Score points, respectively compared to those waiting less than 6 mo[21].

In our study, 55.49% of patients had increased joint pain and 67.2% of patients had decreased functionality respectively, since the postponement of their TJA. Patients that wanted TJA despite the COVID-19 pandemic experienced significantly greater decrease in function compared to those who were prepared to wait. This was demonstrated by significant differences in decreased functionality due to joint pain (P = 0.002) and decreased walking distance (P = 0.034) respectively. Additionally, patients between the ages of 45 to 60 years had significantly more decreased functionality due to joint pain compared to patients younger than 45 years of age (78.5% *vs* 46.3%; P = 0.015). Brown *et al*[14] in their survey of TJA patients in the united states reported that joint pain had increased for 54% of patients and activity levels had decreased for 50% of patients, respectively since their surgery cancellation. This has long-term implications as several studies have demonstrated significantly less improvement in WOMAC and 36-item short form survey scores for patients with lower baseline function compared to those with higher baseline function persisting through 24 mo follow-up after TJA[12,13]. A recent study by Scott *et al*[11] demonstrated that patients with low scores on the Euro Qol five-dimension general health questionnaire achieved significantly worse joint-specific Oxford scores and satisfaction rates 1 year after TJA, compared with those with higher scores pre-operatively (P < 0.001).

Patient consent prior to elective surgery during the COVID-19 pandemic must focus on counseling and education, particularly for high-risk patients. Our study found that the percentage of patients who wanted elective surgery at the earliest opportunity decreased from 88.65% to 54.05% after receiving patient education about the COVID-19 pandemic. Patients in our study that were in the receptive group had significantly less insight on the impact of COVID-19 regarding both their individual health and the response of the healthcare system. Patients in the receptive group were less likely to be aware of the increased morbidity (P = 0.046) and mortality (P = 0.001) associated with COVID-19 if infected peri-operatively when compared to non-infected patients. A purposeful patient education program was implemented by the orthopedic department of the New York University Langone Health in response to the COVID-19 pandemic[6]. Orthopedic surgeons counseled patients regarding need for the postponement of surgery due to the COVID-19 pandemic and addressed patient concerns and questions which alleviated their anxiety[6].

In our study, the continued demand group had been awaiting surgery for a shorter length of time (24.7 mo) than the defer group (25.32 mo) and the receptive group (28.91 mo). Despite the shorter waiting period, the continued demand group experienced significantly greater pain than other patients. The continued demand group had a higher mean pain score (P < 0.000) and the greatest proportion of patients with increased joint pain (P = 0.035) since the postponement of surgery compared to the other patient groups.

There are unique challenges that must be considered during the re-initiation of elective surgery. Rizkalla *et al*[22] proposed that the decision to proceed with either primary or revision hip arthroplasty should be assessed for urgency. The urgency to proceed with hip arthroplasty should be based on both the potential harm of delaying surgery and the potential risk of performing surgery in the context of COVID-19[22]. In addition to patient outcomes, the economic implications of the postponement of elective surgery place an increasing burden on healthcare systems[23,24]. There have been several guidelines developed to facilitate the return of elective surgery in many parts of the world[23,24]. The reinstitution of elective surgery must be carefully implemented to ensure patient and staff safety and the responsible management of healthcare resources and equipment[23,24]. Waiting lists should no longer operate on a first-in, first-out basis as was previously used in our institution. The effect of TJA postponement on patients should be assessed on an individualized basis and waiting lists should be prioritized for urgency.

One of the weaknesses of our study is that the waiting period was already long in comparison to worldwide rates. An additional limitation is that the interview was done telephonically, however, to mitigate this there were two individuals conducted interviews and all conversations were recorded.

CONCLUSION

Patient education and counseling are essential for those who have had elective procedures postponed during the COVID-19 pandemic. South Africa has longer waiting periods for TJA in comparison to international reports and the further postponement of surgery increases the risk of poor post-operative outcomes. There is deterioration in patients' physical and mental health whilst awaiting TJA and should be individually reassessed before rescheduling their surgery. Waiting lists should be prioritized for urgency with the re-initiation of elective surgery based on their current overall health status.

ARTICLE HIGHLIGHTS

Research background

The postponement of elective surgery in response to the coronavirus disease 2019 (COVID-19) pandemic resulted in a total shutdown of total joint arthroplasty (TJA). The impact of elective surgery postponement has resulted in the cancellation of approximately 92.6% TJAs in Europe. The demand for TJA is already high and waiting lists continue to grow with 150000 procedures per month postponed in the United States.

Research motivation

There is wide variation across countries worldwide; with the average median waiting time of 113 d (range 50-282 d) for total hip arthroplasty and 189 d (range 45-839 d) for total knee arthroplasty respectively. Patients awaiting surgery longer than 6 mo and those with poor pre-operative baseline function have demonstrated increased risks for poor outcomes after TJA. The unprecedented postponement of elective TJA in response to the COVID-19 pandemic may impact patients awaiting surgery.

Research objectives

Our aim was to assess the impact of TJA postponement on the physical and mental health of patients awaiting elective surgery. We secondarily sought to determine the demand for TJA and average waiting time for our South African population. Additionally, we investigated the role of patient insight after providing education and counseling regarding the healthcare system's response to the COVID-19 pandemic. The effect of TJA postponement on patients should be considered with the re-initiation of elective surgery and waiting lists should be prioritized to optimize outcomes.

Research methods

A prospective cross-sectional telephonic interview-based study of patients awaiting TJA at an academic referral institution in South Africa during the COVID-19 pandemic. We recorded baseline demographic data and length of time awaiting surgery and demand for TJA. A 5-point Likert scale was used to determine the degree to which the patient felt the postponement of surgery had affected various characteristics of their physical and mental health. We assessed patient insight regarding elective surgery cancellation in response to the COVID-19 pandemic and subsequently re-evaluated demand for TJA after providing education and counseling.

Research results

Patients with comorbidities were 8.45-fold less likely to want elective surgery at earliest possibility compared to those with no comorbid conditions (P = 0.013). In our study in South Africa, the mean length of time for patients awaiting total hip arthroplasty was 28.29 mo and total knee arthroplasty was 25.03 mo, respectively. Before and after receiving patient education, the number of patients who demanded elective TJA decreased respectively, from 164 patients (88.65%) to 100 patients (54.05%) (continued demand group). The continued demand group had a higher mean pain score ($P < 0.000$) and the greatest proportion of patients with increased joint pain ($P = 0.035$) since the postponement of surgery compared to the other patients.

Research conclusions

The effect of TJA postponement on patients should be assessed on an individualized basis and waiting lists should be prioritized for urgency. Patient consent prior to elective surgery during the COVID-19 pandemic must focus on counseling and education, particularly for high-risk patients, to ensure optimal outcomes. The urgency to proceed with TJA should be based on both the potential harm of delaying surgery and the individual risk profile of performing surgery incurred by each patient, respectively, in the context of the COVID-19 pandemic.

Research perspectives

There is a demonstrated need to postpone elective surgery in response to the COVID-19 pandemic, particularly in high-risk patients. Patients should be reassessed and thoroughly counseled prior to rescheduling their elective procedures, particularly those at increased risk for morbidity and mortality if infected with COVID-19 peri-operatively. In addition to the potential negative impact on patient outcomes, the economic implications of the postponement of elective surgery place an increasing burden of healthcare systems worldwide. The reinstitution of elective surgery must be carefully implemented to ensure patient and staff safety and the responsible management of institutional resources.

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SCIENTOMETRICS

Bibliometric analysis of research on the effects of human immunodeficiency virus in orthopaedic and trauma surgery

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Abstract

BACKGROUND

There is little research investigating how human immunodeficiency virus (HIV) affects outcomes in orthopaedic surgery. With advances in treatment, HIV has become a chronic health problem and the chance of orthopaedic surgeons encountering it in clinical practice is increasing.

AIM

To ascertain the quantity and quality of peer-reviewed publications in orthopaedic journals about HIV.

METHODS

A search of the Web of Science database was carried out, identifying any articles relating to HIV published in orthopaedic journals. These were assessed for geographic origin and level of evidence.

RESULTS

Of 48.7% of orthopaedic journals listed on the Web of Science database had

Specialty type: Orthopedics

Country/Territory of origin: South Africa

Peer-review report's scientific quality classification

Grade A (Excellent): 0
Grade B (Very good): 0
Grade C (Good): C, C
Grade D (Fair): 0
Grade E (Poor): 0

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published articles relating to HIV. There were 168 articles about HIV in orthopaedic journals with only 40.5% (n = 68) published in the time frame we analysed (January 2007 to September 2017). Very few articles came from low-income countries and any articles published from that setting were collaborations. All of the articles were low level of evidence.

CONCLUSION

There is a need for more high level orthopaedic and trauma research investigating the effects of HIV, particularly research from low-income countries, where higher level research will help to guide improvements in their treatment of its musculoskeletal manifestations and complications.

Key Words: Human immunodeficiency virus; Research; Bibliometric analysis; Analysis; Orthopaedic

Core Tip: This paper looks in to the research being carried out in orthopaedic journals regarding human immunodeficiency virus and how it affects outcomes in orthopaedic and trauma surgery. We have shown that there is a significant lack of research in to this subject despite the fact there is a high prevalence of the disease in the setting which has the greatest burden of disease from trauma. Our findings highlight the need for further research to improve outcomes in trauma and orthopaedic surgery in these settings.

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INTRODUCTION

The World Health Organization in 2018 estimated that there are 37.9 million people globally living with human immunodeficiency virus (HIV), with well over half of these people (25.7 million, 69.8%) living in sub-Saharan Africa[1].

The introduction of antiretroviral therapy (ART) in 1997 has altered the course and nature of patients infected with HIV by increasing the duration of asymptomatic infection and, consequently, patients with HIV are attaining close to normal life spans[2]. Because individuals are now living longer, they commonly present with complications that result from the virus directly or the ART used to treat it[3].

HIV can present with a number of different orthopaedic pathologies, including osteonecrosis of the hip or knee, osteoporosis, septic arthritis and primary HIV arthropathy[4]. Furthermore, ART treatment is also associated with osteonecrosis and increase in risk of osteoporosis, potentially resulting in increased risk of sustaining a fracture[5,6]. With the increasing availability of ART and the major decline in HIV-related mortality levels[7], orthopaedic surgeons are more likely to encounter patients with HIV in their surgical practice. This is particularly relevant for orthopaedic surgeons operating in sub-Saharan Africa and in low-income countries (LIC), where HIV is more prevalent[1].

In the current orthopaedic literature, there has been little research investigating the effects of HIV on outcomes in orthopaedic surgery[8]. We found in a previous study that, despite a significant proportion of the global burden of disease from musculoskeletal disease and trauma occurring in LIC, there was little musculoskeletal disease and trauma research being produced in that setting[9]. Similarly, LIC have a much higher prevalence of HIV[1] but the current literature would suggest that orthopaedic research into how HIV may impact outcomes in musculoskeletal disease and trauma, is being conducted outside of the setting where it is most needed.

The aim of this paper was to ascertain the number of peer-reviewed articles being published in orthopaedic journals across all sub-specialties within orthopaedic surgery that related to HIV. We also sought to determine the geographic origin of the research and what proportion was being conducted in LIC, the setting that would most benefit from the research.

MATERIALS AND METHODS

We searched the 'Clarivate Analytics' Web of Science database to obtain all indexed articles regarding HIV published in all orthopaedic journals listed on the database. We then filtered this to search just the last 10 years, going back from the time point the search was conducted (January 2007 to September 2017). Inclusion criteria consisted of articles limited to English language publications. We used Web of Science as it is possible to filter journals so only English language orthopaedic journals are included.

Search terms used on the database consisted of the following: 'human immunodeficiency virus' OR 'HIV'. We then recorded the number of articles returned for each journal. Subsequently, abstracts and full texts were reviewed for each article to determine its relevance. This was done by two of the researchers (Brennan C and Graham SM).

Articles were included if the main focus of research was HIV. Excluded articles were those that had no relevance to HIV or had an additional focus such as tuberculosis, as well as letters or comments.

All relevant indexed articles were analysed for the following information: journal title, year of publication, geographic location and country, level of evidence and number of citations. The level of evidence was determined in accordance with the criteria established in the *Journal of Bone and Joint Surgery American Volume*[10,11] following review of abstracts and full texts.

Countries producing research were categorised into high-income countries (HIC), upper and lower middle-income countries (UMIC/LMIC) and low-income countries (LIC) according to the World Bank data for the current 2020 fiscal year[12] (Table 1).

RESULTS

There are 76 orthopaedic journals listed on the Web of Science database. Initial searches showed that there were 168 published articles relating to HIV across 37 different orthopaedic journals (48.7% of the listed journals).

Of these 168 articles, 68 (40.5%) were published in the time frame analysed for this paper (January 2007 to September 2017), in 26 different orthopaedic journals (34.2%). (See Table 2 for full list of journals).

The 5 orthopaedic journals with the most papers relating to HIV in that time period each had 5 published articles. These were: *The Journal of Bone and Joint Surgery-American volume*; *Journal of Arthroplasty*; *Injury*; *Skeletal Radiology* and *The Journal of the American Podiatric Medical Association*.

The 68 articles originated from 20 different countries (See Table 3 for full list of countries).

The majority of publications originated from the United States (n = 34, 50%), with the next four highest yield countries being: United Kingdom (n = 7, 10.3%), South Africa (n = 6, 8.8%), Malawi (n = 5, 7.4%) and Ireland (n = 4, 5.9%) respectively. Of the 68 articles, 9 (13.2%) were collaborations between authors or groups from different countries.

Of the 20 countries producing research into HIV in orthopaedic surgery, research from 5 countries was solely collaborative and there was no individual research output from that country. These countries were Malawi (5 collaborative articles), Norway (2 collaborative articles), Australia, Canada and Japan (each with 1 collaborative article).

The majority (13/20, 65%) of research output, including the collaborative research, was from HIC. They accounted for 78% (46/59) of the non-collaborative articles, as well as 100% of the collaborative articles. Only 4 countries (20%) were UMIC, with a research output of 12 of the 68 articles (17.7%) and 2 collaborative articles. There were just 2 (10%) LMIC, which produced 3 articles (4.4%), none of which were collaborative research papers. Finally, only 1 country (5%) was a LIC. This was Malawi, and 100% of the research from there was collaborative and with authors from HIC.

Collaborative research was conducted between: HIC and HIC, HIC and UMIC or HIC and LIC (See Table 4 for a full list of the countries participating in collaborative studies).

Sixty-six of the 68 included articles (97.1%) were low level of evidence articles (IV or

Table 1 Countries divided by their economic status, as per World Bank classifications (10)

High-income countries	Upper middle-income countries	Lower middle-income countries	Low-income countries
Australia	Brazil	Cameroon	Malawi
Canada	China	Nigeria	
France	South Africa		
Germany	Turkey		
Ireland			
Italy			
Japan			
Netherlands			
Norway			
South Korea			
Spain			
United Kingdom			
United States			

V) and there were no level I or II high evidence studies. The remaining 2 articles were level III evidence and none were from LIC. One was a systematic review and meta-analysis of observational studies looking into gait and balance impairments as a result of HIV infection[13] and was a collaborative paper from South Africa and Germany. The other being a systematic review of studies looking at correlation between osteopaenia and HIV from Brazil[14]. The vast majority of low level of evidence articles (IV or V) was case reports or case series.

DISCUSSION

This study has shown that there is little research conducted into HIV and its impact on orthopaedic surgery. Fewer than half of all the orthopaedic journals have any published research on the subject and less than half of this has been produced in the preceding 10-year period analyses in this research paper.

People living with HIV in all income settings are living longer[15,16] and therefore there is a call for more research to be conducted to facilitate the practice of evidence based medicine in treating these patients. Studies have shown equivocal evidence as to whether HIV is an independent risk factor for outcomes in orthopaedic surgery such as post-operative infection or fracture union, again highlighting the need for further research to be carried out to further evidence based practice[17-20]. A good example of this is seen in the systematic review by Wijesekera *et al*[8], which showed no statistically significant difference between infection rates following surgery in HIV-positive patients compared to control groups in 3 different studies, but one smaller cohort study did report a significantly higher infection rate in the HIV-positive group compared to controls. This highlights a need for more higher level of evidence research to be conducted.

Despite the fact that the vast majority of people living with HIV are located in low- and middle-income countries, with an estimated 68% living in sub-Saharan Africa[21], the majority of publications focusing on HIV in orthopaedic literature originate from high-income countries. South Africa has the world's largest HIV positive population[22], yet we have found that less than 10% of research looking in to this subject originated from South Africa. The overriding majority of research came from the United States which has 7 times fewer people living with HIV compared to South Africa[21]. There were only 2 LMIC countries, Cameroon and Nigeria, that had any published research on HIV amongst the orthopaedic journals listed and both of these were low level of evidence. Only 1 LIC, Malawi, had any articles in the orthopaedic journals on the database and these were all collaborative studies with HIC but once again were all low level of evidence. This shows a struggle for LIC and LMIC to publish research, particularly high level of evidence studies, in a subject that has a

Table 2 Orthopaedic journals with published articles on human immunodeficiency virus in the last 10 years

Journal name	Number of articles
Journal of Bone and Joint Surgery-American Volume	5
Journal of Arthroplasty	5
Injury	5
Skeletal Radiology	5
Journal of the American Podiatric Medical Association	5
Clinical Orthopaedics and Related Research	4
Physical Therapy	4
Spine	4
BMC Musculoskeletal Disorders	4
Acta Orthopaedica	3
Spine Journal	3
Archives of Osteoporosis	3
Orthopedics	3
International Orthoapedics	2
Bone and Joint Journal	2
Journal of the American Academy of Orthopaedic Surgeons	1
Journal of Shoulder and Elbow Surgery	1
Journal of Orthopaedic Research	1
European Spine Journal	1
Osteoarthritis and Cartilage	1
Foot and Ankle International	1
Journal of Pediatric Orthopaedics	1
Orthopaedics & Traumatology – Surgery and Research	1
Indian Journal of Orthopaedics	1
Acta Orthopaedica Belgica	1
Acta Ortopedica Brasileira	1
Total = 26	68

greater impact on their patient demographic than those in HIC.

Possible reasons for this are the barriers faced by LIC in implementing research studies such as issues with funding, lack of expertise in conducting high level research or reluctance of journals to publish research from LIC. The lower publication rate from LIC could also be due to authors in this setting not being well informed about how to get published even in the context of higher quality research.

The Lancet report[23], “Global Surgery 2030: Evidence and solutions for achieving health, welfare and economic development”, highlights the need for financial support in helping LIC and LMIC achieve the surgical care to meet population demand. This also includes improving research capabilities in these countries to improve overall surgical care. We found in this study that research in HIV and orthopaedics coming from LIC was through collaborative efforts with HIC. The Lancet report also highlights the need to develop effective research collaborations to maximise the impact of research outcomes.

As well as funding, the capacity for LIC to be able to carry out high level research is hindered by the fact their physicians are required to serve a much greater population with fewer resources. World bank data[24] on the number of physicians per population show that a LIC such as Malawi has only 0.016 doctors per 1000 people (as of 2016), whereas a HIC like the United Kingdom has 2.806 doctors per 1000 people (as of 2017). This, combined with the fact the burden of trauma is greater in LIC[25], make high

Table 3 Countries of origin for articles on human immunodeficiency virus in the last 10 years

Publication country of origin	Number of articles (collaborations)
United States of America	34 (2)
United Kingdom	7 (3)
South Africa	6 (2)
Malawi	5 (5)
Ireland	4 (1)
Brazil	3 (0)
Cameroon	2 (0)
China	2 (0)
Germany	2 (0)
Norway	2 (2)
Australia	1 (1)
Canada	1 (1)
France	1 (0)
Italy	1 (0)
Japan	1 (1)
Netherlands	1 (0)
Nigeria	1 (0)
South Korea	1 (0)
Spain	1 (0)
Turkey	1 (0)

Table 4 Collaborative research by country of origin and economic status

HIC: HIC	HIC: UMIC	HIC: LIC
United States: Ireland	United Kingdom: South Africa	United Kingdom (+Australia): Malawi
United States: Japan	Germany: South Africa	United Kingdom: Malawi
United Kingdom: Australia (+Malawi)		Norway: Malawi
		Norway: Malawi
		Canada: Malawi

HIC: High-income countries; UMIC: Upper middle-income countries; LIC: Low-income countries.

orthopaedic research output in these settings difficult. This again highlights the need for greater collaborative effort in producing high evidence research between HIC with more resources and LIC, where exists the larger population of HIV positive patients.

Lastly, readers of journals are more likely to be from HIC settings due to access and availability of resources. This can result in a reluctance of journals wanting to publish research from LIC as it can often be less relevant to their target audience.

Limitations

A limitation of the study is the fact that our Web of Science database search methodology selected solely orthopaedic journals and therefore any articles in journals not listed on their database as an orthopaedic journal would not have been included in the search results. This includes any orthopaedic publication in non-orthopaedic journals, such as the *Lancet*, or in virology focused journals, such as the *Journal of Medical Virology*. Furthermore, in clinical practice and in literature in low-income countries, trauma and orthopaedics is often grouped with other surgical specialties and publications such as the *Tropical Doctor* and *East and Central African Journal of Surgery,* which are not included on the Web of Science database. This may have led to an underestimate of the number of orthopaedic research articles published on the topic of HIV.

CONCLUSION

People living with HIV are living longer and are becoming more prone to various musculoskeletal and orthopaedic complaints, as a result of both their treatment and age-related conditions. We have found that there is little research conducted looking at how HIV affects outcomes in orthopaedic surgery and that the research that is being done is preferentially carried out in HIC rather than LIC, where these problems are more prevalent. Current research tends to be of a low level of evidence. Collaborative research between LIC and HIC has proven to be a useful method for increasing research output in the LIC setting. This article highlights a greater need for high level of evidence research in this field to be carried out and done so in the LIC setting where it is of most benefit. One way this can be achieved is through more collaborative efforts with HIC.

ARTICLE HIGHLIGHTS

Research background

Human immunodeficiency virus (HIV) has become a chronic health problem with advances in treatment, and the chance of orthopaedic surgeons encountering it in clinical practice is increasing. It is also known that HIV may present with various musculoskeletal manifestations or treatment may result in a number of orthopaedic pathologies. There is little research in the current literature investigating how HIV effects outcomes in orthopaedic surgery.

Research motivation

The current literature highlighted a lack of research looking at the effects of HIV in trauma and orthopaedic surgery, particularly coming from geographic areas most in need of this evidence base for clinical practice. By highlighting this gap in the literature, it should pave the way for future research to be conducted in the appropriate setting to help improve outcomes in this patient cohort.

Research objectives

This study aimed to investigate the quantity and quality of peer-reviewed publications in orthopaedic journals about HIV.

Research methods

A bibliometric analysis was conducted using the ‘Clarivate Analytics’ Web of Science database. All articles in orthopaedic journals relating to HIV were identified. All relevant articles were analysed for the following information: journal title, year of publication, geographic location and country, level of evidence and number of citations. This is a novel research method for determining the volume and quality of publications about HIV in trauma and orthopaedic surgery.

Research results

Less than half of orthopaedic journals listed on the Web of Science database had articles published relating to HIV. Only 168 articles were identified in the literature, with only 40.5% (n = 68) published in the time frame analysed in the study (January 2007 to September 2017). These articles tended to be low level of evidence papers. The majority of research output came from high-income countries and any articles published from low-income countries were collaborations.

Research conclusions

The findings of this study show that there is a need for more research to be carried out on how HIV affects outcomes in orthopaedic and trauma surgery. This further research should be carried out in the area of greatest clinical need, particularly in low-income countries, where the burden of disease is higher. One way to achieve, as shown from the results of this study, is with greater collaborative research efforts between high-income and low-income countries.

Research perspectives

The direction of future research should be focused on larger scale clinical trials, including collaborative studies, investigating the effects of HIV in orthopaedic and trauma surgery to produce high level of evidence research, to improve clinical outcomes.

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