Archives of Osteoporosis (2025) 20:11
https://doi.org/10.1007/s11657-024-01482-4

ORIGINAL ARTICLE

Lee's TRIAD—osteoporosis, fragility fracture, and bone health optimization

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Received: 8 September 2024 / Accepted: 5 December 2024

Abstract

Summary Osteoporosis, fragility fractures, and bone health optimization share the same pathophysiology, diagnostic tools, risk assessment, and treatments. Grouping them into "Lee's TRIAD" allows surgeons and physicians to collaborate more efficiently, using unified principles and strategies for managing these conditions.

Purpose The primary goal of osteoporosis management is to prevent fragility fractures, which occur from falls from standing height or less in individuals over fifty. However, the management of bone health optimization is often neglected in patients undergoing elective surgeries, such as arthroplasty and spinal surgeries. The objective of this article is to link all these three conditions into a TRIAD so that surgeons and physicians can collaborate more effectively, utilizing similar principles and strategies for better management.

Methodology Clinical approaches based on country-specific guidelines are commonly used to manage osteoporosis. However, skeletal assessments are rarely conducted before or after elective procedures, leading to overlooked conditions such as osteoporosis, osteopenia, and fragility fracture risk factors. These three conditions are illustrated from the patient case study shown, to highlight the importance of not neglecting bone health optimization in high risk individuals undergoing elective surgery, with underlying osteopenia and multiple risk factors who sustained fragility fracture intraoperatively.

Result Patients undergoing elective surgeries often have their bone health neglected, leading to a higher incidence of complications such as aseptic loosening and peri-prosthetic fractures due to poor bone quality and density. Bone health assessment and optimization therefore is essential in patients with osteoporosis, osteopenia with clinical risk factors, and patients with history of fragility fracture, to ensure implants sit on bone with good density and quality to minimize the complications.

Conclusion By combining osteoporosis, fragility fractures, and bone health optimization into a TRIAD, "Lee's TRIAD," surgeons and physicians can collaborate more effectively, utilizing similar principles and strategies for better management.

Keywords Osteoporosis · Fragility fracture · Bone health optimization · Lee's TRIAD

Introduction

Osteoporosis is a systemic skeletal disorder characterized by diminished bone strength, which encompasses both bone density and bone quality. This condition predisposes individuals, particularly those over 50 years old, to an increased risk of fractures, commonly referred to as fragility fractures. A fragility fracture, often resulting from a fall from standing height or less, is the hallmark of osteoporosis and serves as a critical indicator of the disease's severity. However, the implications of osteoporosis extend beyond these fractures, influencing outcomes in elective orthopedic surgeries, such as hip and knee arthroplasties and spinal stabilization procedures.

Elective orthopedic patients, particularly those with osteoarthritis, frequently present with undiagnosed or untreated osteoporosis. The absence of proper skeletal assessment and bone health optimization before surgery can lead to suboptimal outcomes, including poor implant fixation, aseptic loosening, and periprosthetic fractures. These complications not only compromise the longevity of the implants but also significantly affect the patient's quality of life. Therefore, it is imperative that orthopedic surgeons adopt a comprehensive approach to bone health, integrating osteoporosis management, fragility fracture prevention, and bone health optimization into routine practice.

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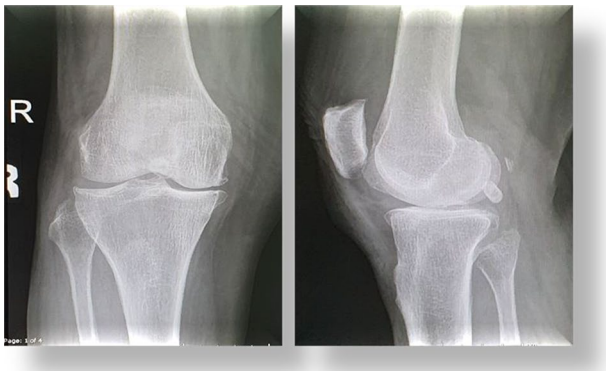
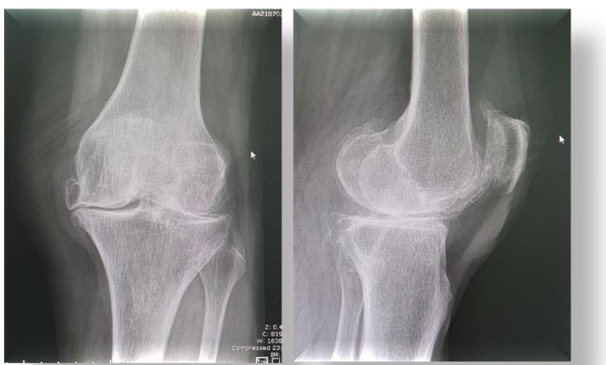
Published online: 23 January 2025

Patient case

Madam MYC, a 67-year-old woman with known rheumatoid arthritis, had been treated with DMARDs and prednisolone by her rheumatologist for many years. She presented with severe pain in both knees and was unable to bear weight. Her quality of life and functional status had significantly deteriorated, and she had been housebound for almost 6 months. X-rays of both knees were performed, revealing severe osteoarthritis with marked narrowing of the joint spaces. The X-rays also showed poor bone quality with thin cortical bone.



X ray Right knee

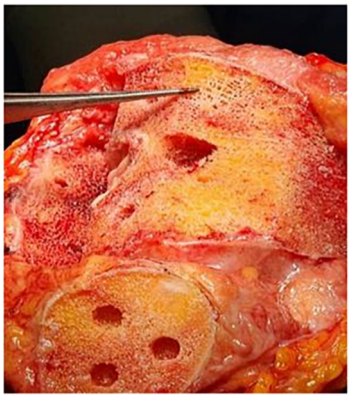


X Ray Left Knee

As part of the skeletal assessment before surgery, bone mineral density (DXA scan) was done on lumbar spine and left hip.

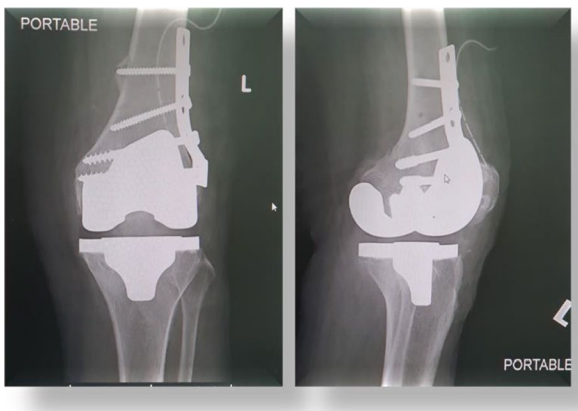
Her lumbar spine bone mineral density has a *T*-score of − 2.7 which was osteoporosis. The left hip bone mineral density has a *T*-score of − 2.1. Using FRAX with Malaysia reference (there are 3 different ethnic options for Malaysia), her 10-year hip fracture risk is 8–10% and her major fracture risk ranged from 19 to about 30%. According to Malaysian Osteoporosis Society Clinical Practice Guideline, anti-osteoporosis medication should be recommended when the 10-year hip fracture risk is 3% or above or major fracture risk is 20%.

Madam MYC underwent bilateral total knee replacement surgery. Intra-operatively, her bone quality was noted to be very poor (corresponded to the DXA result showing osteoporosis). During the preparation of the joints for implant insertion, minimal resistance was encountered while resecting the distal femur and proximal tibia.



Intraoperative findings of distal femur and patella

Right knee surgery was straight forward without any technical difficulty. Total knee replacement was done without any complication. While preparing the intercondylar notch of left femur for intramedullary guide, just with a light knock of the intercondylar notch with small osteotome, a crack propagating from the inter-condylar notch to lateral supracondylar was seen. Buttress plating with lag screw fixations on the inter-condylar fracture was done. Left total knee replacement was done following fracture fixation without difficulty.



X ray showed left total knee replacement with buttress plating fixation of the intercondylar fracture

Post-operatively, Madam MYC underwent the same rehabilitation program as any other patient who has undergone bilateral total knee replacement. She was able to bear weight immediately on both knees, initially walking with a frame for a short period of time, followed by using a single walking stick. She achieved a full range of movement within a month after her surgeries.

Madam MYC has multiple risk factors, including rheumatoid arthritis and a history of treatment with DMARDs and prednisolone. Her pre-operative DXA showed osteoporosis which correlate well with the intra-operative assessment, which revealed very poor bone quality. She sustained an intra-operative iatrogenic fracture of the distal femur even with a very light knock to the intercondylar region. This can be classified as a fragility fracture. Subcutaneous romosozumab 210 mg monthly was initiated before she was discharged from the ward. She completed the 1-year course of romosozumab and subsequently started long-term subcutaneous denosumab 60 mg. Her lumbar spine BMD showed a 9.3% increase, and her hip BMD increased by 4.2% after completing the romosozumab.

Osteoporosis: the silent epidemic

Osteoporosis is a systemic skeletal disease characterized by low bone mass and microarchitectural deterioration of bone tissue that leads to bone fragility and a consequent increase in fracture risk [1]. Osteoporosis is often referred to as a "silent epidemic" because it progresses without symptoms until a fracture occurs. The World Health Organization (WHO) defines osteoporosis based on bone mineral density (BMD) measurements obtained through dual-energy X-ray absorptiometry (DXA). A *T*-score of − 1 to − 2.5 is classified as osteopenia, indicating low bone mass, while a *T*-score of − 2.5 or lower signifies osteoporosis. When a fragility fracture is present in conjunction with a *T*-score of − 2.5 or lower, the condition is termed severe osteoporosis [2].

Diagnosis of osteoporosis based on WHO definition of *T*-score on DXA scan is well established. Bone mineral density (BMD) using dual-energy X-ray absorptiometry (DXA) is an important predictor for fragility fracture. However, the reliability of DXA results is very operator-dependent. Performing a quality DXA includes correct methods of acquisition and interpretation of the scans performed, with the region of interest (ROI) plotted correctly. There are many artifacts which can give rise to false negative or false positive results. Presence of facet joint arthritis, calcified aorta, and anterior compression fracture of vertebra give rise to false negative results.

Despite the reliance on BMD for diagnosis, it is essential to recognize that BMD alone does not fully capture fracture risk. Most fragility fractures occur in individuals with BMD values in the osteopenic range, highlighting that factors beyond bone density contribute to bone strength. Bone quality, which includes trabecular microarchitecture, the thickness of the vertical struts and horizontal plates, the connectivity of the trabeculae, cortical thickness, and bone turnover, plays a crucial role in determining bone strength and fracture risk.

The concepts of BMD and bone quality are well established, well understood, and widely accepted in the understanding of the pathogenesis, pathophysiology, and treatment of osteoporosis. All aspects of osteoporosis, including risk assessment, diagnosis, and treatment, are based on BMD and bone quality. FRAX, the tool used to predict the 10-year probability of hip fracture and major osteoporotic fractures, incorporates various clinical risk factors with or without femoral neck bone mineral density. FRAX Plus, the latest version of FRAX, further refines the clinical risk factors, such as glucocorticoid dose, the duration of diabetes mellitus, the recency of fragility fractures, hip axis length, lumbar spine BMD, and others.

Trabecular bone score (TBS) is a grey-level textural measurement usually obtained from conventional lumbar spine dual-energy X-ray absorptiometry (DXA) BMD images, providing a validated index of bone microarchitecture that correlates with the mechanical properties of bone [3–8]. TBS, which measures the degradation of bone, is used in some facilities to assess poor bone quality, particularly in patients with diabetes mellitus. The addition of TBS assessment to FRAX and/or BMD enhances fracture risk prediction in both primary and secondary osteoporosis, providing valuable information for treatment decision-making and monitoring [9].

Quantitative CT (QCT) scans using Hounsfield units (HU) are also used to diagnose osteoporosis. HU values can be determined for any region of interest using standard imaging software and strongly correlate with bone mineral density. A threshold of less than 135 HU for the L1 vertebral body indicates a risk for osteoporosis [10].

The advent of tools such as the trabecular bone score (TBS) and quantitative CT (QCT) has enhanced our ability to assess bone quality. TBS, derived from DXA images, provides an index of bone microarchitecture, offering insights into trabecular connectivity and structure. QCT, on the other hand, allows for three-dimensional assessment of bone density and quality, with Hounsfield units (HU) correlating strongly with BMD. These advancements enable a more nuanced assessment of fracture risk and guide therapeutic decisions, particularly in cases where BMD alone may not provide a complete picture.

Fragility fractures: a clinical and public health concern

Fragility fractures are defined as fractures sustained following a fall from standing height or less in individuals aged 50 years and above. Some fragility fractures occur without any injury, such as anterior compression fractures of the vertebrae, which can happen spontaneously.

Fragility fractures are a major clinical and public health concern, particularly in the aging population. The most common sites for fragility fractures include the hip, distal radius, proximal humerus, vertebrae, and pelvis. These fractures not only cause significant morbidity but also increase the risk of subsequent fractures, creating a cycle of worsening bone health and escalating fracture risk.

Distal radius fractures, often the first sign of underlying bone fragility, typically occur in individuals in their 50 s following a fall on an outstretched hand. While many of these fractures are treated conservatively with immobilization, some require surgical intervention, particularly when displacement is significant.

Vertebral compression fractures, which commonly occur in individuals in their 60 s, are often spontaneous and may result in chronic pain, loss of height, and kyphosis (Dowager's hump). These fractures are associated with a significant increase in morbidity and mortality, comparable to hip fractures.

Hip fractures, which predominantly affect individuals in their 70 s and 80 s, carry the highest mortality rate among fragility fractures, with first-year mortality rates approaching 25%. The complications arising from hip fractures, including immobilization, pneumonia, pressure ulcers, and urinary tract infections, contribute to this high mortality rate. Moreover, hip fractures often lead to permanent disability, with many patients requiring long-term use of walking aids or becoming homebound or bedbound.

Fractures involving the proximal humerus in the shoulder are also common following a fall on an outstretched hand or direct impact on the shoulder. Most proximal humerus fractures are treated conservatively. Some displaced fractures of the proximal humerus are surgically treated, either with plates and screws or through arthroplasty. Frequently, the range of motion in the shoulder is compromised following proximal humerus fractures.

Fractures involving the knee joint (distal femur and proximal tibia) or distal tibia (around the ankle) are also commonly seen. Distal femur fractures account for 4–6% of osteoporosis-related femur fractures in the elderly population. They are a significant cause of morbidity and mortality in geriatric patients, with a reported 1-year mortality rate reaching 30% [11]. Fractures around the knee joint often involve the intra-articular surfaces of the femur or tibia and require open reduction and internal fixation. Fractures around the ankle may disrupt the ankle mortise, leading to an unstable ankle, which also requires open reduction, internal fixation, and stabilization.

The concept that "fracture begets fracture" underscores the importance of early intervention in patients with fragility fractures. A first fracture significantly increases the risk of subsequent fractures, particularly within the first year. This phenomenon highlights the critical need for secondary fracture prevention strategies, which aim to reduce the risk of further fractures in individuals who have already sustained one.

Hip fractures are often considered the end result of a 30-year progression of multiple fragility fractures, beginning with distal radius fractures in the fifties, followed by vertebral or proximal humeral fractures in the sixties, and culminating in hip fractures in the eighties [12].

It is well documented that a first osteoporotic fracture significantly increases the risk of further fractures, with an overall increased risk of 86% for any fracture in patients who have already experienced a break [13]. Patients with multiple baseline fractures have a new fracture incidence of 17.3%, compared to 10.4% for those with one baseline fracture ($p = 0.007$) [14]. After a fragility fracture, a woman is five times more likely to suffer another fracture within 1 year, and her risk remains elevated over time if left untreated [15]. Compared to the risk of a first fracture, the relative risk of a subsequent fracture is highest in the first year after the initial fracture (RR 5.3; 95% CI 4.0–6.6) [15]. An incident fragility fracture is associated with an increased risk of a subsequent fracture occurring within 1–2 years [16]. Very high fracture risk (VHFxR) has long been recognized as an indication for osteoporosis pharmacotherapy [17].

Bone health optimization: a comprehensive approach

Bone health optimization (BHO) represents a paradigm shift in orthopedic practice, emphasizing the importance of optimizing bone health before, during, and after elective orthopedic surgeries such joint replacement and spinal stabilization and instrumentation surgeries. As a result of population aging and patient demand for improved mobility, it is projected that the number of total knee arthroplasty (TKA) and total hip arthroplasty (THA) procedures will increase by about 400% and 300% respectively by 2040 such that joint replacement will be the most common elective surgical procedure [18]. With the increasing demand for elective surgeries such as total knee arthroplasty (TKA), total hip arthroplasty (THA), and spinal

surgeries, there is a growing recognition of the need to address underlying bone health to improve surgical outcomes and implant longevity.

The average age of THA and TKA is in the 60 s [19]; it could be expected that osteoporosis would be common in patients undergoing these procedures. Consistent with this, in about 2000 largely female patients who obtained DXA the day prior to TKA, an osteoporosis prevalence of 50% was observed [20]. In a smaller cohort of patients scheduled for THA, osteoporosis was present in 18% and osteopenia in 41% [21].

TKA induces substantial distal femur bone loss of about 15% within 6 months postoperatively [22]. Additionally, falls are common in older adults osteoarthritis prior to and following arthroplasty with fall rates in the first year following TKA ranging up to 43% and 36% for THA [23].

Arthritis patients may become deconditioned due to pain and the resulting functional loss prior to arthroplasty surgery. This can lead to negative consequences on both bone mass and muscle strength, further increasing the risk of falls and fractures.

With the proper surgical approach, technique, and implant selection, joint replacement implants can last for more than 10 to 20 years. However, many patients experience implant loosening and failure earlier than expected. Periprosthetic fractures, which occur adjacent to the implant after a fall from standing height in individuals who have undergone joint replacement surgery, are also considered fragility fractures. Periprosthetic fractures and aseptic loosening are associated with very high morbidity and mortality. Revision surgeries for implant loosening and periprosthetic fractures present significant technical challenges, often leading to more bone loss, higher complication rates, and more difficult post-operative rehabilitation.

Bone health optimization (BHO), which involves improving bone density and quality before and/or after elective orthopedic surgery, is a clinical approach that should become the standard of care in orthopedic practice. Patients who present to orthopedic surgeons for elective procedures, such as those with severe knee and hip osteoarthritis, lumbar spinal spondylosis, or spondylolisthesis with spinal instability, often require elective arthroplasty of the knees and hips or spinal instrumentation and stabilization surgery. Bone health optimization aims to enhance the implant-bone interface by improving bone density and quality. Often, underlying osteoporosis or osteopenia with high fracture risk is neglected. As bone density and quality deteriorate over time, implants may not remain firmly and steadily seated in the bone. This can lead to aseptic loosening and periprosthetic fractures, resulting in a higher rate of revision surgeries as the longevity of implants is compromised due to poor bone density and quality.

Pre-operative skeletal assessment is a critical component of BHO. Patients scheduled for elective orthopedic surgeries should undergo thorough evaluation to identify those at risk for osteoporosis and fragility fractures. This assessment should include DXA, FRAX® scoring (a tool that estimates the 10-year probability of hip and major osteoporotic fractures), and, where available, TBS and QCT. Identifying patients with osteoporosis or osteopenia and associated clinical risk factors allows for timely intervention to improve bone quality before surgery. Treatment of underlying osteoporosis or osteopenia with clinical risk factors or preexisting fragility fracture is necessary to improve bone quality and density before elective surgery, provided that the elective surgery can be delayed and do not need immediate surgical intervention.

Intervention strategies in BHO include both pharmacological and non-pharmacological approaches. Pharmacological treatments, such as anabolic agents (e.g., teriparatide, romosozumab) and anti-resorptives (e.g., bisphosphonates, denosumab), are used to enhance bone formation and reduce bone resorption, respectively. In the pre-operative period, patients with diagnosed osteoporosis or high fracture risk should receive treatment with these agents to improve bone density and quality. For patients with severe arthritis or spinal conditions where surgery cannot be delayed, surgery should be carried out with extra care to avoid intra-operative iatrogenic fracture. Post-operatively, they should undergo post-operative bone health optimization. Pharmacological treatment should be instituted to treat the underlying osteoporosis.

Intra-operative care is equally important in BHO. Surgeons must take extra care in handling bones during surgery, particularly in patients with poor bone quality. The selection of implants should be tailored to the patient's bone health status, with cemented implants often preferred in those with severe osteoporosis to provide primary stability and facilitate early weight-bearing. Augmentation techniques, such as cementing or bone grafting, may also be employed to improve the implant-bone interface.

In some patients who have undergone elective arthroplasty or spinal surgeries, pre-operative skeletal assessment does not review osteoporosis or osteopenia with clinical risk factors. However, intra-operative findings have revealed poor bone quality and density, with minimal resistance to instrumentation or poor purchase of the bone-implant interface. These patients should receive bone health optimization to improve the underlying bone quality and density.

Post-operative management is a continuation of BHO, with ongoing pharmacological treatment and monitoring of bone health. Patients who have received pre-operative treatment should continue the same regimen post-operatively, while those identified intra-operatively as having poor bone

quality should be initiated on appropriate therapy. Post-operative follow-up should include re-assessment of fracture risk and adjustment of treatment as needed to ensure long-term bone health. Therefore, bone health optimization (BHO) is not limited to pre-operative assessment and intervention alone as what was reported in many other studies. It encompasses more, at three different stages, pre-operative, intra-operative, and post-operative. The process of BHO includes identification, investigations, and intervention before, during, and after surgery.

Clinical practice guidelines recommend 1–2 years of osteoanabolic therapy (e.g., 12 months of romosozumab or 18–24 months of teriparatide or abaloparatide) to rapidly increase bone mass and reduce fracture risk. The resulting BMD gains should be consolidated (i.e., preserved or further increased) by follow-on therapy with potent antiresorptives such as amino-bisphosphonates (BPs, e.g., alendronate or zoledronic acid) or denosumab (DMAb) [24].

Fracture risk should be re-evaluated thereafter to determine the need for continued therapy; if fracture risk remains high, consider additional treatment with potent anti-resorptives or re-treat with osteoanabolics. If fracture risk is sufficiently reduced, bisphosphonate therapy may be stopped or temporarily suspended, though discontinuation of denosumab without another follow-on therapy (e.g., bisphosphonate or romosozumab) leads to rapid bone loss and an increased risk of vertebral fractures [24].

Lee's TRIAD: integrating osteoporosis, fragility fractures, and BHO

The TRIAD concept, which integrates osteoporosis, fragility fractures, and bone health optimization, offers a holistic approach to managing patients at risk for poor bone health outcomes. By addressing these three interconnected aspects of bone health, orthopedic surgeons can improve surgical outcomes, reduce the incidence of revision surgeries, and enhance the overall quality of life for their patients.

Osteoporosis, fragility fractures, and bone health optimization are interrelated based on the principles of bone density and quality deterioration, leading to fragile bones that break easily with minimal trauma or even without significant injury. Patients undergoing elective surgeries, such as total knee and total hip arthroplasty or spinal instrumentation, might already suffer from underlying osteoporosis or osteopenia with clinical risk factors. Therefore, these patients warrant a thorough approach, including proper skeletal assessment and pharmacological intervention before and/or after surgery.

The basic principles of bone health optimization (BHO) management are similar to those for managing osteoporosis and fragility fractures. Most clinical guidelines worldwide categorize patients into low risk, high risk, and very high-risk categories. Anti-resorptive agents, such as denosumab and bisphosphonates, are recommended as the first line of treatment for the high-risk category. Anabolic agents, such as romosozumab and teriparatide, are recommended as the first line of treatment for the very high-risk category. This paradigm shift towards using anabolic agents as the first line of treatment for very high-risk patients has been well accepted worldwide. After completing treatment with an anabolic agent, sequential therapy with an anti-resorptive agent is recommended.

Treatment with anabolic agents first provides faster and greater gains in bone mineral density compared to starting with anti-resorptive agents. The sequence of using anabolic agents followed by anti-resorptive agents also results in better changes in bone mineral density than using anti-resorptive agents first. Anti-resorptive agents suppress bone turnover, and starting with them before switching to anabolic agents provides a slower response to the anabolic treatment. There is a window period where bone mineral density changes can be observed after transitioning from anti-resorptive agents to anabolic agents.

Osteoanabolics are increasingly used as the first-line treatment for patients with very high fracture risk (VHFxR) because they are superior to anti-resorptives for rapidly increasing bone mineral density and reducing fracture risk [25–28]. They also produce greater BMD gains when used before rather than after anti-resorptives [29]. Potent anti-resorptive agents, such as denosumab (an anti-RANKL antibody) and zoledronic acid (an intravenous bisphosphonate), are also recommended options for patients with VHFxR [30].

The same principles, identification, investigation, and interventions using pharmacological agents apply to the management of osteoporosis, fragility fractures, and bone health optimization. Bone health optimization (BHO) is not a new concept but reinforces what should be done in daily orthopedic practice for patients presenting for elective surgeries, including those who have not been diagnosed with osteoporosis, those diagnosed but untreated, and those who do not have fragility fracture. They present to us with elective orthopedic conditions and planned for elective surgeries.

Key components of Lee's TRIAD

1. Osteoporosis: Recognize and treat osteoporosis in all patients undergoing elective orthopedic surgeries. Use DXA, FRAX®, TBS, and QCT to assess bone health and identify those at risk. This depends on the availability and accessibility of the methods of skeletal assessment. It also depends on the local clinical practice guideline.

2. Fragility fractures: Implement secondary fracture prevention strategies in patients with a history of fragility fractures. Early intervention is crucial to prevent subsequent fractures, particularly within the first year. Patients with history of fragility fractures warrant special care to assess their skeletal health and receive appropriate anti-osteoporosis therapy either pre or post-surgery.
3. Bone health optimization: Incorporate BHO into routine orthopedic practice and should be the standard of care in our daily orthopedic practice. Optimize bone health before, during, and after surgery to improve implant stability and reduce the risk of complications such as aseptic loosening and periprosthetic fractures.

Key practice points for orthopedic surgeons

1. Routine skeletal assessment: Ensure that all patients scheduled for elective orthopedic surgeries undergo comprehensive skeletal assessments, including DXA, FRAX® scoring, and TBS or QCT where available.
2. Early pharmacological intervention: Initiate pharmacological treatment in patients diagnosed with osteoporosis or those at high fracture risk. Use anabolic agents or anti-resorptives to improve bone density and quality before surgery.
3. Intra-operative care: Select appropriate implants based on the patient's bone health status, considering cemented implants and augmentation techniques in those with poor bone quality to enhance implant stability.
4. Post-operative monitoring and treatment: Continue pharmacological treatment post-operatively and reassess fracture risk regularly. Adjust treatment regimens based on the patient's response and ongoing fracture risk.
5. Patient education and counseling: Educate patients about the importance of bone health and the risks associated with osteoporosis, particularly in the context of elective orthopedic surgeries. Encourage adherence to prescribed treatment regimens and lifestyle modifications.
6. Interdisciplinary collaboration: Collaborate with endocrinologists, geriatricians, and fracture liaison services to provide comprehensive care for patients with osteoporosis and fragility fractures. Interdisciplinary management ensures that all aspects of bone health are addressed, leading to better outcomes.

Conclusion

Osteoporosis is a prevalent and often underdiagnosed condition that significantly impacts the outcomes of elective orthopedic surgeries. The Lee's TRIAD approach—combining osteoporosis management, fragility fracture prevention, and bone health optimization—provides a comprehensive strategy to improve patient outcomes. By integrating these three components into routine practice, orthopedic surgeons can enhance the quality of care for their patients, reduce the incidence of surgical complications, and ultimately improve the long-term success of orthopedic interventions.

Declarations

Conflicts of interest None.

References

1. Consensus development conference (1991) prophylaxis and treatment of osteoporosis. Am J Med 90:107–110
2. (2003) Prevention and management of osteoporosis: report of a WHO scientific group. World Health Organization
3. Pothuaud L, Carceller P, Hans D (2008) Correlations between grey-level variations in 2D projection images (TBS) and 3D microarchitecture: applications in the study of human trabecular bone microarchitecture. Bone 42(4):775–787
4. Pothuaud L, Barthe N, Krieg MA, Mehsen N, Carceller P, Hans D (2009) Evaluation of the potential use of trabecular bone score to complement bone mineral density in the diagnosis of osteoporosis: a preliminary spine bmd–matched, case-control study. J Clin Densitom 12(2):170–176
5. Hans D, Barthe N, Boutroy S, Pothuaud L, Winzenrieth R, Krieg MA (2011) Correlations between trabecular bone score, measured using anteroposterior dual-energy X-ray absorptiometry acquisition, and 3-dimensional parameters of bone microarchitecture: an experimental study on human cadaver vertebrae. J Clin Densitom 14(3):302–312
6. Winzenrieth R, Michelet F, Hans D (2013) Three-dimensional (3D) microarchitecture correlations with 2D projection image gray-level variations assessed by trabecular bone score using high-resolution computed tomographic acquisitions: effects of resolution and noise. J Clin Densitom 16(3):287–296
7. Muschitz C, Kocijan R, Haschka J, Pahr D, Kaider A, Pietschmann P, Hans D, Muschitz GK, Fahrleitner-Pammer A, Resch H (2015) TBS reflects trabecular microarchitecture in premenopausal women and men with idiopathic osteoporosis and low-traumatic fractures. Bone 79:259–266
8. Ramalho J, Marques IDB, Hans D, Dempster D, Zhou H, Patel P, Pereira RMR, Jorgetti V, Moyses RMA, Nickolas TL (2018) The trabecular bone score: relationships with trabecular and cortical microarchitecture measured by HR-pQCT and histomorphometry in patients with chronic kidney disease. Bone 116:215–220
9. Shevroja E (2023) Update on the clinical use of trabecular bone score (TBS) in the management of osteoporosis: results of an expert group meeting organized by the European Society for Clinical and Economic Aspects of Osteoporosis, Osteoarthritis and Musculoskeletal Diseases (ESCEO), and the International Osteoporosis Foundation (IOF) under the auspices of WHO Collaborating Center for Epidemiology of Musculoskeletal Health and Aging. Osteoporos Int 34:1501–1529. https://doi.org/10.1007/s00198-023-06817-4
10. Anderson PA et al (2018) Clinical use of opportunistic computed tomography screening for osteoporosis. J Bone Joint Surg 100(23):2073–2081. https://doi.org/10.2106/JBJS.17.01376
11. Canton G et al (2019) Osteoporotic distal femur fractures in the elderly: peculiarities and treatment strategies. Acta Biomed

90(Supplement 12):25–32. https://doi.org/10.23750/abm.v90i12-S.8958
12. Mitchell PJ (2009) Fracture liaison services: a systematic approach to secondary fracture prevention. Osteoporosis Review 17(1):14–16
13. Siris ES et al (2007) Enhanced prediction of fracture risk combining vertebral fracture status and BMD. Osteoporos Int 18(6):761–770
14. van Helden S et al (2006) Risk of new clinical fractures within 2 years following a fracture. Int 17(3):348–354
15. van Geel TACM et al (2009) Clinical subsequent fractures cluster in time after first fracture. Ann Rheum Dis 68(1):99–102
16. Adachi JD et al (2021) Fragility fracture identifies patients at imminent risk for subsequent fracture: real-world retrospective database study in Ontario Canada. BMC Musculoskeletal Disord 22:224
17. Kanis JA, Borgstrom F, De Laet C et al (2005) Assessment of fracture risk. Osteoporos Int 16:581–589
18. Singh JA, Yu S, Chen L, Cleveland JD (2019) Rates of total joint replacement in the United States: future projections to 2020–2040 using the national inpatient sample. J Rheumatol 46:1134–1140
19. Fang M, Noiseux N, Linson E, Cram P (2015) The effect of advancing age on total joint replacement outcomes. Geriatr Orthop Surg Rehabil 6:173–179
20. Ha CW, Park YB (2020) Underestimation and undertreatment of osteoporosis in patients awaiting primary total knee arthroplasty. Arch Orthop Trauma Surg 140:1109–1114
21. Delsmann MM, Strahl A, Mühlenfeld M, Jandl NM, Beil FT, Ries C, Rolvien T (2021) High prevalence and undertreatment of osteoporosis in elderly patients undergoing total hip arthroplasty. Osteoporos Int 32:1661–1668
22. Prince JM, Bernatz JT, Binkley N, Abdel MP, Anderson PA (2019) Changes in femoral bone mineral density after total knee arthroplasty: a systematic review and meta-analysis. Arch Osteoporos 14:23
23. Lo CWT, Tsang WWN, Yan CH, Lord SR, Hill KD, Wong AYL (2019) Risk factors for falls in patients with total hip arthroplasty and total knee arthroplasty: a systematic review and meta-analysis. Osteoarthr Cartil 27:979–993
24. Curtis EM, Reginster JY, Al-Daghri N et al (2022) Management of patients at very high risk of osteoporotic fractures through sequential treatments. Aging Clin Exp Res 34:695–714
25. Kendler DL, Marin F, Zerbini CAF et al (2018) Effects of teriparatide and risedronate on new fractures in post-menopausal women with severe osteoporosis (VERO): a multicentre, double blind, double-dummy, randomised controlled trial. Lancet 391:230–240
26. Miller PD, Hattersley G, Riis BJ et al (2016) Effect of abaloparatide vs placebo on new vertebral fractures in postmenopausal women with osteoporosis: a randomized clinical trial. JAMA 316:722–733
27. Leder BZ, Mitlak B, Hu MY, Hattersley G, Bockman RS (2020) Effect of abaloparatide vs alendronate on fracture risk reduction in postmenopausal women with osteoporosis. J Clin Endocrinol Metab 105:938–943
28. Saag KG, Petersen J, Brandi ML et al (2017) Romosozumab or alendronate for fracture prevention in women with osteoporosis. N Engl J Med 377:1417–1427
29. Cosman F (2019) The evolving role of anabolic therapy in the treatment of osteoporosis. Curr Opin Rheumatol. 31:376–80 (Explains rationale for earlier rather than "last resort" use of osteoanabolics in patients with high fracture risk; identifiespatients for whom first-line osteoanabolic therapy maybe appropriate)
30. Camacho PM, Petak SM, Binkley N et al (2020) American Association of Clinical Endocrinologists/American College of Endocrinology clinical practice guidelines for the diagnosis and treatment of postmenopausal osteoporosis-2020 update. Endocr Pract. 26:1–46 (Highly regarded osteoporosis CPGs with updated criteria for very high fracture risk and use of osteoanabolic agents)