

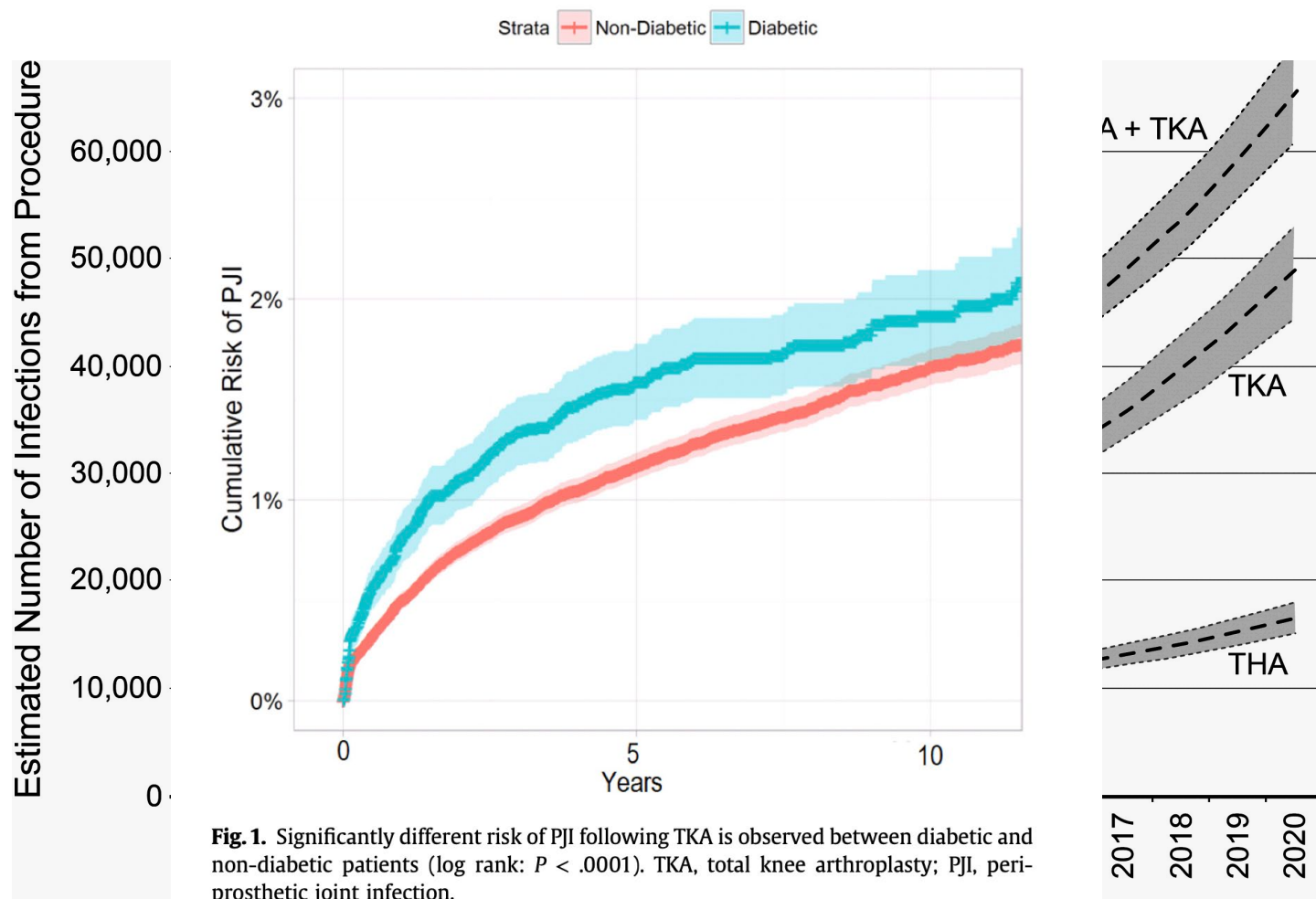
DAIR, 1-stage, 2-stage: Where do we stand in 2025

ELI KAMARA, MD, FAAOS, FAOA
ASSOCIATE PROFESSOR
EKAMARA@MONTEFIORE.ORG

I (and/or my co-authors) have something to disclose.

**All relevant financial relationships
have been mitigated.**

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- PJI incidence ~1–2% of primary arthroplasties
- High morbidity, mortality, and cost
- Goal: infection eradication & functional preservation

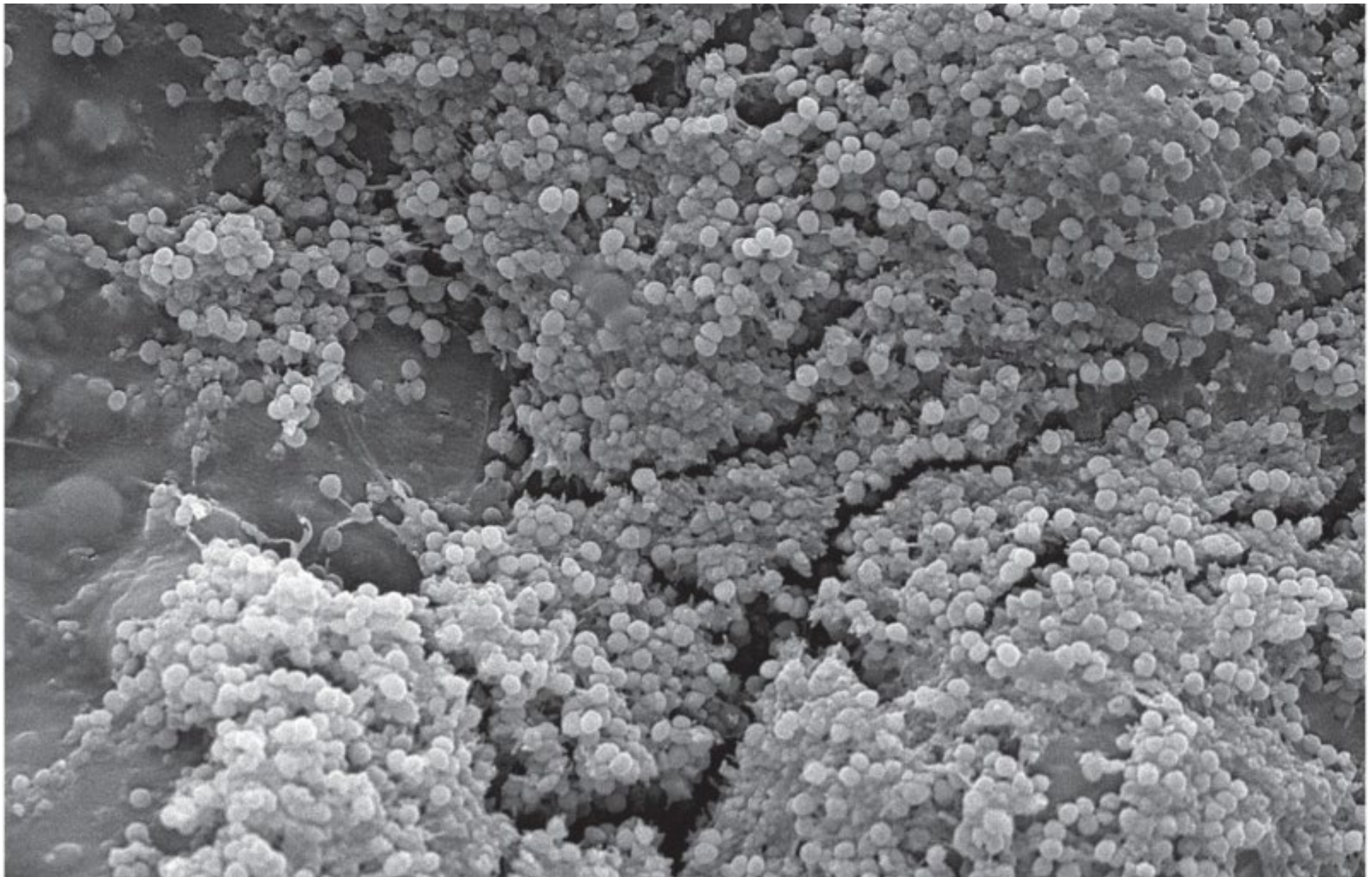


Timeline of Spacer Exchange Evolution

- 1960s–1970s: Early attempts – antibiotics, DAIR, resection arthroplasty
 - 1979: Buchholz (Germany) – antibiotic-loaded cement spacers
 - 1983: Insall (U.S.) – staged revisions for TKA
 - 1980s–1990s: ENDO-Klinik & Mayo reports – 85–95% success
 - 1990s–2000s: Articulating spacers, refined antibiotic use, candidacy criteria
 - 2000s–present: Gold standard in U.S.; Germany maintains one-stage protocols
 - 2020s: Renewed interest in one-stage (Fehring RCT 2024)
- Montefiore Einstein**

Treatment Approach Overview

- DAIR (Debridement, Antibiotics, Implant Retention)
- One-Stage Revision
- Two-Stage Revision
- Choice traditionally depended on timing, organism, host, implant, soft tissue



DAIR

Concept & Indications

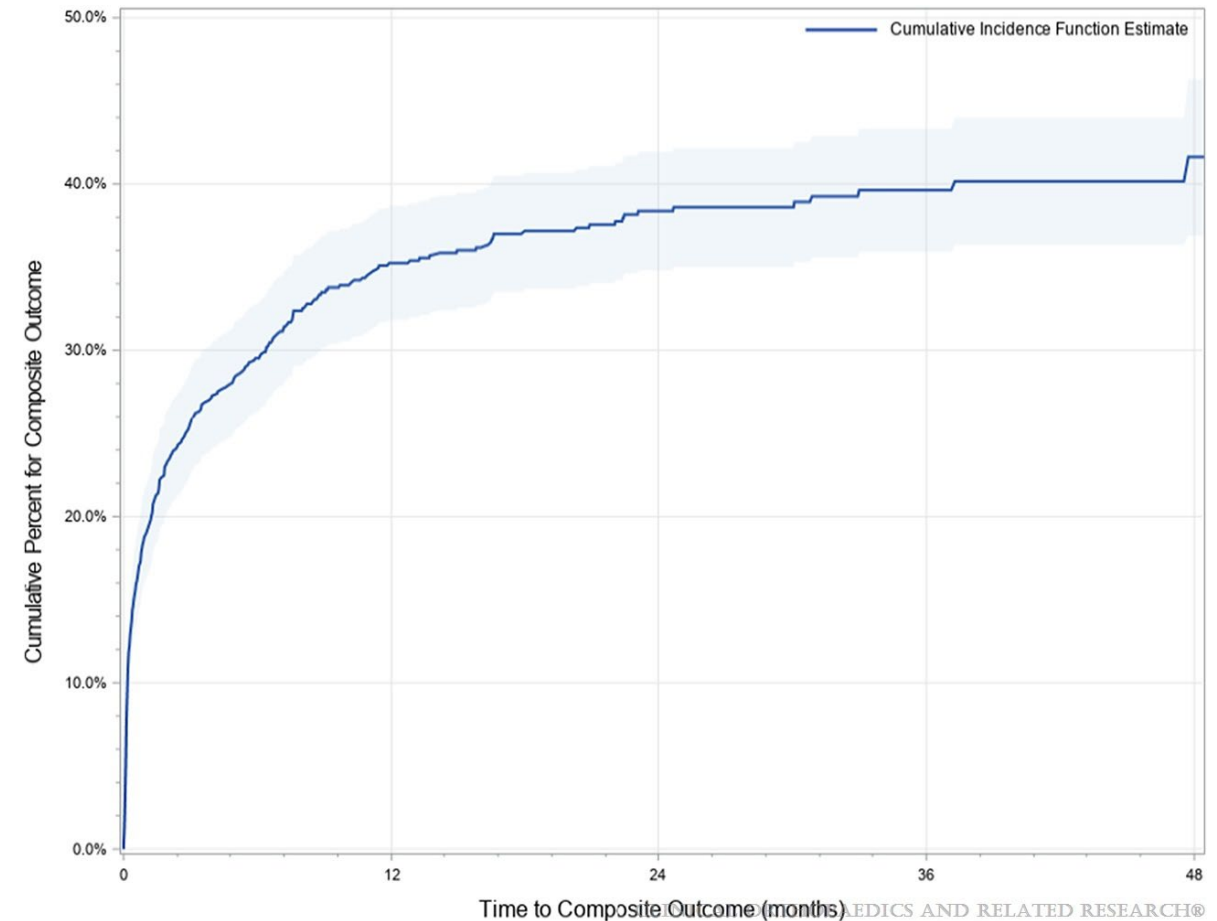
- Aggressive debridement, modular component exchange
- Indications: acute (<6 weeks) or acute hematogenous, stable implant, intact soft tissue, known organism
- Advantages: less invasive, preserves bone

Outcomes & Limitations

- Success 45–92%
- Better in acute PJI
- Staphylococcal infections less favorable
- Risk: biofilm persistence, failure may affect future outcomes

Trends and Outcomes of DAIR for Periprosthetic Joint Infection: AJRR 2012–2020 – De et al., 2024

- Study Design: Registry-based retrospective study
- Level of Evidence: II
- Number of Patients: 5,432 PJI cases with DAIR
- Key Outcomes:
 - Among the DAIR population, **35% of TKAs and 38% of THAs had additional PJI-related event**
 - 62% had single DAIR, 38% multiple DAIRs
 - Risk of reoperation and failure increased with repeated DAIRs





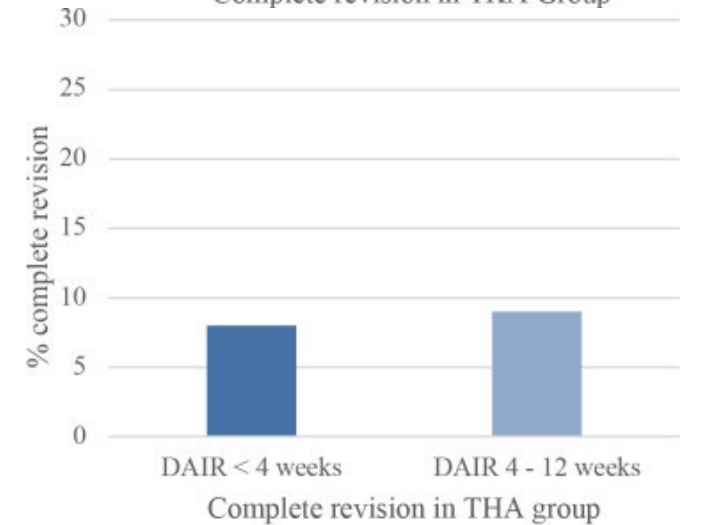
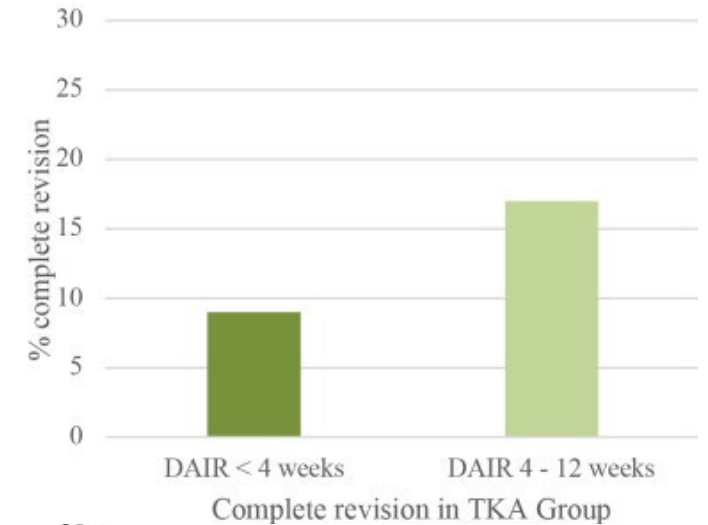
Efficacy of DAIR in Hip and Knee Arthroplasty (Abbaszadeh JOA 2025)

- Systematic review & meta-analysis of 81 studies (2013–2023)
- Population: PJI after primary hip or knee arthroplasty
- Primary outcome: **DAIR failure rate**
- Subgroups: early/acute postop, acute hematogenous, late chronic
- Hip vs Knee outcomes assessed
- Overall pooled DAIR failure
 - **35.9% (95% CI 23.9–48.0)**
- Early/acute postop
 - **34.2% failure**
- Acute hematogenous
 - **39.1% failure**
- Late chronic
 - **73.6% failure**
- Hip
 - **25.8% failure**
- Knee
 - **38.8% failure**
- S. aureus most frequent cause of failure
- DM & CVD prevalent in failures

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DAIR in early postoperative period may work

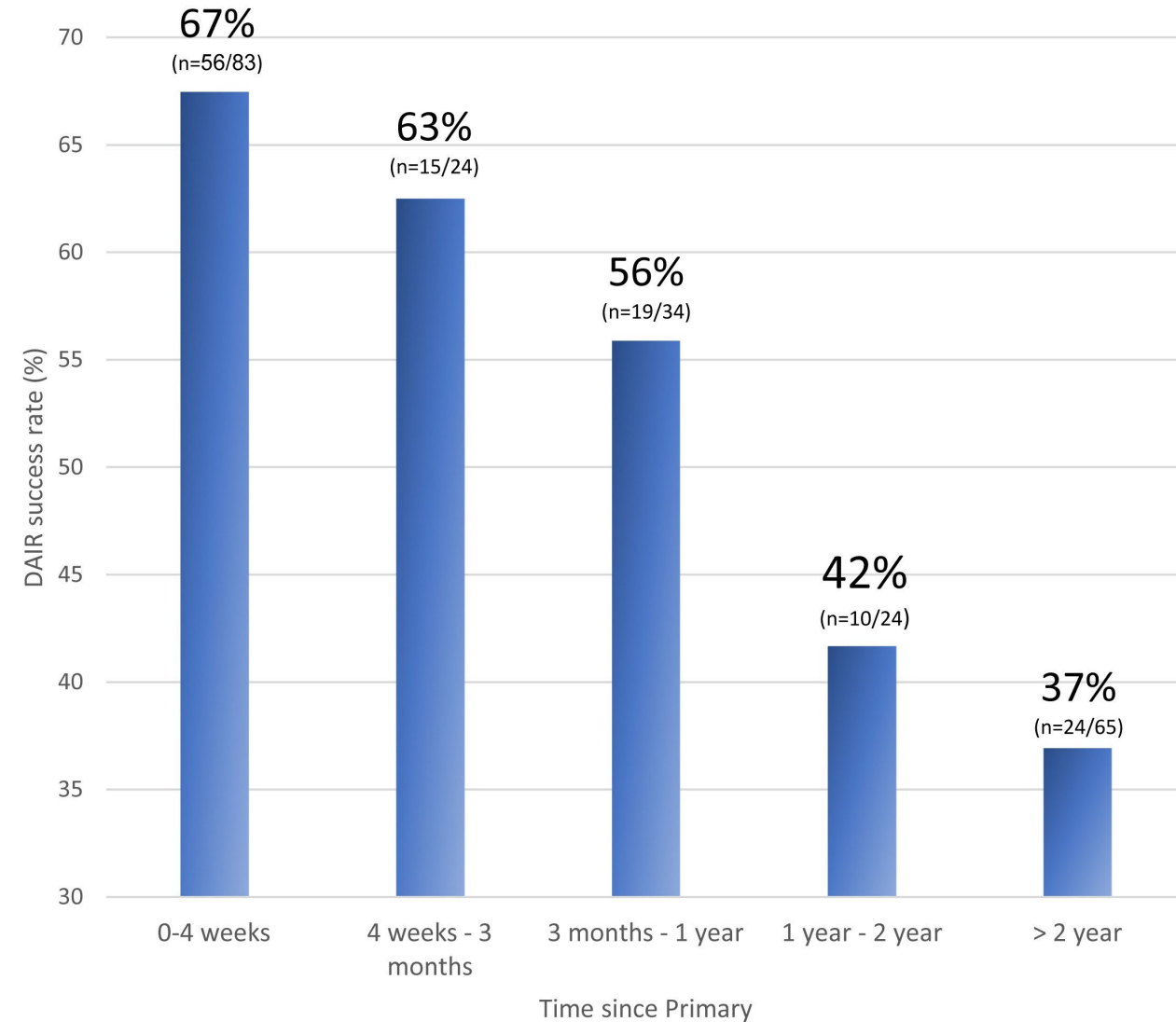
- Registry study, 514 patients (305 THA, 209 TKA)
- Period: 2007–2016, Dutch Arthroplasty Register
- Groups: <4 weeks vs 4–12 weeks post-op
- DAIR defined as revision for infection with modular exchange
- Primary outcome: complete re-revision within 1 year
- Hip (THA):
 - **<4 wks: 8% complete revision**
 - **4–12 wks: 9%**
- Knee (TKA):
 - **<4 wks: 9% complete revision**
 - **4–12 wks: 17%**



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Success Rates of DAIR in 230 Infected TKAs (Zhu et al., J Arthroplasty. 2021)

- Design: Multicenter retrospective cohort
- Level of Evidence: III
- N: 230 TKA PJIs
- Key Findings:
 - **~54% success overall**
 - Better outcomes in early PJIs (<1 yr)
 - *S. aureus* and gram-negatives predicted failure



PIANO Multicenter Cohort - Australia AAHKS 2022

- Design: Retrospective cohort
- Level of Evidence: III
- N: 189 TKA PJIs treated with DAIR
- **Overall success ~45%**
- Best in acute (<1 yr) infections
- Poor outcomes in chronic/hematogenous cases

DAIR in Acute Hip PJI – Mayo AAHKS 2024

- Design: Retrospective cohort
- Level of Evidence: III
- N:133 acute hip PJIs (≤6 wks post-op)
- **5-yr infection-free survival = 77%**
- No difference in survivorship between early postoperative and acute hematogenous
- Increased failure risk associated with McPherson Host Grade C

Timing of Debridement, Antibiotics, and Implant Retention is Critical: A Multicenter Matched Cohort Study – Wouthuyzen-Bakker et al., 2020

- Study Design: Multicenter matched cohort
- Level of Evidence: III
- Number of Patients: 264 DAIR cases (132 early-acute, 132 late-acute)
- Key Outcomes:
 - **Higher infection control in early-acute PJIs (~74%) vs late-acute (~45%)**

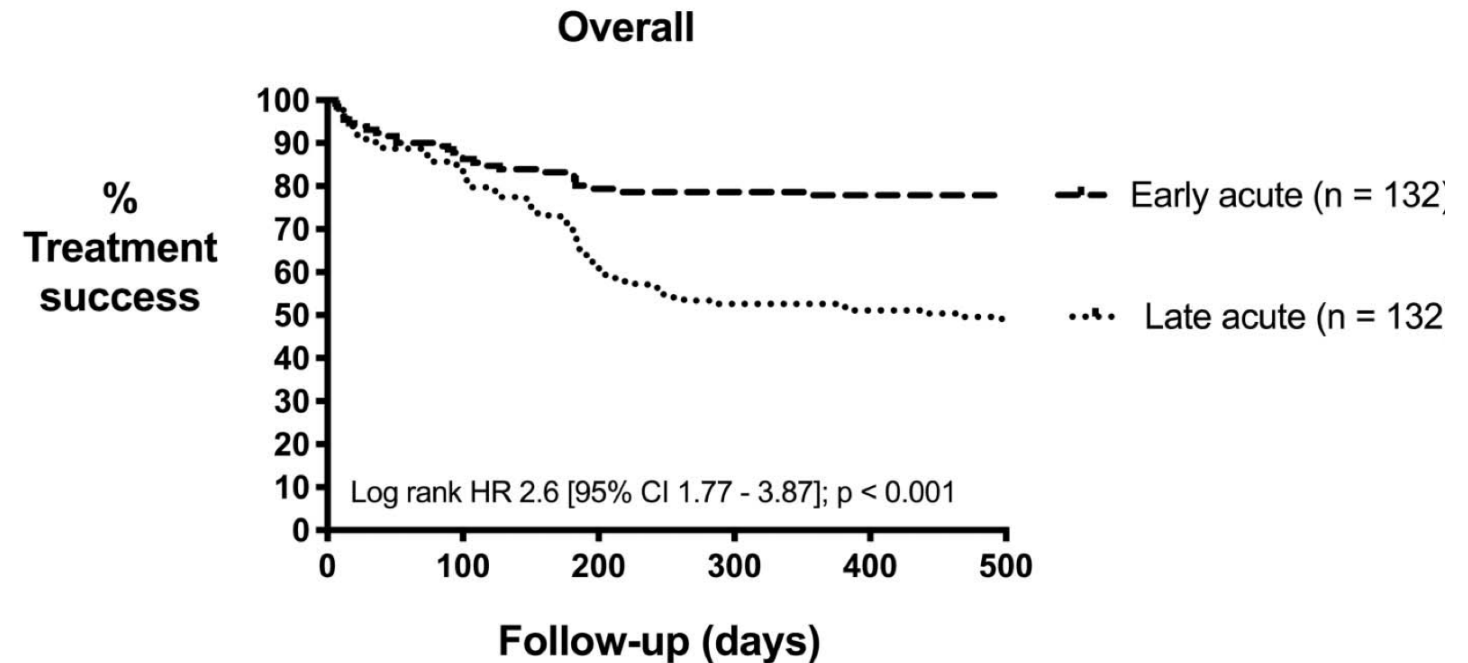


Fig. 1 Treatment success of surgical débridement, antibiotics and implant retention (DAIR) in early acute and late acute PJI is shown here.



Perioperative Demographic & Lab Predictors of Failed DAIR (Ashkenazi et al., J Arthroplasty. 2024)

- Design: Retrospective cohort
- Level of Evidence: III
- N: 83 acute PJIs (≤ 3 mo)
- Increased failure risk associated with higher
 - Charlson Comorbidity index
 - CRP
 - Synovial WBC
 - PMN%

Accuracy of Predictive Algorithms in Acute PJI Treated With DAIR (Chalmers et al., J Arthroplasty. 2021)

- Design: Retrospective validation study
- Level of Evidence: III
- N: 256 (122 acute post-op, 134 hematogenous)
- Key Findings: DAIR failure 25–43% at 2 yrs
- Predictive scores (KLIC, CCI, McPherson) **poorly predicted DAIR failure** (CRIME80 best for hematogenous PJIs)

Long-Term Antibiotic Suppression in DAIR: Systematic Review (Malahias et al., J Arthroplasty. 2020)

- Design: Systematic review (low-level studies)
- Level of Evidence: III–IV
- N: 437 DAIR + suppression cases
- Key Findings: ~75% infection-free; adverse effects 15%; evidence quality low; more trials needed



Fate of Two-stage Reimplantation After Failed I&D

- Design:
 - Multicenter, retrospective review (1994–2008)
 - 83 knees: I&D → later two-stage revision
 - Outcome = failure = any additional surgery for infection
- Results
 - **34% (28/83) failed two-stage reimplantation**
 - Failure procedures: repeat I&D (15), fusions (3), resections (4), amputations (3), repeat two-stage (2)
 - No difference by age, gender, ASA status
 - Predominant organisms: Staphylococcus spp. (incl. MRSA)
 - Successful group had longer interval between I&D and explantation (6.9 vs. 3.6 months, $p=0.03$)

Is There Harm in DAIR vs Two-Stage for Knee PJI? (Huffaker et al., J Arthroplasty. 2022)

- Design: Registry-based, propensity-weighted cohort
- Level of Evidence: III
- N: 1,410 PJIs (DAIR ~1,000)
- Key Findings
 - **DAIR had higher re-revision risk HR ~3.1**
 - **Salvage 2-stage similar to initial 2-stage outcomes**

Septic Revision	Incidence	HR (95% CI)	P Value
DAIR	272 (29.6)	3.09 (2.22-4.42)	<.001
Two-stage revision	41 (11.6)	Reference	–

Septic Revision	Incidence	HR (95% CI)	P Value
Failed DAIR	17 (12.6)	1.11 (0.58-2.12)	.747
Two-stage revision	41 (11.6)	Reference	–

DAIR for PJI: Summary

Success rates variable
(45–90% depending on
chronicity, joint,
definition)

Better outcomes in
acute/early PJIs vs
chronic/hematogenous

Predictors of failure:
S. aureus, gram-
negatives, high
CRP/ESR, poor host
status

DAIR vs 2-stage:
higher failure risk, but
salvage often
comparable

Long-term suppression
may help, but evidence
is weak

One Stage Revision

Concept & Indications

- Remove all implants, debridement, reimplant same surgery
- Indications: good host, organism identified & susceptible, good soft tissue
- Advantages: one surgery, faster recovery

Outcomes & Limitations

- Widely used in Europe
- Success ~80–97% in selected patients
- Traditionally requires strict selection



■ THE INFECTED HIP REPLACEMENT

One-stage exchange

IT ALL BEGAN HERE

T. Gehrke,
A. Zahar,
D. Kendoff

*From Helios Endo
Klinik Hamburg,
Hamburg, Germany*

“Generally we see very few arguments against a one stage revision protocol”

Indications

- Positive bacterial culture with sensitivity profile
- Adequate soft tissue & bone stock

Contraindications

- ≥ 2 failed one-stage attempts
- Neurovascular involvement
- Untreatable organism
- Severe soft tissue deficit

Technique (Essential Steps)

- Radical Debridement
- Wound/canals packed with polymeric biguanid-hydrochlorid (polyhexanid) soaked swabs
- Entire team re-scrub and re-drapes
- Second dose of antibiotics after 1.5 hours operating time
- Post-op antibiotics: 10–14 days

Outcomes

- 80–90% infection-free

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European Evidence on Single-Stage Exchange for PJI

Country / Centre	Study (Year)	Joint(s)	Design	N	Technique	Infection-Free Survival	Follow-Up	Notes
Germany (Endo-Klinik)	Zahar et al., 2019	Hip	Retrospective cohort	85	1-stage, cemented w/ antibiotics	94% at 10 yrs	10 yrs	HHS improved 43→75
Denmark (CORIHA Network)	Lange et al., 2018	Hip	Multicenter prospective	56	Cementless 1-stage protocol	91%	≥2 yrs	Oxford Hip Score improved
Denmark (Single Centre)	Riemer & Lange, 2022	Hip (early PJI)	Case series	18	Cementless 1-stage	100% retention	60 mo	Early PJI ≤6 wks
UK (UCLH)	Haddad et al., 2015	Knee	Comparative cohort	102	Strict protocol 1-stage	0% reinfection vs 7% (2-stage)	≥3 yrs	Better KSS in 1-stage
Austria (Vienna)	Winkler et al., 2008	Hip	Single-centre cohort	37	Uncemented 1-stage, antibiotic allograft	92%	4.4 yrs	Bone graft with AB
Austria (Vienna)	Winkler et al., 2006	Hip + Knee	Mixed cohort	48	1-stage, antibiotic allograft	96% (46/48)	1–7 yrs	Included knees, fixation
France (Paris)	Zeller et al., 2014	Hip	Prospective cohort	157	1-stage, cemented (no AB cement)	95% at 5 yrs	5 yrs	12 wks systemic antibiotics



How Often Do Patients with Chronic PJI Meet One-Stage Exchange Indications? – Dombrowski et al., 2020 CORR

- Study Design: Single-center cohort, ICM criteria audit
- Level of Evidence: IV
- Number of Patients: 162 chronic PJI cases
- Key Outcomes:
 - **Only 21% met ICM criteria for one-stage exchange**
 - Common exclusions: resistant organisms, poor soft tissues
 - One-stage is applicable to a narrow subset of chronic PJIs

Eligibility for One-Stage (Elmenawi et al., AAHKS 2024)

- Study design: Retrospective review
- Level of Evidence: IV
- Number of Patients: 509 two- stage revision TKAs
- Key Outcomes
 - **Only 20% met one-stage criteria**
 - Ineligible pts had 2x higher revision risk (13% vs 7% at 2 yrs)
 - Patient selection is key

Risk Factors for Failure After 1-Stage Exchange TKA in PJI Management - (Helios ENDO-Klinik Hamburg)

- Design: Retrospective case-control
- Level of Evidence: III
- 697 one-stage revisions (2008–2017)
- 91 failures matched 1:1 to controls
- Outcomes: risk factors for re-revision (any cause & reinfection)

Key Findings

- Independent risk factors for reinfection
 - **Previous 1-stage exchange** (OR ~29)
 - **Previous 2-stage exchange** (OR ~6)
 - Enterococcus (OR ~17)
 - Streptococcus spp. (OR ~6)
- Failures mostly <2 yrs

Conclusion

- Failures mainly procedure-related, not comorbidity-driven

Overall Takeaways – European Evidence on Single-Stage PJI Exchange

- Across Germany, Denmark, UK, Austria, and France: ~90–95% infection-free survival in selected patients
- Best outcomes in patients with good host status, favorable organisms, and intact bone/soft tissue, first time infections
- Cementless (Austria) and cemented (France, Endo-Klinik) approaches both effective
- Functional recovery and patient-reported outcomes generally superior to two-stage
- Major limitations: most studies are observational, single-center or regional, with mid-term follow-up



Fehring et al. RCT (AAHKS 2024) – One-Stage vs Two-Stage

Design: Multicenter, randomized controlled trial

Population: 323 patients with chronically infected primary hip or knee arthroplasties (per MSIS criteria, organism identified)

Exclusions: revision cases, fungal infections, immunosuppression, or soft tissue not permitting closure

Randomization:

- 166 patients → one-stage exchange
- 157 patients → two-stage exchange

Treatment Protocol:

- Double surgical setup, identical irrigation
- 6 weeks IV antibiotics → 6 months oral antibiotics

Follow-Up:

- Two-year data available for 234 patients
- Remaining: 21 deceased, 8 retained spacers, 43 lost to follow-up, 17 pending two-year results

Outcome

- Success defined as no reoperation for PJI

Results

One-stage: 97% success (115/118)

Two-stage: 91% success (106/116)

p=0.058 (trend toward superiority of one-stage)

Conclusion

• At two years, one-stage and two-stage approaches achieved **similar success rates**

Two-Stage Revision

Concept & Indications

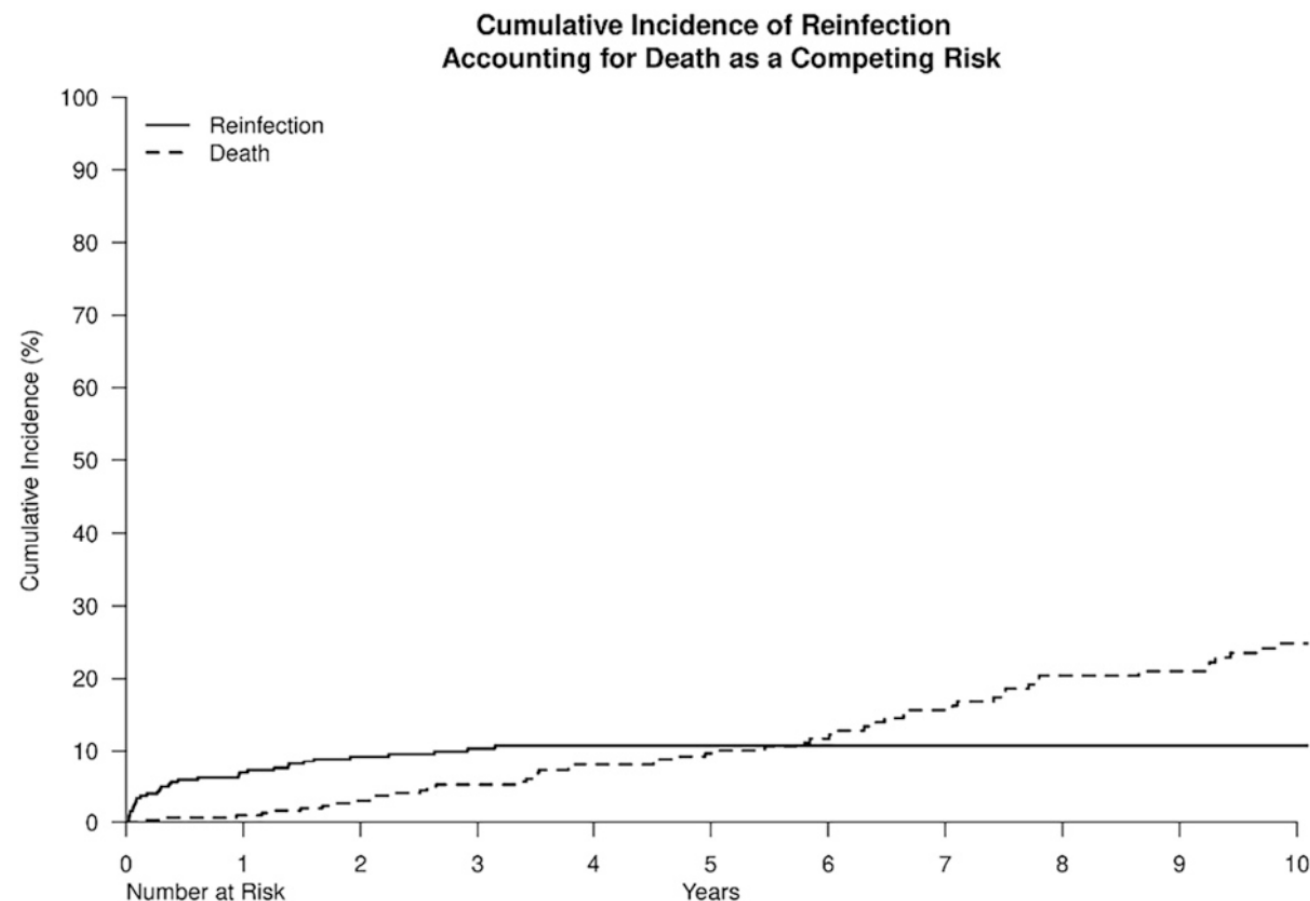
- Remove implants, antibiotic spacer
- IV antibiotics 6–12 weeks
- Reimplant new prosthesis later
- Indications: chronic infection, resistant/unknown organisms, poor soft tissue

Outcomes

- Success 74–96%
- High eradication rates
- Drawbacks: multiple surgeries, higher morbidity, longer hospitalization, cost

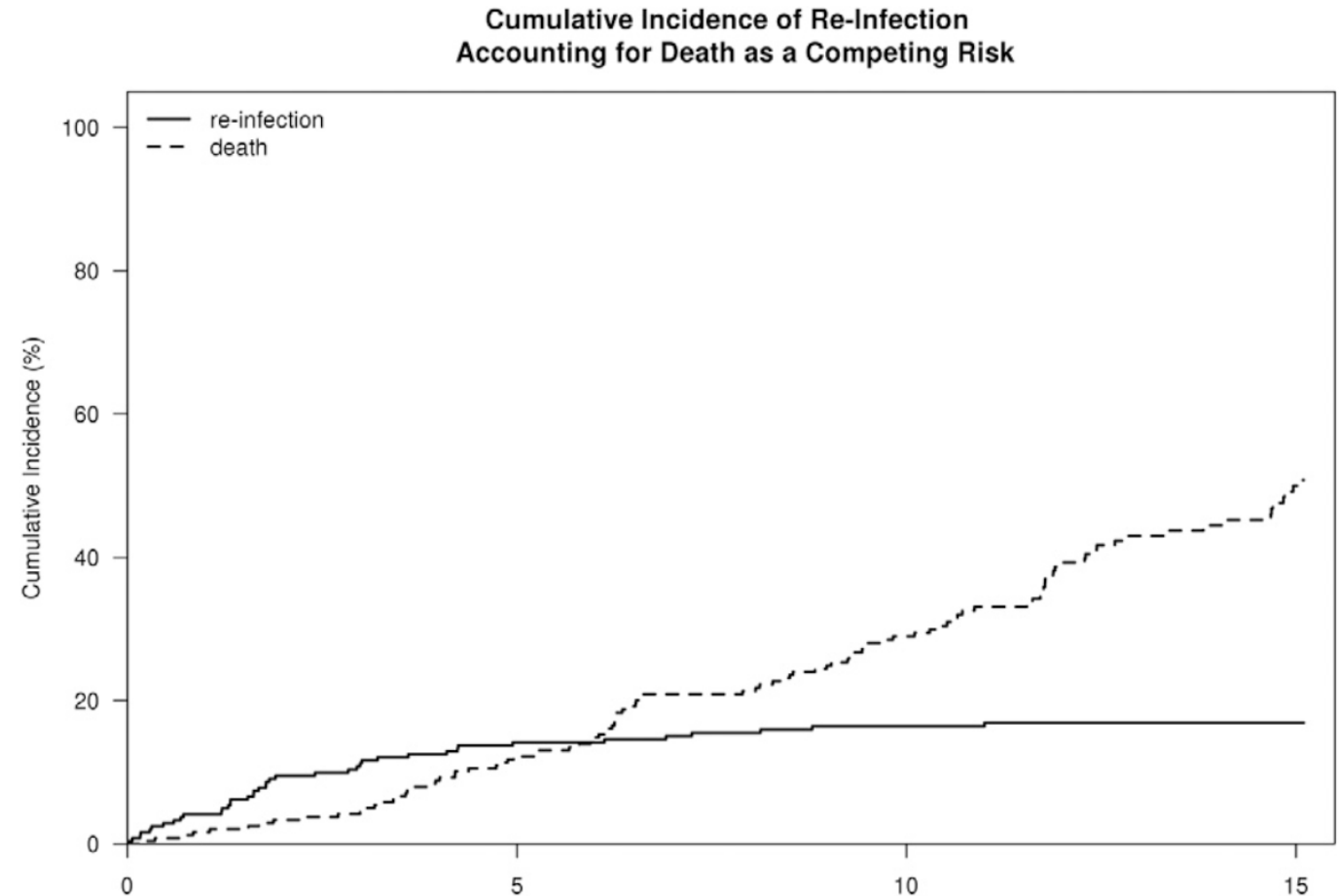
Two-Stage Exchange for PJI After THA: 10-Year Outcomes (JBJS Am, 2025)

- Design: Retrospective cohort, mean follow-up 8 years
- Level of Evidence: III
- Sample size: 331 hips
- Key Findings:
 - **Reinfection:**
 - 7% at 1 yr
 - 11% at 5–10 yrs
 - Any revision ~13% at 5–10 yrs
 - Aseptic revision ~8% at 10 yrs
 - Dislocation ~11% at 10 yrs (risk: female sex, BMI < 30)



Two-Stage Exchange for PJI After TKA (JBJS Am, 2019)

- Design: Retrospective cohort, long-term follow-up (mean 14 years)
- Level of Evidence: IV
- Sample size: 245 knees
- Key Findings
 - **Reinfection:**
 - 4% at 1 yr
 - 14% at 5 yrs
 - 16% at 10 yrs
 - 17% at 15 yrs
 - Risk factors: BMI ≥ 30 , prior revision, McPherson grade C
 - 2-year mortality ~11%



The Fate of Spacers in PJI Treatment (Gomez et al., JBJS 2015)

- Design: Retrospective cohort
- Level of Evidence: IV
- Sample size:
 - 504 PJIs (326 knees, 178 hips), 1999–2013
- Intervention: Resection arthroplasty + spacer (72% static, 28% articulating)
- Follow-up: Mean 56 months
- Outcomes:
 - Reimplantation in 82.7% (mean 4.2 mo)
 - **Success rate after reimplantation: ~81%**
 - 12% required interim spacer exchange
 - 17% never reimplanted → spacer retention (low success), amputation, arthrodesis, or Girdlestone
 - **Mortality: 6.5% at 1 yr; 10.3% at 2 yrs**

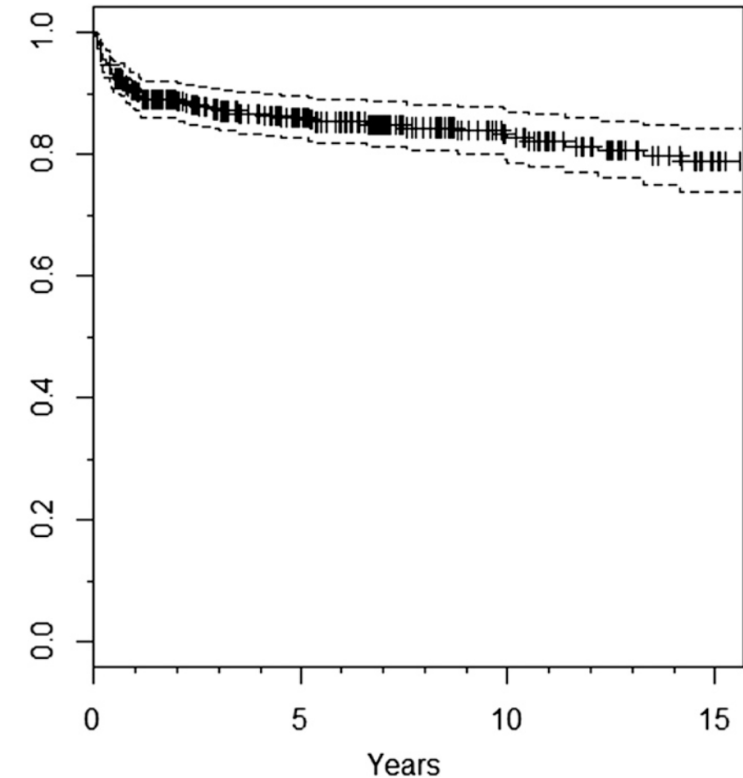


Fig. 2
Kaplan-Meier survivorship curve with treatment failure as an end point. The dashed lines indicate the 95% confidence interval.



Long-Term Outcomes of Two-Stage Revision (Chronic PJI – Knee)

- Retrospective review, 178 patients, mean follow-up 6.6 yrs (range 2–22)
- Level of Evidence: IV
- Infection eradication: **85.4% overall; 89% with ≥ 5 yrs follow-up**
- Failures:
 - **14.6% reinfection overall**
- Mortality: 30% overall; 33% at ≥ 5 yrs
- Organism risk:
 - Streptococcus: 47% failure
 - Polymicrobial: 28.6% failure
 - MRSA: 23% failure



Two-Stage Exchange Arthroplasty for PJI – U.S. Outcomes

- Systematic review (65 studies, 26,354 patients, 2014–2024)
- 29% THA, 69% TKA
- Infection eradication: **~74%**
- Reinfection rate: **~16%**
- MSIS-defined success: **~56%**
- Mortality: **~7–8% interstage, ~6% post-reimplantation**
- Risk factors for failure: diabetes, CKD, obesity, resistant organisms, advanced age, comorbidities



Clinical Outcomes After Revision Hip Arthroplasty Due to PJI

- Study Design:
 - Retrospective single-center study (Finland, 2008–2021)
- 369 hips revised for PJI, ≥ 1 year follow-up
- Interventions: DAIR (134), One-stage (114), Two-stage (121)
- Key Findings:
 - **Reoperation at 1 year: Overall 26.6%**
 - **DAIR: 36.6% (highest)**
 - **One-stage: 20.2% (lowest)**
 - **Two-stage: 21.5%**

Klemm et al., 2021 – Single-Stage Revision in Infected TKA

- Study Design
 - Retrospective cohort with propensity score matching
- Population: 185 patients with chronic periprosthetic joint infection (PJI) after TKA (2015–2018)
- Single-stage (53) v Two-stage (132) revision patients
- Two-stage revision: 132 patients
- Key Findings
 - **Reinfection: 25.0% vs 27.2%**
 - **Amputation: 2.2% vs 1.1%**



A Brief Word on 1.5 Stage

- **One-and-a-Half-Stage Exchange vs Two-Stage for Hip PJI: Clinical Outcomes & Survivorship**
- Study Design: Multicenter retrospective cohort
- **Level of Evidence: III**
- Number of Patients: 105 (1.5-stage THA) vs 135 (two-stage THA)
- Key Findings: **1.5-stage provided non-inferior infection eradication compared to two-stage.**
- **Permanent Articulating Spacers vs Two-Stage Exchange for Chronic PJI**
- Study Design: Retrospective propensity-matched cohort
- **Level of Evidence: III**
- Number of Patients: 92 (permanent spacers) vs 92 (two-stage)
- Key Findings: **Infection control rates were similar.**

Comparative Summary

- DAIR: Early/acute, less invasive, 45–70*%
- One-Stage: Known organism, faster rehab, 80-97%
- Two-Stage: Chronic/resistant, 74–96%



Emerging Directions

- Local antibiotic delivery systems
- Biofilm-targeted therapies
- Suppressive antibiotics for non-surgical candidates
- Unified PJI definition
- Expanding role of One-Stage Revision

Unified Criteria for PJI – ICM 2025

Unified Criteria for Periprosthetic Joint Infections (PJI)

Standalone criteria

Clinical features

- A sinus tract communicating from the joint to the outside environment that develops or persists after the incision has or should have healed

Microbiology

- Two positive cultures with a phenotypically indistinguishable organism from periprosthetic tissue
- One positive culture from synovial fluid or sonicate fluid PLUS one positive culture from periprosthetic tissue with a phenotypically indistinguishable organism

Inflammatory markers and histology

- Synovial leucocyte count >3000 cells/ μ L
 - Synovial polymorphonuclear cells >75%
 - Positive histology: 5 or more neutrophils in each of 5 or more high power fields (400x)
- All without any alternative explanation¹

Specificity >95%

Supportive criteria

Microbiology

- A single positive synovial fluid, sonicate fluid or periprosthetic tissue culture
- A positive molecular test of any organism in synovial fluid, tissue or sonication fluid

Imaging

- A positive WBC-scintigraphy³
- A positive [¹⁸F]-FDG-PET/CT when performed more than 6 months after the index arthroplasty⁴

Inflammatory markers

- Synovial leucocyte count 1500 - 2999 cells/ μ L
- Synovial polymorphonuclear cells 65 - 74%
- Any alternative positive synovial fluid biomarker⁵

All without any alternative explanation¹

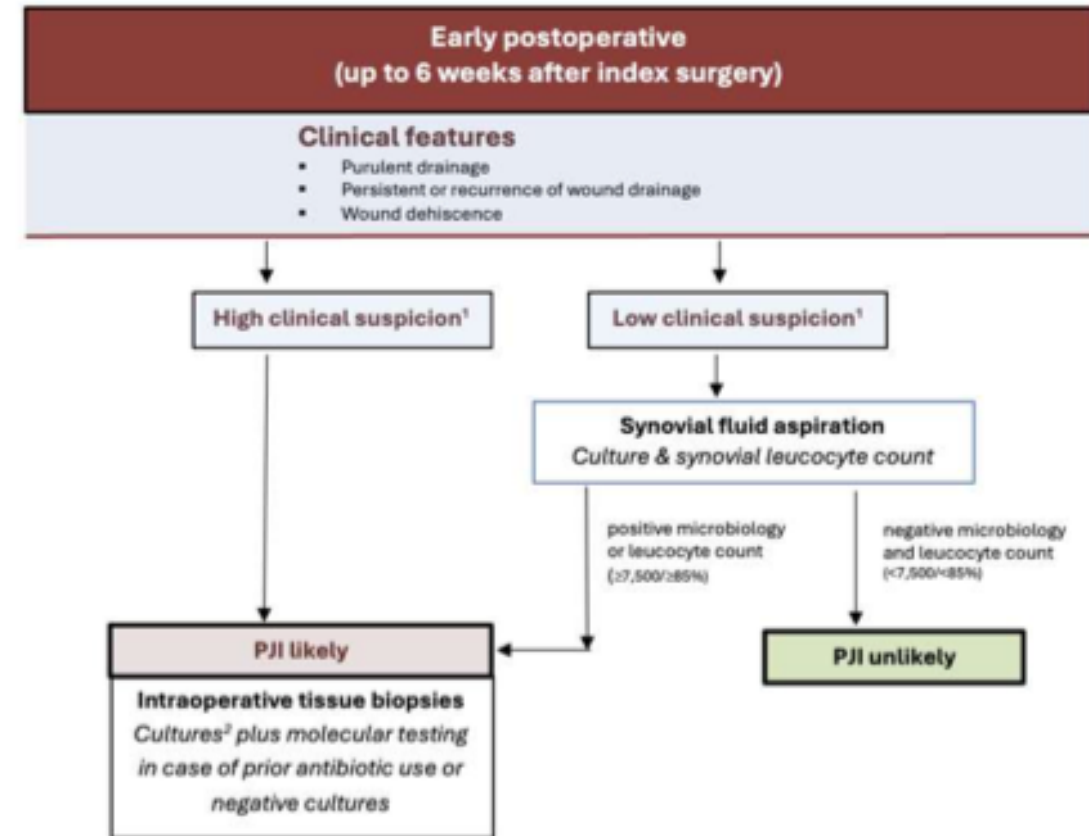
Specificity >80%

Confirmed PJI

One standalone criterion in any category

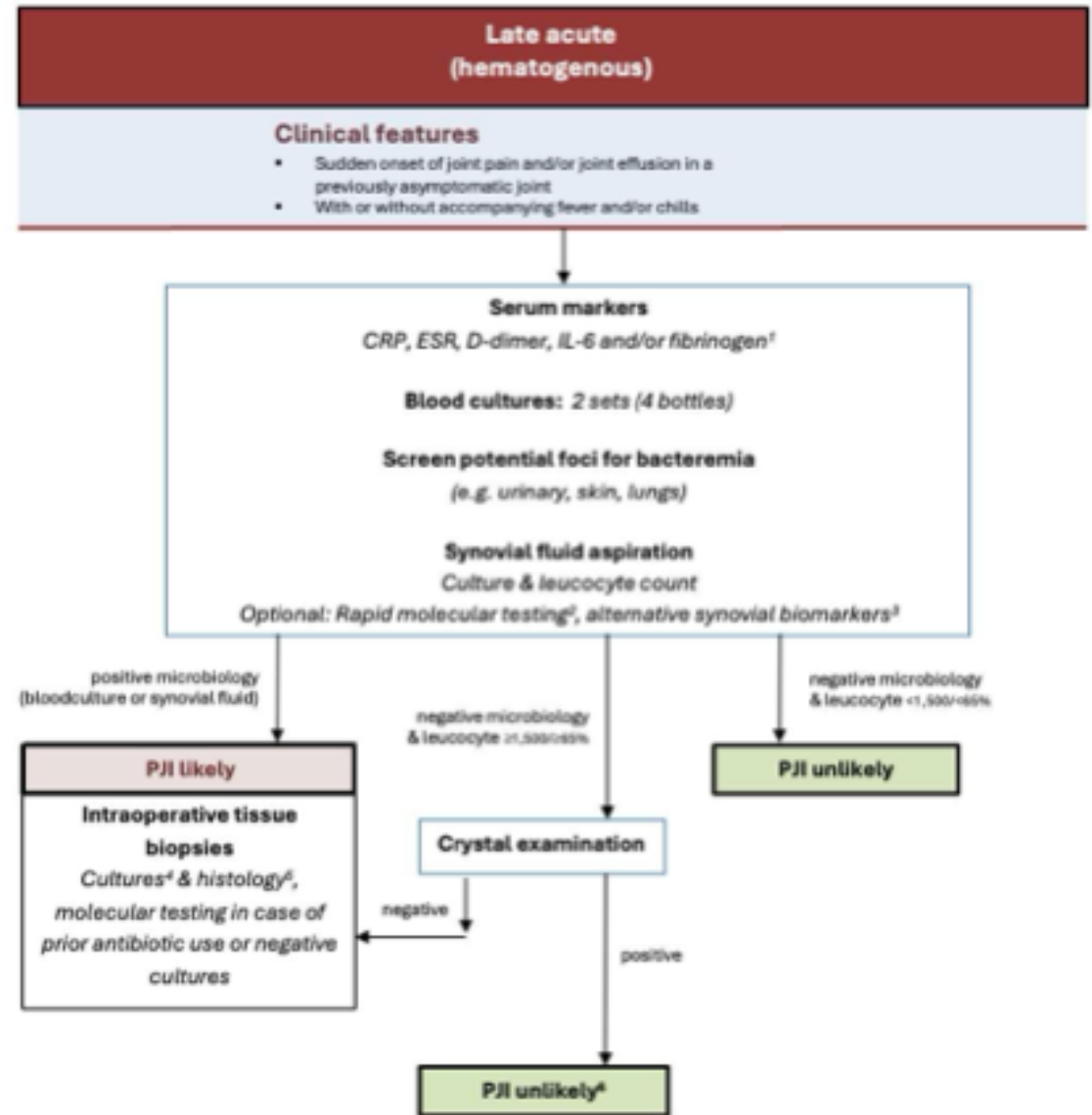
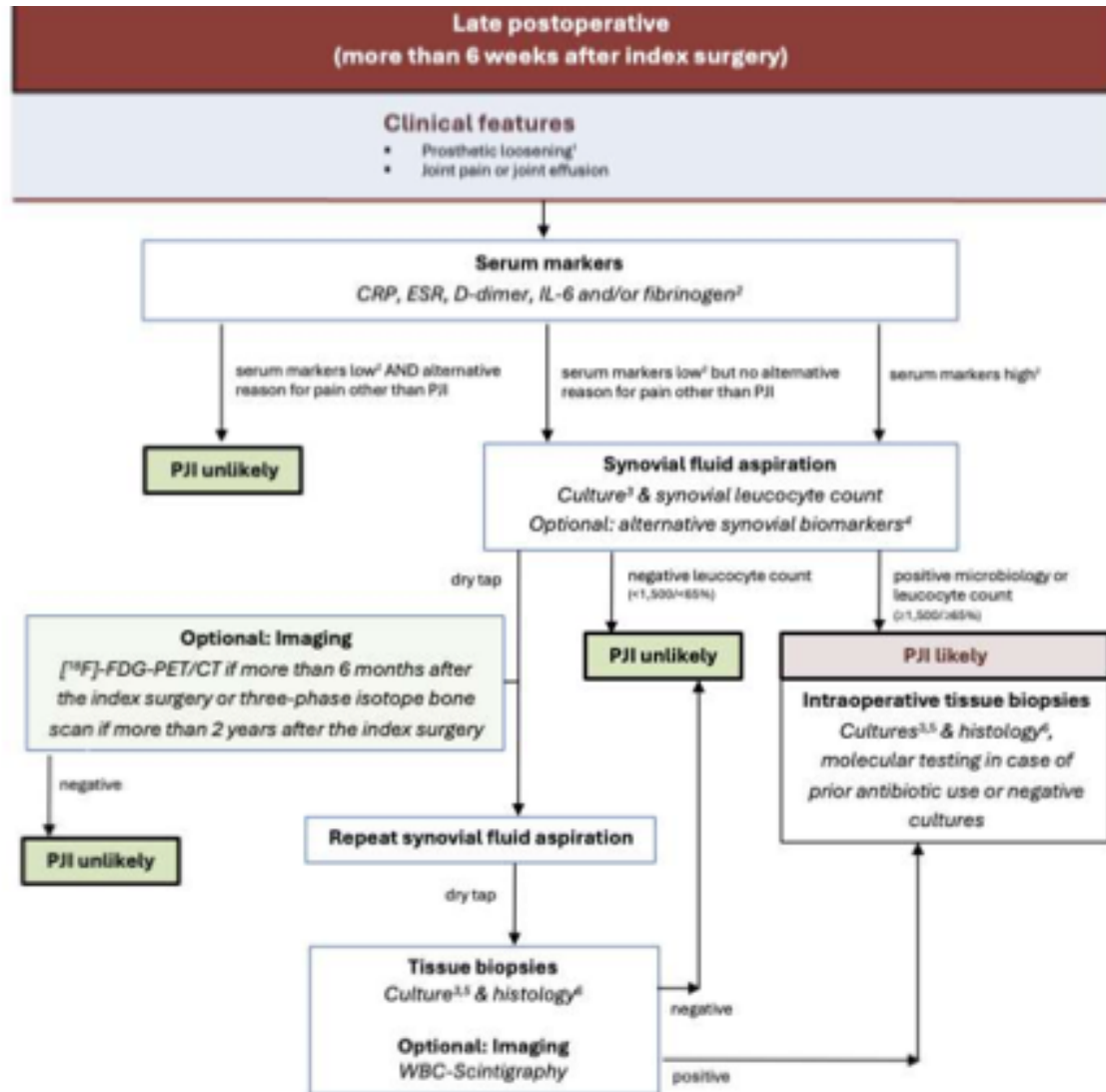
Probable PJI

One supportive microbiology criterion PLUS one supportive inflammatory criterion or imaging criterion



¹High clinical suspicion: purulent drainage or any drainage from day 8 post-operatively, especially when drainage is increasing or reoccurs

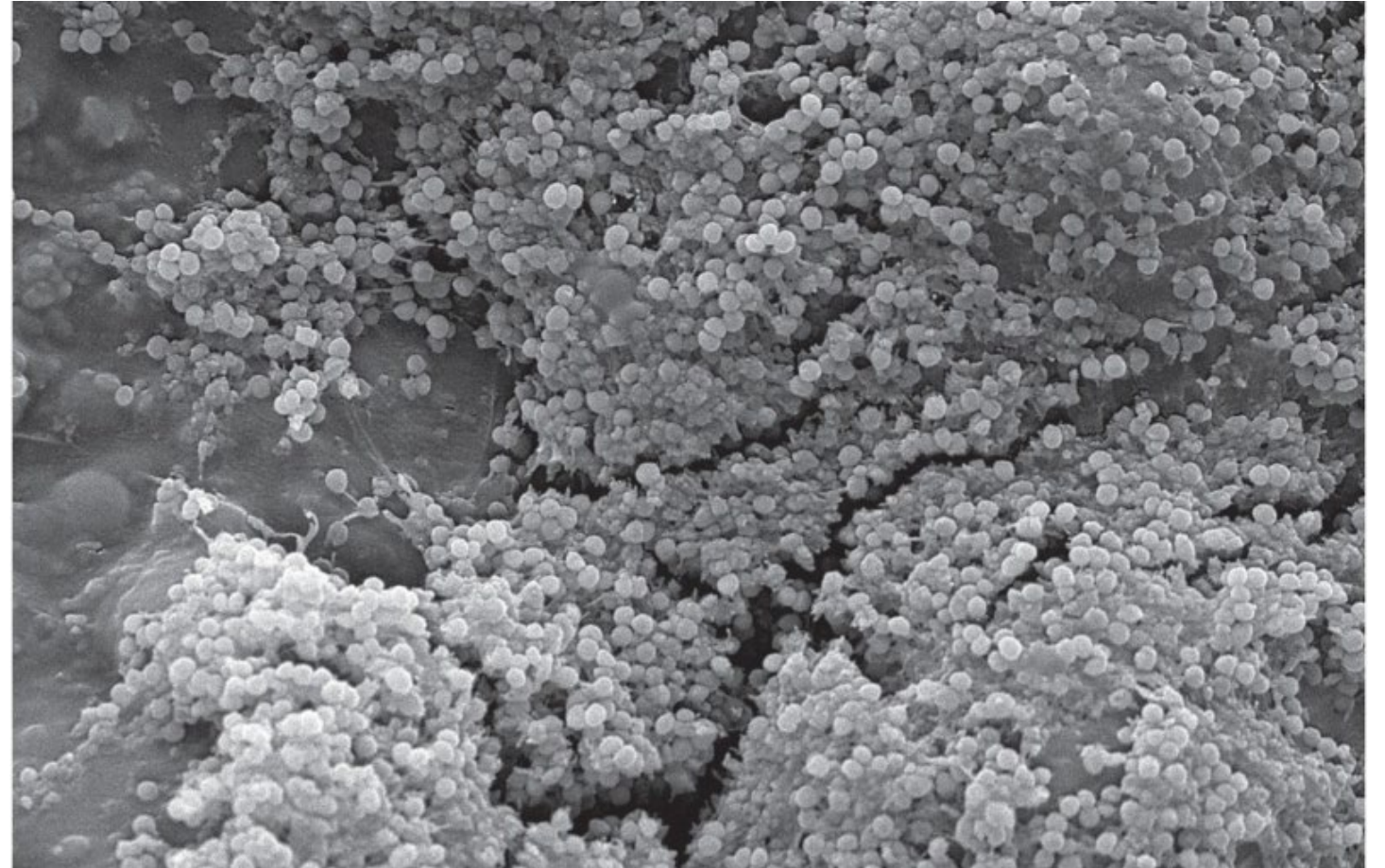
Unified Criteria for PJI – ICM 2025





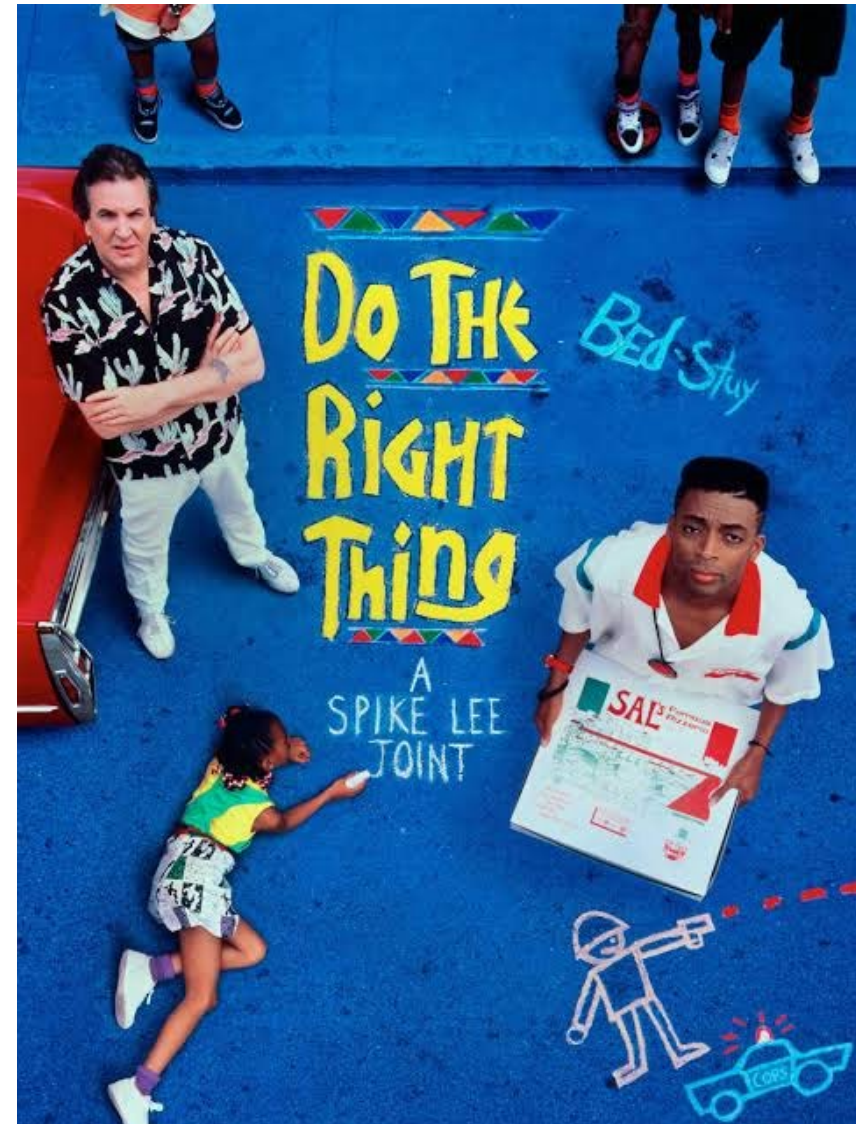
Decision-Making Factors

- Infection: timing, organism, resistance
- Patient comorbidities, immune status
- Implant stability, bone loss
- Institutional expertise
- Shared decision-making



Take-Home Messages

- DAIR
 - option only in acute cases
- One-Stage
 - good option in select cases
- Two-Stage
 - standard for chronic/resistant cases



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DAIR, 1-stage, 2-stage: Where do we stand in 2025

ELI KAMARA, MD, FAAOS, FAOA
ASSOCIATE PROFESSOR
EKAMARA@MONTEFIORE.ORG

Direct Inpatient Medical Costs of PJI vs Aseptic Revisions (JBJS Am, 2021)

- Design: Retrospective economic analysis
- Level of Evidence: Economic IV
- Sample size: 176 THA + 266 TKA 2-stage PJIs vs >2,800 aseptic revisions
- Key Findings:
 - - 2-stage PJI cost ~\$58k (THA) / \$57k (TKA)
 - - Roughly 2× the cost of aseptic revisions
 - - I&D for PJI also ~2× cost of aseptic partial exchange
 - - Highlights substantial

Large Registry Review (MSIS 2025) – Two-Stage

- • 359 PJIs (hips & knees)
- • 2.4-yr infection-free survival = 51%
- • 27% required additional revision
- • 7% mortality during follow-up

Candida PJI Multinational Study (MSIS 2025)

- • 269 fungal PJIs
- • Two-stage success = 69.2%
- • Better than DAIR (46.9%),
similar to one-stage (67.1%)
- • Highlights aggressive
approach for fungal PJI

Two-Stage Revisions in Revision TKA (AAHKS 2024)

- • High morbidity after two-stage revision TKA
- • 90-day readmission = 26%, reoperation = 31%
- • 1-yr mortality = 3%
- • Only 63% retained implants at 3.4 yrs