

General

Robotic-Assisted Total Knee Arthroplasty in HIV-Positive Patients: Precision Surgery for a Changing Epidemic

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Keywords: Osteoarthritis, Total Knee Arthroplasty, Robotic-Assisted Total Knee Arthroplasty, Human Immunodeficiency Virus

<https://doi.org/10.52965/001c.165230>

Orthopedic Reviews

Vol. 18, 2026

Background

Osteoarthritis(OA) and Human Immunodeficiency Virus(HIV) infection are two major global health burdens increasingly intersecting in orthopaedic practice. The global HIV-positive population is aging due to effective antiretroviral therapy, leading to a growing number of patients presenting with end-stage knee osteoarthritis requiring total knee arthroplasty(TKA). Conventional TKA, while successful in the general population, remains vulnerable to aseptic loosening and periprosthetic joint infection(PJI); complications that may be accelerated in immunocompromised hosts with altered bone biology. Simultaneously, robotic-assisted TKA (RA-TKA) is transforming knee arthroplasty by improving implant alignment, reproducibility and soft-tissue protection. However, no studies have directly evaluated outcomes of RA-TKA in HIV-positive patients.

Aims of the review

This narrative review synthesises current data on OA prevalence, HIV pathophysiology, TKA outcomes, and robotic technology to examine how precision arthroplasty may alleviate or exacerbate risks in this unique and growing population.

Key findings

This review highlights an aging HIV-positive population with increasing demand for TKA, due to improved management. HIV-positive patients show mixed short- and long-term TKA outcomes. RA-TKA enhances precision but may increase surgical time, infection risk, pin-site sepsis and osteoporotic bone-related fractures. Mitigation of these potential adverse events is essential and surgeons should follow guidelines to reduce risks.

Conclusion

The increasing subpopulation of people living with HIV and requiring TKA needs to be addressed. Strategies to combat complications that are prone to this group need to be highlighted. Advances in treatment strategies have enabled us to address this intersection between HIV and TKA.

INTRODUCTION

Osteoarthritis (OA) impacts roughly 528 million people worldwide and is expected to increase by about 75% by 2050 if current patterns continue.¹⁻⁵ In the United States, the lifetime prevalence of symptomatic OA is 9,961 per 100,000, while over 40 million individuals in Europe are affected.³⁻⁶ Factors such as aging, obesity, and sedentary lifestyles accelerate joint deterioration.^{4,7} The lifetime risk of developing symptomatic OA ranges from 41% to 45%, making it the leading global cause of chronic pain and dis-

ability.^{4-6,8} In South Africa, radiographic or clinical knee OA affects 33.1% of adults aged >35 years in rural populations, highlighting a significant public health issue.⁹

Total knee arthroplasty (TKA) is the gold standard surgical procedure for end-stage knee OA, accounting for over 95% of surgical interventions.^{4,5,10-13} Its utilisation continues to increase, with more than 100,000 procedures performed annually in the United Kingdom and over one million in the United States.^{5,11,13} However, 10-20% of patients remain dissatisfied postoperatively, often because

of residual pain, stiffness or instability frequently attributed to malalignment or soft-tissue imbalance.^{12,14-17}

This limitation has driven increased interest in robotic-assisted TKA (RA-TKA), which offers benefits such as improved accuracy, consistency and better implant placement.^{12,14-21} Meta-analyses indicate that RA-TKA enhances mechanical alignment, reduces outliers and may lead to a shorter hospital stay compared to traditional TKA.^{14,16,21,22} Adoption rates are rising rapidly, with forecasts suggesting that by 2030, up to 70% of all TKAs in the United States will be performed using robotics.^{19,23} Nonetheless, patients with complex medical conditions, such as osteoporosis, immune system disorders and HIV, are still underrepresented in studies of RA-TKA.

METHODS

A narrative review was conducted to synthesise current evidence on total knee arthroplasty (TKA) outcomes in people living with HIV (PLWH) and the emerging role of robotic-assisted TKA (RA-TKA). Electronic databases were searched for English-language studies up to 2026 using relevant keywords. Eligible sources included systematic reviews, cohort studies and registry analyses. Study selection was based on relevance to HIV-related pathophysiology, arthroplasty outcomes and robotic technology. Emphasis was placed on contemporary HAART-era data. Findings were synthesised qualitatively, focusing on clinically relevant outcomes, including survivorship, complications, infection risk and functional recovery, given the heterogeneity of the available evidence.

HIV EPIDEMIOLOGY AND ITS EMERGING ORTHOPAEDIC

Globally, between 31.6 and 44.5 million people live with HIV, with over one million new cases each year.^{8,24-32} The majority of the burden lies in low- and middle-income countries, especially in sub-Saharan Africa, where there are about 23.5 million cases.^{27,32} Thanks to the widespread use of highly active antiretroviral therapy (HAART), HIV-related deaths have decreased by approximately 45%, turning HIV into a manageable, chronic illness.^{8,24,26,33-36}

As the HIV population ages, more individuals are facing age-related conditions like osteoporosis, osteonecrosis and degenerative joint disease.^{8,24,27-34,37-39} In regions such as South Africa, where HIV prevalence is high, this demographic change suggests a significant increase in the need for elective arthroplasty among people living with HIV (PLWH).

The intersection of HIV and OA presents new challenges: immunodeficiency increases infection risk, antiretroviral therapy (ART) induces metabolic bone disease and chronic inflammation impairs osseointegration.⁴⁰ Together, these mechanisms may heighten the risk of mechanical failure and PJI after TKA.

THE ECONOMIC AND CLINICAL BURDEN OF TOTAL KNEE ARTHROPLASTY

TKA volumes have increased by 150% over the past two decades,⁴ with projections estimating 5.5 million primary TKAs annually by 2040, and associated costs exceeding US\$11 billion per year in the United States.^{13,38} Revisions, predominantly due to infection and loosening, account for less than 10% of cases but represent 25% of total arthroplasty expenditure.⁶

In sub-Saharan Africa, where resources are constrained and HIV prevalence is high, the financial burden of revision arthroplasty is disproportionately high. Therefore, preventing complications, particularly infection, offers the greatest potential for cost containment and improved outcomes.

PATHOPHYSIOLOGY OF HIV-ASSOCIATED BONE AND IMMUNOLOGICAL DYSFUNCTION

BONE REMODELLING ABNORMALITIES

HIV significantly disrupts skeletal homeostasis. As many as 67% of PLWH exhibit osteopenia, while 23% have osteoporosis.^{8,34} Viral proteins such as Tat and gp120 induce osteoblast apoptosis and promote osteoclast differentiation via the tumour necrosis factor- α (TNF- α) and receptor activator of nuclear factor kappa-B Ligand (RANKL) pathways.^{13,41} Dysregulation of B- and T-cell functions increases RANKL levels and decreases osteoprotegerin (OPG), thereby shifting bone remodelling towards resorption.^{8,12,13} Additionally, chronic inflammation, characterised by elevated levels of interleukin-6 (IL-6) and TNF- α , exacerbates bone loss, contributing to increased fragility and deterioration of bone microarchitecture.⁸

ANTIRETROVIRAL THERAPY AND ENDOCRINE EFFECTS

While HAART extends lifespan, it also accelerates bone loss. Agents such as Tenofovir disoproxil fumarate (TDF) and protease inhibitors (PIs) cause a 2-6% reduction in bone mineral density (BMD) within two years of starting treatment.^{8,14-16,42} Tenofovir alafenamide (TAF) is less harmful to the kidneys and bones but is not without risk.⁴³ Hypogonadism in men and oestrogen deficiency in women worsen bone fragility.¹⁷ Additionally, vitamin D deficiency, which affects 60-75% of ambulatory PLWH, together with tenofovir-induced phosphate wasting, impairs mineralisation and bone integration.^{8,28,32}

CONSEQUENCES FOR ARTHROPLASTY

These molecular alterations manifest clinically as a three-fold increased risk of fractures among PLWH compared with HIV-negative controls.^{8,34,38} Impaired osteogenesis and heightened bone turnover undermine prosthetic fixation, thereby increasing the likelihood of periprosthetic fractures, micromotion and aseptic loosening.³⁸ Furthermore, chronic immune activation and malnutrition diminish host

defences, thereby exacerbating the risk of periprosthetic joint infection (PJI).⁸

FAILURE MECHANISMS OF CONVENTIONAL TOTAL KNEE ARTHROPLASTY

ASEPTIC LOOSENING

Aseptic loosening is the leading cause of late TKA failure, accounting for 20-40% of revisions.²⁹ Micromotion at the bone-cement interface and osteolysis caused by polyethylene debris contribute to mechanical instability. In PLWH, osteopenia and altered remodelling may accelerate these processes.

PERIPROSTHETIC JOINT INFECTION (PJI)

PJI occurs in 0.5-2% of primary TKAs and as many as 10% of revision TKAs.^{30,31,36} The mortality rate after PJI can reach 20% within five years.³¹ PLWH are at increased risk, especially when CD4 counts are below 200 cells/mm³ or viral loads exceed 30,000 copies/mL, due to compromised neutrophil chemotaxis and macrophage dysfunction.^{8,27,38} Additionally, biofilm formation by *Staphylococcus aureus* and coagulase-negative staphylococci makes eradication more difficult.³⁴

Modern HAART-era data show improved outcomes. Lin et al. reported no significant difference in complication rates between PLWH and HIV-negative patients (7.8% vs 8%).⁴⁴ While Issa et al. reported 98% implant survivorship in HIV-positive patients versus 99% in controls, with comparable Knee Society Scores (KSS).⁴⁵ In contrast, Boylan et al. found a slightly higher risk of superficial infection (OR = 2.78; P = 0.024) and a 17% longer hospital stay, but no increase in revision or mortality rates.⁴⁶ A review of 4,765 HIV-positive patients across six studies found low complication rates, similar between HIV-positive and HIV-negative patients (7.8% vs 8.0%).⁴⁷ Patient-reported outcomes were positive; HIV-positive patients improved in mean Knee Society scores (88±12 vs 90±13), with no significant difference; UCLA activity levels improved similarly from baseline.⁴⁷

INSTABILITY, WEAR AND FRACTURE

Instability and wear continue to be prevalent modes of late failure following TKA. Osteoporotic bone elevates the risk of intraoperative and late periprosthetic fractures, especially in PLWH exhibiting decreased BMD or extended corticosteroid therapy.

ARTHROPLASTY OUTCOMES IN PLWH

Early (pre-HAART) studies involving haemophiliac patients showed catastrophic infection rates of 30-37%, which caused historical hesitation to perform operations.³⁶ However, modern groups show significant progress with better-managed patients.⁸ Lin et al.⁴⁴ noted similar perioperative complication rates between HIV + and negative patients;

similarly, Issa et al.⁴⁵ reported comparable survivorship and functional scores, while Boylan et al.⁴⁶ noted minor differences mainly related to wound complications. See **TABLE 1**. Miller et al. reported comparable Implant survivorship, with one study reporting 98% in HIV-positive patients and 99% in controls and Kaplan-Meier curves showed no significant difference.⁴⁷ Yeramosu et al. observed no complications in strictly optimised HIV-positive arthroplasty patients.³³ These findings confirm that, in virally suppressed and medically optimised PLWH, TKA can yield results that are equivocal to those of the general population.⁴⁰ A review by Miller et al highlighted a low wound infection rate of 0.6% in HIV-positive patients versus 0.4% in HIV-negative patients.⁴⁷ However, close attention to infection and delayed wound healing remains necessary.

ROBOTICS IN TOTAL KNEE ARTHROPLASTY: TECHNOLOGY AND EVIDENCE

PRECISION AND ACCURACY

Robotic assistance improves the precision of component alignment and bone resection.⁴⁸ Semi-active systems like MAKO, ROSA, CORI and VELYS offer haptic boundaries that limit cuts to pre-determined zones, minimising human error.⁴⁸ RA-TKA results in average mechanical axis deviations of ≤ 1.7°, whereas navigated or manual TKA show approximately 2.3°. ^{14,15}

Early functional outcomes following robotic-assisted TKA (RA-TKA) appear favourable. Kayani et al. observed quicker straight-leg raises, less pain and shorter hospital stays.¹² Similarly, Tran et al. demonstrated significantly higher early functional scores, with KSFS at 6 weeks being 60.7 compared to 46.9 and at 3 months, 75.3 versus 65.3 (P < 0.01).¹⁴

COMPLICATIONS AND LIMITATIONS

The complication rates associated with RA-TKA are comparable to those of conventional TKA (RR 1.20; 95% CI 0.88-1.63).^{14,15} Unique considerations include pin-site infections (~0.6%), pin-related fractures (0.1-1.4%) and extended operative durations (an additional 15-25 minutes).^{21,49-51} Prolonged operative times exceeding 120 minutes are associated with approximately a 1.8-fold increase in infection risk.⁴⁹

Preventive measures include unicortical peri-articular pin placement, using the primary arthrotomy incision for tracker insertion, and reducing pin dwell time.^{21,50,51} Imageless handheld systems also help lower risk by using smaller unicortical pins.⁵²

ECONOMIC AND WORKFLOW CONSIDERATIONS

RA-TKA involves higher initial costs; however, it has the potential to offset these expenses by decreasing revision rates and enhancing efficiency after the learning curve of approximately 20-30 cases is attained.^{18,52} The approach demonstrates the greatest cost-effectiveness in high-vol-

Table 1. Total Knee Arthroplasty Outcomes in Patients Living with HIV

Study	Design & Population	Key Findings in HIV-Positive Patients	Clinical Implication	Level of Evidence
Lin et al. (2013) ⁴⁴	Retrospective database (THA/TKA)	Comparable perioperative complication rates (7.8% vs 8%)	HIV infection is not an independent predictor of early postoperative complications	III
Issa et al. (2017) ⁴⁵	Comparative cohort (TKA)	Survivorship (98%) and functional outcomes (KSS) equivalent to controls	Optimised HIV patients achieve outcomes comparable to the general population	III
Boylan et al. (2015) ⁴⁶	Retrospective cohort (TKA)	Increased superficial infection risk and longer hospital stay; no difference in revision or mortality	Slight increase in minor complications without impact on major outcomes	III
Yeramosu et al. (2022) ³³	Narrative review (optimised HIV patients)	No complications reported in virally suppressed patients	Preoperative optimisation (CD4 count, viral load) is critical to favourable outcomes	IV
Enayatollahi et al. (2016) ³⁷	Registry/database analysis	Reduced infection risk in the modern HAART era compared to historical cohorts	Advances in HIV management have improved arthroplasty safety	III
Chalmers et al. (2017) ⁴⁰	Cohort study (THA/TKA)	Comparable mid-term outcomes and implant survivorship	Arthroplasty is safe in appropriately selected HIV-positive patients	III
Sakthivelnathan et al. (2022) ³⁸	Propensity-matched database study	Increased medical complications (renal failure, transfusion) and higher cost burden	HIV patients may have higher systemic perioperative risk despite acceptable implant outcomes	III
O'Neill et al. (2019) ³⁶	Systematic review	Historically high infection rates (30-37%) pre-HAART; markedly improved modern outcomes	Contemporary outcomes reflect a paradigm shift in HIV care	II-III

TKA = Total knee arthroplasty; THA = Total hip arthroplasty; KSS = Knee Society Score. Level of Evidence: (Level II: Systematic review / higher-quality cohort studies, Level III: Retrospective cohort/database studies & Level IV: Case series / narrative review)

ume centres performing more than 50 cases annually. For low-resource regions such as sub-Saharan Africa, selective implementation targeting high-risk populations, including PLWH, may provide the most significant benefit.

THE INTERSECTION OF HIV AND ROBOTIC-ASSISTED ARTHROPLASTY

POTENTIAL ADVANTAGES IN PLWH

RA-TKA offers numerous theoretical and practical advantages, particularly for PLWH. One of the primary benefits is its precision in osteoporotic bone, a common characteristic among HIV-positive patients, in which diminished bone mineral density and trabecular weakness impair fixation.^{8,34} Robotic systems attain sub-millimetric accuracy in bone resection and facilitate controlled load distribution, thereby potentially enhancing implant congruence and reducing the risk of periprosthetic fractures.^{12,14-20} Unlike traditional jig-based TKA, robotic systems circumvent intramedullary canal violation by utilising unicortical peri-articular pins for registration, which reduces marrow embolisation, minimises intraosseous bleeding and preserves endosteal bone integrity; features that are especially advantageous in osteopenic or immunocompromised bone.¹⁸⁻²¹ PLWH have a two- to tenfold increased risk of venous thromboembolism compared with the general population of the same age.⁵³ However RA-TKA has not been

shown to increase postoperative DVT rates compared with conventional TKA despite longer operative times; in a consecutive series of 141 knees.⁵⁴

Furthermore, RA-TKA's haptic-guided boundaries and three-dimensional planning enable highly precise bone resection, thereby diminishing collateral soft-tissue trauma, postoperative inflammation and wound complications; factors particularly relevant in PLWH, who experience delayed healing and possess a heightened susceptibility to infection.^{12,14-18,21,48} Improved accuracy in achieving balanced flexion-extension gaps facilitates earlier functional recovery and mobilisation, which may reduce the risk of venous thromboembolism and deconditioning associated with prolonged immobility.^{12,14} Additionally, the capacity to reproduce patient-specific kinematics with consistent limb alignment could be especially advantageous for the younger, more active HIV-positive cohort, who tend to require arthroplasty at a younger age and seek durable functional outcomes.^{12,14-20} Collectively, these advantages, rooted in precision, position RA-TKA as a promising technique for enhancing early recovery and long-term implant stability in this complex, biologically vulnerable population.

POTENTIAL DRAWBACKS

Despite the advantages of RA-TKA, several limitations must be acknowledged, particularly in immunocompro-

mised populations. Prolonged operative time, typically 15-25 minutes longer than conventional TKA, has been associated with a higher risk of infection, a concern heightened in PLWH with impaired immune function, emphasising the necessity for surgical efficiency.⁴⁹ Pin-site complications, including superficial infection rates of approximately 0.6% and fracture rates up to 1.4%, present additional challenges, especially in osteoporotic bone where cortical integrity and healing capacity are compromised.^{21, 49-51} Furthermore, significant cost constraints related to robotic system acquisition, maintenance and disposable instrumentation restrict accessibility in low- and middle-income countries (LMICs), where the burden of both osteoarthritis and HIV remains highest, thereby underscoring the importance of selective, evidence-based adoption.⁵²

INFECTION PREVENTION IN RA-TKA FOR PLWH

Although the reported infection rates in the general RA-TKA population are low (~0.15%), extrapolation to PLWH remains uncertain.²² Strict adherence to aseptic techniques, utilisation of laminar flow theatres, perioperative antibiotic administration, and meticulous pin-care protocols are essential. Collaboration with infectious disease specialists and wound-care teams enhances patient outcomes.

CLINICAL RECOMMENDATIONS

The timing of elective TKA in PLWH is of paramount importance for minimising complications and optimising postoperative outcomes. Surgery is preferably postponed until CD4 counts surpass 200 cells/mm³ and viral loads are diminished below 1,000 copies/mL, as both indicators are strongly associated with immune competence and the risk of postoperative infection.^{8,27,33,44,45} Patients exhibiting uncontrolled viremia or opportunistic infections tend to experience higher perioperative morbidity, thereby underscoring the necessity of collaborative optimisation with infectious disease specialists prior to proceeding with arthroplasty.^{8,27,33}

Assessing bone health before surgery is crucial, given the high prevalence of osteopenia and osteoporosis among HIV-positive individuals, reaching up to 67% and 23%, respectively.³⁴ All HIV-positive candidates for TKA should have a DEXA scan to evaluate their BMD and guide treatment plans. Addressing vitamin D deficiency, which affects 60-75% of ambulatory PLWH, can improve calcium absorption and support better osseointegration.²⁸ For patients with low BMD, bisphosphonate therapy may enhance bone stability around implants, particularly when combined with antiretroviral medications like tenofovir or protease inhibitors that have known skeletal side effects.^{14-16,32,34}

The fixation method should be tailored to each patient. Cemented implants are generally recommended for patients with limited bone quality, as they provide immediate stability and decrease micromotion at the bone-cement interface.^{29,34,44} In contrast, cementless fixation may be better suited for younger, virally suppressed patients with

good bone health, there is limited evidence supporting this approach in HIV-positive populations.^{33,44,45}

Antibiotic prophylaxis is crucial for preventing PJI, which remains a leading cause of revision in TKA and carries mortality rates of nearly 20% within 5 years.^{30,31,55} The standard first-line antibiotic is cefazolin, with vancomycin added in high-risk or Methicillin-resistant *Staphylococcus aureus* (MRSA)-endemic situations. Due to the immunological vulnerability of PLWH, extending prophylaxis to 48-72 hours may be appropriate in some cases. Additionally, using antibiotic-loaded bone cement can offer extra protection, especially in revision surgeries or high-risk primary procedures.^{30,31,34}

RA-TKA involves specific technical considerations. Managing pin sites is critical, as superficial infections occur in about 0.6% and fractures up to 1.4%, at tracker insertion points.^{21,49-51} These risks are higher in patients with osteoporosis or immune suppression. To minimise cortical damage and infection risk, using unicortical periarticular pins, ideally inserted through the primary arthrotomy, is recommended. Each pin tract should be covered with a sterile, occlusive dressing and early postoperative wound monitoring for erythema or discharge is essential.^{21,49-51}

Optimal outcomes rely on a multidisciplinary approach that combines expertise in orthopaedics, infectious disease, physiotherapy and nutrition. Collaboration helps patients achieve viral suppression, immune system recovery and proper nutrition; key factors associated with better functional recovery and lower readmission risk.^{8,27,33} Early physiotherapist-guided mobilisation also reduces thromboembolic events, while nutritional support promotes wound healing and protein synthesis, which are often impaired in advanced HIV infection.^{8,27,34}

Ultimately, effective data collection and registry integration are crucial for enhancing care in this developing patient group. Recording HIV status, CD4 count, viral load, fixation method and infection outcomes in both institutional and national arthroplasty registries will facilitate large-scale analyses. Such data will help identify risks, compare performance and develop evidence-based guidelines for future treatments.^{19,33,44,45}

FUTURE RESEARCH DIRECTIONS

Future research should focus on well-designed prospective studies of RA-TKA in virally suppressed PLWH to evaluate infection risk, outcomes, and implant longevity. Advanced biomechanical models are necessary to understand fixation in osteoporotic bone affected by long-term antiretroviral therapy. Cost-effectiveness analyses will aid in assessing the scalability of robotic platforms in high-HIV-prevalence settings. Infection-control trials should optimise pin-site care and perioperative strategies for robotic workflows. Finally, linking national arthroplasty registries with HIV cohorts can produce real-world evidence to inform clinical practice and policy.

CONCLUSION

As survival rates for HIV improve worldwide, more PLWH will require a TKA. The mechanical and biological issues associated with HIV, including osteoporosis, inflammation and increased infection risk, closely align with common causes of TKA failure. While conventional TKA generally remains effective, it presents higher risks for immunocompromised patients.

RA-TKA offers potential benefits, including improved precision, better alignment, and reduced soft-tissue damage, which may reduce the risk of mechanical failure in fragile bones. Nonetheless, robotics also carries risks, such as longer surgical duration and pin-site complications, which may increase the risk of infection in PLWH.

By carefully selecting patients, optimising immune function and strictly following aseptic protocols, RA-TKA can be safely used for HIV-positive patients. Future multicentre studies are needed to determine its role at the intersection of infectious diseases and advanced orthopaedic techniques.

ABBREVIATIONS

OA : Osteoarthritis
TKA : Total knee arthroplasty
RA-TKA :Robotic-Assisted Total Knee Arthroplasty
HIV : Human Immunodeficiency Virus
PLWH : People Living With HIV
BMD : Bone mineral density
DEXA : Dual-Energy X-ray Absorptiometry
RANKL : Receptor Activator of Nuclear factor Kappa-B ligand
TNF- α : Tumour Necrosis factor- α
OPG : Osteoprotegerin
IL-6 : Interleukin-6
HAART : Highly Active Antiretroviral Therapy
TDF : Tenofovir disoproxil fumarate
TAF : Tenofovir alafenamide
PI : Protease inhibitors

PJI : Periprosthetic Infection

LMICs : Low- and Middle income countries

ACKNOWLEDGEMENTS

We acknowledge the entire staff of the Arthroplasty Unit and the Orthopaedic Division of Charlotte Maxeke Johannesburg Academic Hospital, Johannesburg.

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FUNDING

The review received no external funding.

CONFLICT OF INTEREST / DISCLOSURES

All authors declare no conflicts of interest.

Submitted: April 12, 2026 EDT. Accepted: April 19, 2026 EDT.
Published: September 24, 2026 EDT.

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