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The Aging Spine Surgical Host: Frailty, Sarcopenia, Osteoporosis, and Risk Stratification in Contemporary Spine Surgery

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Abstract: ***Older adults are increasingly offered decompression, fusion, deformity correction, and vertebral fracture procedures, yet chronological age alone is an inadequate measure of operative risk. Frailty, sarcopenia, and osteoporosis represent overlapping but distinct domains of diminished physiologic reserve, impaired muscle function, and compromised bone strength. Each domain is common in spine-surgery candidates and has been associated with adverse perioperative events, prolonged hospitalization, non-home discharge, delayed functional recovery, mechanical complications, and revision surgery. This narrative review summarizes contemporary evidence on frailty, sarcopenia, and osteoporosis in adult spine surgery and proposes a practical perioperative risk-stratification framework for clinical use. Frailty should be considered a multidimensional vulnerability state rather than a synonym for advanced age. Sarcopenia should be screened with functional tools and confirmed with muscle quantity or quality assessment when possible, with attention to Asian diagnostic criteria. Osteoporosis and osteopenia require active preoperative detection because poor bone health increases the risk of screw loosening, cage subsidence, pseudarthrosis, proximal junctional failure, adjacent fracture, and reoperation. Current evidence supports routine screening in at-risk patients, optimization of nutrition and physical function, correction of vitamin D deficiency, and consideration of bone-active therapy before major reconstructive procedures. We propose an Aging Spine Surgical Host framework that integrates frailty, sarcopenia, osteoporosis, nutrition, cognition, mobility, and surgical magnitude into four actionable grades: robust, vulnerable, high-risk, and prohibitive or modifiable high-risk. This framework is intended to improve shared decision-making, trigger prehabilitation and bone-health optimization, and help surgeons select the least morbid durable procedure. Prospective validation is required before formal prognostic use.***

Keywords: Spine; Frailty; Sarcopenia; Osteoporosis; Risk assessment

1. Key Points

- Chronological age alone is an imprecise risk marker for adult spine surgery; physiologic reserve, muscle function, and bone health should be assessed directly.
- Frailty predicts adverse clinical outcomes after degenerative and deformity spine surgery, but frailty does not automatically preclude meaningful postoperative improvement.
- Sarcopenia adds functional and biological information beyond body mass index and is particularly relevant in vertebral augmentation, lumbar degenerative disease, and prolonged recovery.
- Osteoporosis should be actively screened before instrumented fusion because poor bone quality is linked to mechanical failure, pseudarthrosis, junctional complications, and revision surgery.
- The proposed Aging Spine Surgical Host framework is a practical, hypothesis-generating tool for preoperative optimization and shared surgical decision-making.

2. Introduction

The population presenting for adult spine surgery is aging, and the operative indications increasingly include combinations of degenerative stenosis, deformity, osteoporotic vertebral fracture, revision disease, instability, and cervical or thoracolumbar myelopathy. Traditional risk assessment in this group frequently emphasizes age, American Society of Anesthesiologists grade, diagnosis, and operative magnitude. These variables are useful, but they do not adequately capture the biological heterogeneity between two patients of the same chronological age. One patient may be independent, nutritionally replete, physically active, and mechanically suitable for durable fixation; another may be functionally dependent, sarcopenic, osteoporotic, cognitively vulnerable, and unable to tolerate the same surgical stress.

Frailty, sarcopenia, and osteoporosis provide a more clinically useful language for this heterogeneity. Frailty is a state of diminished physiologic reserve and vulnerability to adverse outcomes [1]. It can be conceptualized as a physical phenotype, a cumulative deficit state, or a global clinical impression [2-6]. Sarcopenia is defined by low muscle strength with confirmation by low muscle quantity or quality, and severe sarcopenia includes poor physical performance [7]. Asian Working Group for Sarcopenia criteria are particularly relevant in Asian populations because body habitus and muscle-mass thresholds differ from Western cohorts [8]. Osteoporosis, osteopenia, vitamin D deficiency, and poor trabecular quality affect the mechanical and biological foundation required for spinal instrumentation and fusion [9-11].

The purpose of this narrative review is to synthesize current evidence on these three domains in spine surgery and to propose a practical risk-stratification framework for the aging spine surgical host. The framework is not intended to replace validated prediction models. Rather, it is designed to structure preoperative assessment, guide optimization, and support shared decision-making.

3. Review Methodology

A targeted narrative review was performed using PubMed, Google Scholar, and journal-specific searches through June 2026. Search concepts included spine surgery, frailty, modified frailty index, Adult Spinal Deformity Frailty Index, sarcopenia, psoas muscle area, paraspinal muscle degeneration, osteoporosis, Hounsfield units, vitamin D, teriparatide, vertebral augmentation, adult spinal deformity, lumbar fusion, cervical fusion, prehabilitation, and bone health optimization. Priority was given to systematic reviews, meta-analyses, clinical practice guidelines, consensus statements, and spine-specific cohort studies. The review was not registered and did not use a formal systematic-review protocol; therefore, quantitative pooling was not attempted. Because this article is a narrative review of published literature, ethics approval and informed consent were not required.

Conceptual distinction: frailty, sarcopenia, and osteoporosis

Frailty, sarcopenia, and osteoporosis are related but not interchangeable. Frailty describes global vulnerability to physiologic stress. It reflects deficits across comorbidity, mobility, cognition, nutrition, function, and social support. Sarcopenia describes impaired muscle strength and muscle quantity or quality. It can exist in patients who are not underweight and may be missed when body mass index is used as a proxy for nutritional or functional reserve. Osteoporosis describes compromised bone strength and microarchitecture, with direct implications for pedicle screw fixation, interbody support, arthrodesis biology, and junctional failure.

These conditions often cluster. Reduced physical activity and endocrine changes contribute to muscle and bone loss; muscle-bone crosstalk links muscle quality with skeletal metabolism [9]. Pain, deformity, and neurologic compromise further accelerate inactivity, falls, deconditioning, and loss of independence. For the spine surgeon, the key clinical point is that each domain has different consequences and different modifiable components. A frail patient may need geriatric co-management and delirium prevention; a sarcopenic patient may need resistance training and protein optimization; an osteoporotic patient may need bone-active therapy and fixation modifications.

Frailty in Spine Surgery

Frailty has become one of the most consistent preoperative predictors of adverse outcomes in spine surgery. A 2021 systematic review concluded that frailty adversely affects outcomes after spine surgery [12]. A subsequent systematic review and meta-analysis in degenerative spine surgery included 38 studies and 474,651 patients and found that frailty was associated with higher mortality, major complications, acute renal failure, myocardial infarction, reintubation, non-home discharge, and longer hospital stay [13]. Importantly, changes in Oswestry Disability Index were not consistently associated with frailty, suggesting that frail patients may still experience symptomatic improvement even while facing higher perioperative risk [13].

Frailty instruments used in spine literature include the modified frailty index, 5-item modified frailty index, Clinical Frailty Scale, and Adult Spinal Deformity Frailty Index. The Adult Spinal Deformity Frailty Index has been externally validated in the Scoli-RISK-1 database and was associated with longer hospital stay and major complications [14]. The modified frailty index has also been studied in cervical fusion, lumbar fusion, and anterior lumbar interbody fusion cohorts [15-17].

The practical implication is not that frailty should be used to deny surgery. Rather, frailty should trigger a different perioperative pathway. This includes more detailed counseling, realistic expectation setting, discussion of nonoperative options, prehabilitation when surgery is elective, geriatric or anesthetic optimization, postoperative delirium prevention, early mobilization, and discharge planning before admission.

Sarcopenia in spine surgery

Sarcopenia adds an important muscle-specific dimension to risk assessment. The EWGSOP2 framework emphasizes low muscle strength as the primary screening feature and uses low muscle quantity or quality to confirm diagnosis [7]. AWGS 2019 provides Asian-relevant thresholds, including handgrip strength, gait speed, chair-stand performance, calf circumference, and appendicular skeletal muscle mass [8]. In spine practice, sarcopenia has also been estimated from psoas or paraspinal muscle area and fatty infiltration on computed tomography or magnetic resonance imaging. These imaging measures are attractive because spine patients frequently already have cross-sectional imaging, but thresholds vary by level, sex, ethnicity, and measurement technique.

A 2024 systematic review and meta-analysis reported increased risks of adverse events and mortality after spine surgery in patients with sarcopenia, while cautioning that included studies were heterogeneous [18]. An updated meta-analysis in degenerative lumbar surgery reported worse functional and quality-of-life outcomes and longer hospitalization among sarcopenic patients [19]. In osteoporotic vertebral compression fracture patients undergoing vertebral augmentation, an Asian Spine Journal meta-analysis found sarcopenia associated with worse post-procedure outcomes, supporting early recognition and comprehensive management [20]. Sarcopenia has also been associated with degenerative lumbar stenosis, low back pain, and broader orthopedic postoperative outcomes [21-24].

Sarcopenia is especially relevant in lumbar stenosis, sagittal imbalance, vertebral fracture, and revision surgery. Low extensor strength and paraspinal fatty degeneration may impair postoperative rehabilitation, worsen compensatory capacity, and increase fall risk. Screening should therefore include a functional measure such as grip strength, gait speed, 5-time chair stand, SARC-F, or SARC-CalF, supplemented by imaging-derived muscle assessment when available.

Osteoporosis, Bone Quality, and Mechanical Failure

Bone health is the mechanical substrate of instrumented spine surgery. Osteoporosis and osteopenia are associated with screw loosening, cage subsidence, proximal junctional kyphosis or failure, adjacent vertebral fracture,

pseudarthrosis, and reoperation. A 2024 systematic review concluded that osteoporosis is a significant risk factor for mechanical complications after lumbar fusion [25]. Bone health is also central to adult spinal deformity, where long constructs, large corrective forces, and junctional transitions magnify the consequences of poor skeletal quality [26].

Preoperative assessment should not rely solely on clinical impression. The Congress of Neurological Surgeons guideline states that a dual-energy X-ray absorptiometry T-score less than -2.5, computed tomography Hounsfield units less than 97.9, or serum vitamin D3 level less than 20 ng/mL predicts increased risk of postoperative adverse events after spinal instrumentation [11]. Best-practice guidance for elective spinal reconstruction recommends formal bone-health evaluation in patients older than 65 years and in younger patients with risk factors, and supports medical treatment of poor bone health before elective reconstruction [10].

DEXA remains widely used but may be falsely reassuring in lumbar degenerative disease because osteophytes, sclerosis, aortic calcification, and prior instrumentation can elevate apparent lumbar bone mineral density. Opportunistic CT-based Hounsfield unit assessment can complement DEXA, especially when preoperative CT is already available [30,31]. In major reconstruction, low bone quality should influence not only medication but also surgical plan: fixation density, pelvic fixation, cement augmentation, screw trajectory, interbody choice, upper-instrumented vertebra selection, alignment goals, transition strategies, and postoperative bracing or surveillance.

Proposed Aging Spine Surgical Host framework

We propose an Aging Spine Surgical Host framework that integrates frailty, sarcopenia, osteoporosis, nutrition, cognition, mobility, falls, and surgical magnitude. The framework has four grades. Grade 0 represents a robust host with preserved function, no sarcopenia, and acceptable bone quality. Grade 1 represents a vulnerable host with isolated or mild deficits, such as prefrailty, osteopenia, low vitamin D, or possible sarcopenia. Grade 2 represents a high-risk host with established frailty, confirmed sarcopenia, osteoporosis, impaired nutrition, limited mobility, recurrent falls, or planned major reconstruction. Grade 3 represents prohibitive or modifiable high risk, such as severe frailty, severe sarcopenia, untreated osteoporosis in a long fusion candidate, cognitive vulnerability with poor social support, active malnutrition, or multiple concurrent deficits.

This grading system is intended to be practical rather than numerically complex. It does not create a new validated score. Instead, it offers a checklist-driven phenotype that can be documented at the preoperative visit and linked to specific actions. Grade 1 should trigger focused optimization without necessarily delaying surgery. Grade 2 should prompt multidisciplinary optimization and possible modification of surgical magnitude. Grade 3 should prompt reconsideration of indication, staging, less invasive alternatives, delay of elective reconstruction when neurologically safe, or palliative goal-directed surgery.

Optimization and Surgical Decision-Making

Optimization should be domain-specific. Frailty optimization includes medication review, anemia correction, glycemic control, cardiopulmonary optimization, cognitive screening, delirium prevention, shared decision-making, and discharge planning. Sarcopenia optimization includes resistance training, gait and balance work, adequate protein intake, vitamin D repletion, and treatment of reversible contributors such as endocrine disease, chronic inflammation, and prolonged immobilization. Multimodal prehabilitation programs commonly combine exercise, nutritional enhancement, psychological support, and education [34].

Bone-health optimization should begin as early as possible in elective reconstruction. Patients with osteoporosis, osteopenia plus risk factors, low CT Hounsfield units, vitamin D deficiency, fragility fracture, chronic steroid exposure, inflammatory disease, or planned long fusion should undergo formal assessment and treatment. When no contraindication exists, anabolic therapy may be considered in high-risk reconstruction candidates; evidence supports improved fusion biology and lower implant-related complications in selected osteoporotic patients [10,11,32,33]. Antiresorptive therapy remains important for long-term fracture prevention and may be used when anabolic therapy is unavailable or contraindicated.

The operative strategy should match host biology. In a robust patient, standard decompression or reconstruction may be appropriate. In a vulnerable host, the surgeon should consider limiting operative time, blood loss, and fusion length where possible. In a high-risk osteoporotic host, techniques such as cement augmentation, cortical bone trajectory, larger or longer screws, multi-rod constructs, pelvic fixation, hooks, junctional tethers, careful upper-instrumented vertebra selection, and avoidance of overcorrection may reduce mechanical risk. In a frail or sarcopenic host, minimally invasive decompression, staged surgery, or symptom-targeted rather than radiographic-perfect surgery may offer a better balance between benefit and harm.

Implementation in routine practice

A practical clinic workflow should be brief enough to use before every elective operation and detailed enough to identify modifiable risk. We recommend a three-step process. First, screen all patients older than 65 years and younger patients with risk factors using a frailty tool, sarcopenia screen, and bone-health screen. Second, classify the patient into an Aging Spine Surgical Host grade and document the main drivers of risk. Third, link the grade to a pathway: standard care, focused optimization, multidisciplinary optimization with surgical modification, or reconsideration of indication and timing.

This workflow should be embedded into spine clinic templates, pre-anesthesia assessment, and multidisciplinary conferences. For high-risk patients, the risk discussion should be explicit and documented: expected benefit, alternatives, risk of nonoperative management, risk of neurologic deterioration, likelihood of non-home discharge, need for rehabilitation, and mechanical failure risk. The framework may also support research by standardizing host phenotype in registries and prospective studies.

4. Limitations

This article is a narrative review and proposed framework rather than a systematic review or validated prediction model. The literature is limited by heterogeneous definitions of frailty and sarcopenia, inconsistent imaging thresholds, differences between cervical, lumbar, deformity, fracture, and tumor populations, and variable reporting of patient-reported outcomes. Many studies are retrospective and vulnerable to selection bias because the frailest patients may never be offered surgery. In addition, most risk tools are better at predicting population-level risk than individual patient outcomes. The proposed Aging Spine Surgical Host grades therefore require prospective validation for interobserver reliability, calibration, discrimination, and responsiveness to optimization.

5. Conclusions

Frailty, sarcopenia, and osteoporosis are central determinants of risk in contemporary adult spine surgery. They represent different but overlapping vulnerabilities: reduced physiologic reserve, impaired muscle function, and compromised bone strength. Routine screening for these domains can improve preoperative counseling, identify modifiable risk, guide surgical planning, and reduce avoidable mechanical and medical complications. The proposed Aging Spine Surgical Host framework provides a practical structure for integrating these variables into decision-making. Future multicenter studies should validate this framework against complications, discharge disposition, mechanical failure, reoperation, patient-reported outcomes, and cost of care.

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Tables

Table 1: Definitions and practical screening tools for the aging spine surgical host

Domain	Core meaning	Practical screening options	Spine-surgery relevance
Frailty	Reduced physiologic reserve and increased vulnerability to stressors.	Clinical Frailty Scale; modified frailty index; 5-item modified frailty index; Adult Spinal Deformity Frailty Index for deformity cohorts.	Complications, mortality, non-home discharge, longer stay, delirium risk, slower rehabilitation.
Sarcopenia	Low muscle strength with low muscle quantity or quality; severe disease includes poor physical performance.	SARC-F or SARC-CalF; handgrip strength; gait speed; 5-time chair stand; calf circumference; CT/MRI psoas or paraspinal muscle assessment.	Poor functional recovery, fall risk, worse lumbar outcomes, vertebral refracture risk, prolonged hospitalization.
Osteoporosis / poor bone health	Reduced bone mineral density and impaired bone quality affecting fixation and fusion biology.	DEXA; opportunistic CT Hounsfield units; quantitative CT where available; vitamin D; calcium/phosphate/parathyroid/endocrine evaluation when indicated.	Screw loosening, cage subsidence, pseudarthrosis, proximal junctional failure, adjacent fracture, revision surgery.
Nutrition and inflammation	Insufficient substrate for healing, immune function, and muscle recovery.	Albumin/prealbumin where used; total lymphocyte count; body-weight loss; dietician assessment; vitamin D; anemia and inflammatory disease screen.	Wound complications, infection, delayed rehabilitation, impaired fusion biology.
Cognition, mobility, and support	Ability to understand goals, participate in rehabilitation, and safely recover after discharge.	Falls history; gait aid use; Activities of Daily Living; Mini-Cog or equivalent; home support; rehabilitation access.	Delirium, discharge destination, readmission, falls, implant or fracture complications.

Table 2: Spine-surgery consequences of frailty, sarcopenia, and osteoporosis

Risk domain	Medical complications	Functional consequences	Mechanical / surgical consequences
Frailty	Higher risk of mortality, major complications, renal failure, cardiac events, reintubation, and delirium.	Longer length of stay, non-home discharge, slower return to independence.	May require less invasive operation, staging, or goal-directed symptom relief rather than maximal correction.
Sarcopenia	Higher adverse-event and mortality risk in pooled spine-surgery literature.	Reduced walking endurance, weaker compensatory mechanisms, worse rehabilitation tolerance, recurrent falls.	Possible higher vertebral refracture risk after augmentation and poorer recovery after lumbar surgery.
Osteoporosis	Fragility fracture burden and complications related to immobilization.	Pain recurrence, loss of independence, bracing intolerance, fear of falling.	Screw loosening, cage subsidence, junctional failure, adjacent fracture, pseudarthrosis, reoperation.

Risk domain	Medical complications	Functional consequences	Mechanical / surgical consequences
Combined phenotype	Compounded anesthetic, medical, and rehabilitation risk.	High probability of prolonged institutional care or delayed functional recovery.	High risk of construct failure unless surgical magnitude and fixation strategy are modified.

Table 3: Preoperative work-up and optimization checklist

Step	Suggested action	Potential decision effect
Screen	Apply brief frailty screen, sarcopenia screen, falls history, and bone-health screen in all patients older than 65 years and younger high-risk patients.	Identifies patients needing optimization before elective fusion or deformity correction.
Confirm	Confirm sarcopenia with grip strength, gait speed/chair stand, and muscle mass or quality when possible; confirm osteoporosis with DEXA, CT HU, or other bone-health assessment.	Converts general concern into an actionable risk phenotype.
Optimize frailty	Medication review, medical co-management, anemia and glycemic control, cardiopulmonary assessment, cognitive/delirium planning.	May reduce perioperative events and improve discharge planning.
Optimize sarcopenia	Resistance training, gait/balance training, adequate protein intake, vitamin D correction, treatment of reversible contributors.	Improves rehabilitation readiness and may reduce falls and delayed recovery.
Optimize bone	Vitamin D and calcium adequacy; evaluate secondary causes; consider anabolic or antiresorptive therapy based on risk and contraindications.	Improves fixation and fusion environment; may justify delaying elective reconstruction.
Modify surgery	Reduce surgical magnitude if appropriate; use fixation augmentation, pelvic fixation, cortical trajectory, hooks/tethers, multi-rod constructs, or staged surgery when indicated.	Aligns operative strategy with host biology and mechanical risk.
Postoperative pathway	Early mobilization, delirium prevention, fall prevention, rehabilitation placement, nutrition continuation, osteoporosis-medication adherence.	Reduces avoidable complications and protects surgical construct.

Table 4: Proposed Aging Spine Surgical Host grading framework

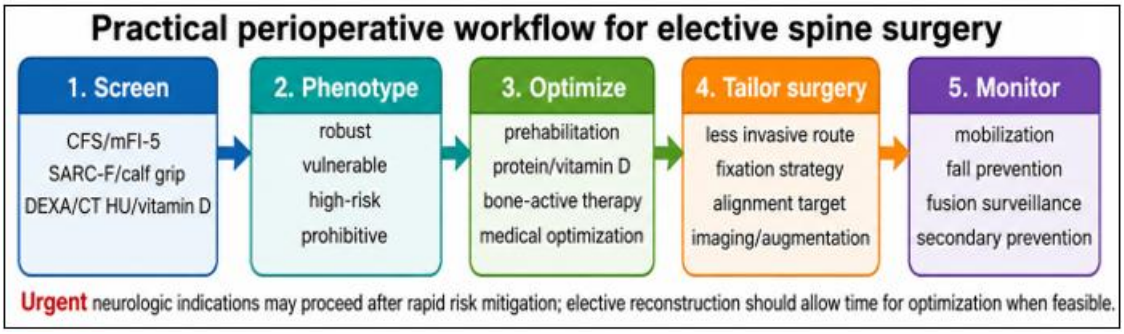
Grade	Host phenotype	Recommended pathway
Grade 0: robust	Independent function; no frailty; no sarcopenia; acceptable bone health; low falls risk; adequate nutrition.	Standard surgical planning and routine perioperative pathway.
Grade 1: vulnerable	Prefrailty or isolated modifiable deficit such as osteopenia, low vitamin D, possible sarcopenia, mild nutritional risk, or single fall.	Focused optimization; proceed with surgery if indication is strong and surgical magnitude is reasonable.
Grade 2: high risk	Established frailty, confirmed sarcopenia, osteoporosis, recurrent falls, impaired mobility, malnutrition, cognitive vulnerability, or planned long fusion.	Multidisciplinary optimization; consider delaying elective reconstruction; modify surgical magnitude and fixation strategy.
Grade 3: prohibitive or modifiable high risk	Severe frailty or severe sarcopenia; untreated osteoporosis in major reconstruction; poor support; active malnutrition; multiple concurrent deficits; limited rehabilitation capacity.	Reconsider indication and timing; prioritize urgent neurologic goals, minimally invasive or palliative options, staged surgery, or nonoperative care until risk is modified.

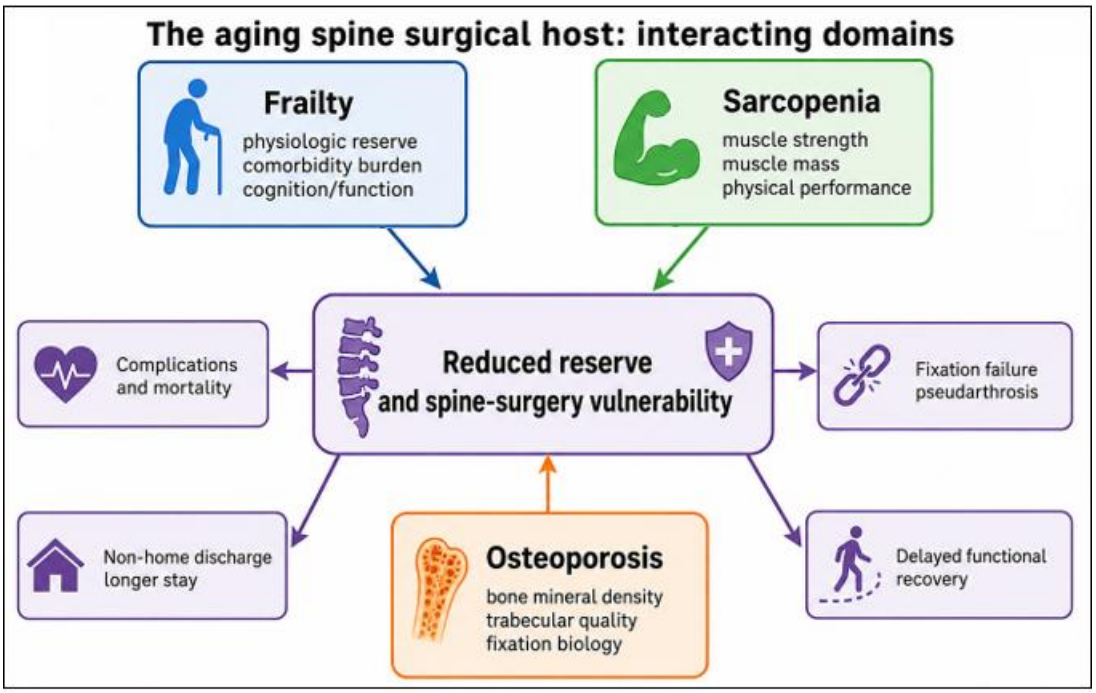
Figure legends

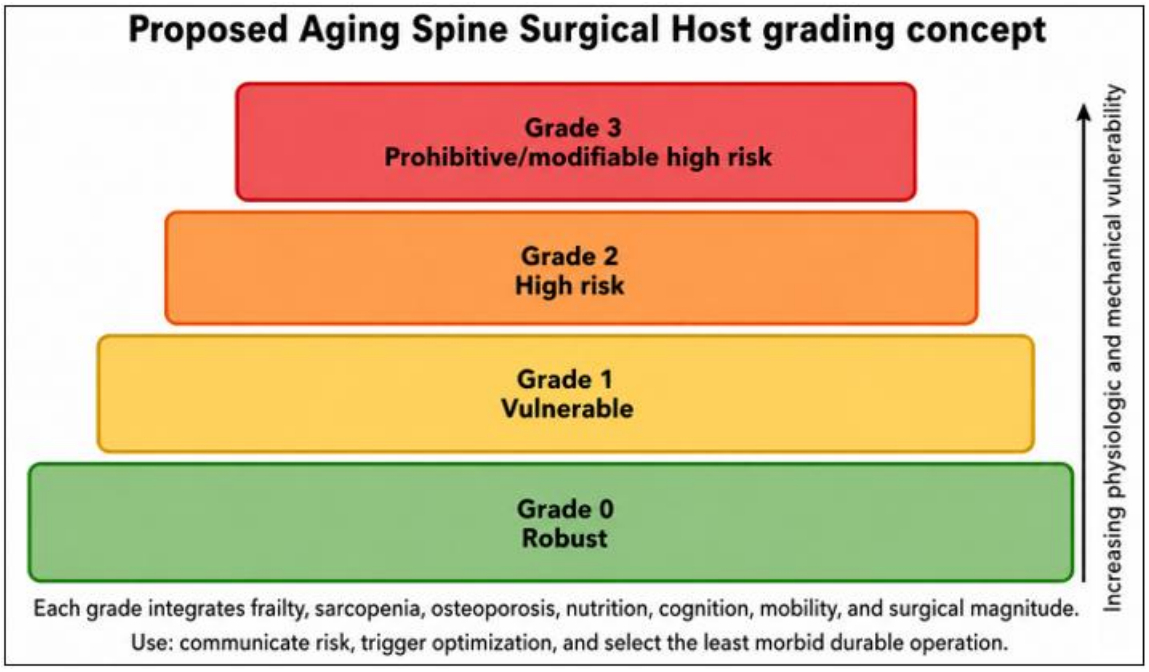
Fig. 1. Conceptual model of the aging spine surgical host. Frailty, sarcopenia, and osteoporosis overlap but contribute different vulnerabilities to surgical stress, recovery, fixation, fusion, and discharge disposition.

Fig. 2. Practical perioperative workflow. Screening should lead to phenotype classification, optimization, surgery tailored to host biology, and postoperative surveillance. Urgent neurologic indications may proceed with rapid risk mitigation.

Fig. 3. Proposed Aging Spine Surgical Host grading concept. The framework stratifies patients into robust, vulnerable, high-risk, and prohibitive or modifiable high-risk phenotypes. It is intended for clinical communication and prospective validation, not as a validated prediction score.







Athor contributions

Conceptualization: Nishant Nishant. Methodology: Nishant Nishant. Literature review: Nishant Nishant. Writing - original draft: Nishant Nishant. Writing - review and editing: Nishant Nishant. Supervision: Nishant Nishant. The author read and approved the final manuscript.