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INTERVIEW


Yutaka Inaba

From a foundational fellowship with the late, great Dr. Lawrence Dorr to his own pioneering work in Japan, Dr. Yutaka Inaba has built a career on the relentless pursuit of surgical precision. He channeled his experience in computer navigation to tackle the unique challenges of developmental dysplasia of the hip, developing novel techniques and systems. Now a leader in both robotics and PJI treatment, he discusses his journey, his mentors, and his vision for the future.

MO: To begin, could you tell our readers about your background? Where were you born and raised?

Yutaka Inaba (Y.I.) : I was born in Tokyo. During my childhood, my family and I moved to Kanagawa Prefecture, where Yokohama is the largest city. I have worked at Yokohama City University for 25 years and still live in the prefecture, in Kawasaki City, which is about a 50-minute drive from my university. We are also excited to host the upcoming WAIOT congress in Yokohama.

MO: What led you to pursue a career in medicine, and specifically, why did you choose to become an orthopedic surgeon? Was there a family influence?

Y.I.: Yes, my father was a medical doctor, and watching him as I grew up inspired me to become a doctor as well. During my time as a medical student and resident, I developed a passion for surgery. Initially, I intended to become a general surgeon, perhaps focusing on gastrointestinal surgery. However, I met one of my key mentors during my residency, Dr. Kikkawa, a Japanese orthopedic surgeon, who inspired me to enter the orthopedic field.

MO: You also spent time training in the United States. Could you tell us about that experience and your mentors there?

Y.I.: I studied abroad in the United States, spending almost a year from 2004 to 2005 at the Dorr Institute in Los Angeles. There, Dr. Lawrence Dorr, a very famous surgeon who sadly passed away in 2020, became a great mentor to me. I respect him immensely and miss him. During my fellowship, I worked with Dr. Dorr on computer navigation for total hip arthroplasty. At the time, he was developing a new system for minimally invasive total hip arthroplasty using computer navigation, and he was always pushing the field forward. This experience was foundational, and after returning to Japan, I continued my studies in computer navigation.

OVERVIEW

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MO: How has that fellowship influenced your current practice? Do you still use navigation, and have you incorporated robotics?

Y.I.: Absolutely. It is a direct continuation. After I left Dr. Dorr's institute, he went on to develop a robotic system for total hip arthroplasty. Today, I use both computer navigation and robot in my practice. Upon my return to Japan, I developed a navigation system specifically for hip osteotomy. This procedure is common in Japan due to the high number of patients with developmental dysplasia of the hip (DDH), but it is technically demanding. About 15 years ago, I developed a computer navigation system to perform these osteotomies more safely and accurately, and we are still using it.

MO: What are the primary benefits of using navigation and robotics in hip arthroplasty?

Y.I.: The main benefit is precision. For both total hip arthroplasty and osteotomy, we can perform the surgery with much greater precision. A major complication in total hip arthroplasty is dislocation, and preventing this requires very accurate implant positioning, including the cup and stem. With navigation and robotic software, we can create a very precise pre-operative plan and then execute it with a high degree of accuracy during surgery.

MO: Is this technology even more critical for patients with hip dysplasia?

Y.I.: Yes, that's correct. In general, total hip arthroplasty for a patient with hip dysplasia is more difficult than in standard cases. However, several papers have shown good results in dysplastic patients when using this technology. We believe that navigation and robotics are very useful tools for this specific patient population.

MO: You mentioned dislocation. Do you often use dual mobility cups in your practice?

Y.I.: Some surgeons in Japan use the dual mobility system, but I do not use it routinely. According to our Japanese registry, the use of dual mobility cups is about 10% in Japan. This is less frequent than in European countries, partly because the system was introduced to Japan only about ten years ago. My belief is that if we achieve very precise implant positioning, particularly with the aid of navigation, we do not need to use a dual mobility system for all patients.

MO: Do you also use navigation for revision surgery?

Y.I.: Yes, we can use navigation in select revision cases. However, most navigation and robotic systems are developed for primary arthroplasty, so applying them to revision surgery can sometimes be difficult, though it is possible.

MO: What is your approach to pre-operative imaging?

Y.I.: In Japan, CT-based navigation and pre-operative planning are very popular. Many surgeons use CT scans because we have a large number of DDH patients with severe deformities. The CT scan allows us to check the three-dimensional structure of the pelvis and femur, which is essential for our CT-based navigation systems. My interest in this CT-based technology is also why I am heavily involved in the Japanese Society for Replacement Arthroplasty, where many surgeons share this interest.

MO: Could you describe your department at Yokohama City University?

Y.I.: I returned to Yokohama City University in 2005 as an assistant professor and was promoted to professor and chairman in 2018. At our university hospital, we have several specialized teams. My specialties include the hip joint and pediatric orthopedics, a field I worked in for six years at a children's hospital. Our department has a hip joint team and a pediatric orthopedic team, and it is within these teams that we have developed new techniques like computer navigation for osteotomy and other pediatric surgeries. In total, our orthopedic department consists of seven teams: spine, hip, knee and foot & ankle, musculoskeletal tumor, sports medicine, and rheumatoid arthritis. Including fellows, we have 35 orthopedic surgeons in the department.

MO: Given the focus of the upcoming WAIOT conference, how is your department organized to handle periprosthetic joint infection (PJI)?

Y.I.: We do not have a separate team for PJI, but our work in this area began about 20 years ago. We started by using an intraoperative PCR test for the diagnosis of PJI, developing primers for both MRS-specific and pan-bacterial PCR. We also applied imaging technologies like FDG-PET and NaF-PET scans to diagnose infection. This work in molecular diagnostics was our starting point and has led to our involvement in infection societies in Japan and internationally, including the recent consensus meeting in Istanbul.

MO: For diagnosing PJI, do you use Japanese-specific criteria or international guidelines?

Y.I.: We do not have specific criteria in Japan. Most Japanese orthopedic surgeons use the international consensus meeting criteria.

MO: Culture-negative PJI is a significant challenge. How do you approach diagnosis in these difficult cases?

Y.I.: To diagnose culture-negative PJI precisely, we use PCR tests and extend the culture incubation period to about two weeks. We use sonication, but only for difficult cases where we suspect culture-negative PJI. If we can already detect an organism, we do not perform sonication, as we reserve those resources for the more challenging diagnostic situations.

MO: What is your primary treatment strategy for PJI? Do you favor one-stage or two-stage revisions?

Y.I.: Previously, we considered two-stage revision surgery the gold standard. However, a new technique called Continuous Local Antibiotic Perfusion (CLAP), developed by Dr. Akihiro Maruo in Japan, is gaining popularity. This technique allows us to retain the implant, so we now perform one-stage revision surgery with CLAP for most cases. We reserve two-stage surgery for very difficult cases with huge bone defects. This technique will be discussed by several Japanese speakers at the upcoming WAIOT meeting.

MO: The CLAP technique sounds interesting. Does it require a long hospital stay?

Y.I.: Yes, the hospitalization period in Japan is quite long due to our national insurance system, which allows patients to stay longer. The average hospitalization for a PJI patient can be 40, 50, or even 60 days. This extended stay allows us to manage the CLAP treatment, though we recognize this might be difficult to implement in other parts of the world.

MO: When you do perform a two-stage revision, what is your protocol for antibiotic spacers and reimplantation?

Y.I.: For spacers, we first try to identify the causative pathogen with a PCR test. Typically, we use vancomycin and gentamicin. For difficult-to-treat fungal infections, we incorporate anti-fungal drugs into the cement. If the structural integrity of the cement is compromised, we use static spacers made of a special hydroxyapatite block that contains antibiotics and releases them gradually. Local antibiotics are a very important part of our treatment algorithm, and we combine this with IV antibiotics, usually for 12 weeks in revision cases. For reimplantation, we use cement loaded with a dual combination of gentamicin and vancomycin.

MO: How do you manage severe acetabular bone loss during reconstructions?

Y.I.: We typically use an allograft combined with cages. For about 15 years, our practice has been to soak the allograft bone in a saline solution containing antibiotics for 10 to 15 minutes before using it to reconstruct the defect. We believe recreating the bone stock is a better long-term solution than implanting a large piece of metal. This more conservative philosophy of preserving bone seems to be a point of commonality between Japanese and European surgeons, in contrast to the more widespread use of large porous metal implants in the United States.

MO: You are hosting the WAIOT conference in Yokohama next month. Could you tell us more about the society and the event?

Y.I.: I became involved with WAIOT seven years ago at the recommendation of Professor Tsuchiya, the current president. He asked me to host this fourth meeting in Yokohama, which will take place on July 23rd and 24th. It's a two-day meeting, and we have already accepted 80 papers from 16 countries. The program will feature sessions with esteemed WAIOT faculty like Dr. Tsuchiya and Dr. Carlo Romano, presentations on current topics in bone and joint infection, and valuable case reports from abroad. Additionally, members from Japan will present their clinical results with the CLAP technique.

MO: Why is Yokohama a good location for this conference?

Y.I.: Yokohama is the second-largest city in Japan and a beautiful, historic port town. It is very conveniently located, only a 30-minute train ride or drive from central Tokyo and Haneda Airport. We have a large and convenient conference and convention center, which is why we are also hosting the 100th anniversary of the Japanese Orthopedic Association here in two years. There are many good reasons to come to Yokohama.

MO: What are your professional projects for the future?

Y.I.: I will be organizing several large meetings in the coming years. I will hold the Japanese Pediatric Orthopaedic Society meeting on this November, and the annual meeting of the Japanese Society for Joint Diseases next year. I am set to hold the annual meeting of the Japanese Society for Study of Bone and Joint Infections in 2027, and in 2028, I will hold both the Japanese Hip Society and the Japanese Society for Replacemet Arthroplasty meetings in Yokohama.

MO: Outside of orthopedics, what are your hobbies and interests?

Y.I.: My main hobby is playing golf. When I was a university student, I played the drums, but I stopped after becoming a doctor. Now, golf is the only sport I play. While there are not many courses directly in the busy cities of Tokyo and Yokohama, there are many good, albeit expensive, courses within a one to one-and-a-half-hour train ride or drive.

MO: Finally, what advice would you give to young doctors who aspire to a successful career in orthopedic surgery?

Y.I.: My advice is to "work hard and play hard." Most importantly, we must be honest with our patients and truly listen to them. I believe there are many important insights contained within the patient's voice. I always tell young doctors to listen carefully to what their patients are telling them. This is essential to becoming a good medical doctor, not just a surgeon. ■

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CHRONIC OSTEOMYELITIS OF THE SMALL TROCHANTER

POSTEROLATERAL SURGICAL APPROACH TO THE SMALL TROCHANTER.

Chingiz ALIZADE

HB Guven Klinika, Baku, Azerbaijan

CASE PRESENTATION

Patient D., 40 years old, woman, was admitted to the reconstructive surgery department of the Azerbaijan Research Institute of Traumatology and Orthopedics on 01/18/2010 (Medical record No. 61) with complaints of pain in the anterior-internal surface of the upper third of the right femur, and presence of fistulas on the lateral surface of the middle third of the thigh.

HISTORY OF PRESENT ILLNESS

According to the patient, in April 2008, pain appeared in the area of the anterior-internal surface of the right thigh. The onset of the disease was not associated with anything specific. She was treated conservatively at a local hospital. Gradually, the pain increased, and swelling appeared on the lateral surface of the middle third of the thigh. On September 15, at a local hospital, the surgeon performed two skin incisions. The patient reports that about 200 ml of purulent fluid was expelled. Since then, one of the fistulas has not healed. Discharge is scant.

CLINICAL EXAMINATION

The patient walks with a limited load on the leg, with a semi-flexed body position, and limps. During walking, tenderness is noted in the groin area.

The patient was examined clinically and radiologically. Fistulography was performed (Figure 1).

The diagnosis was established as: chronic osteomyelitis of the lesser trochanter of the right femur. A surgery was performed — resection of the right femur's lesser trochanter, necroectomy.

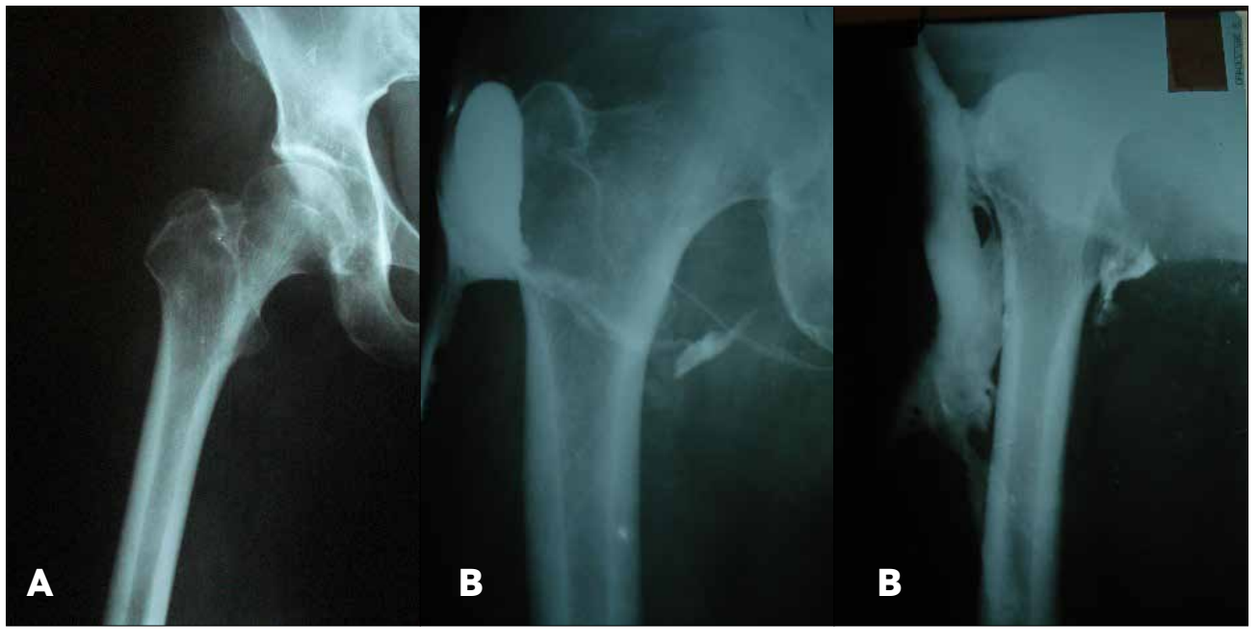

Figure 1 : X-ray images of patient D. A — upon admission, B — fistulograms.

SURGICAL PROCEDURE

The surgical approach was as follows: After tightly filling the fistulous tract with a solution of green dye and hydrogen peroxide along the posterolateral surface of the lower third of the right femur just below the greater trochanter, a skin incision approximately 12 cm in length was made (Figure 2 A).

The subcutaneous fat tissue was separated and the fascia lata of the thigh was exposed. A cavity stained with green dye was found in the area of the lateral surface of the thigh. The fistulous tract extended between the m. tensor fasciae latae and the tendinous part of the m. gluteus maximus to the posterior surface of the femur. A fascial incision was made at the junction of the gluteus maximus and the fascia lata, transitioning into the iliotibial tract directed toward the posterior surface of the femur (Figure 2 B). The limb was rotated inward. During wound revision, a fistulous tract was found, extending along the upper edge of the m. quadratus femoris to the lesser trochanter. The m. quadratus femoris was bluntly separated from its attachment to the femur, and the lesser trochanter was exposed in the wound (Figure 3).

During revision, it was noted that the m. iliopsoas was completely separated from the lesser trochanter. The lesser trochanter lacked periosteum and felt rough to the touch. Surrounding it was a cavity filled with necrotic tissue stained with green dye. A resection of the lesser trochanter was performed. The specimen showed green dye penetrating inside the lesser trochanter (Figure 4).

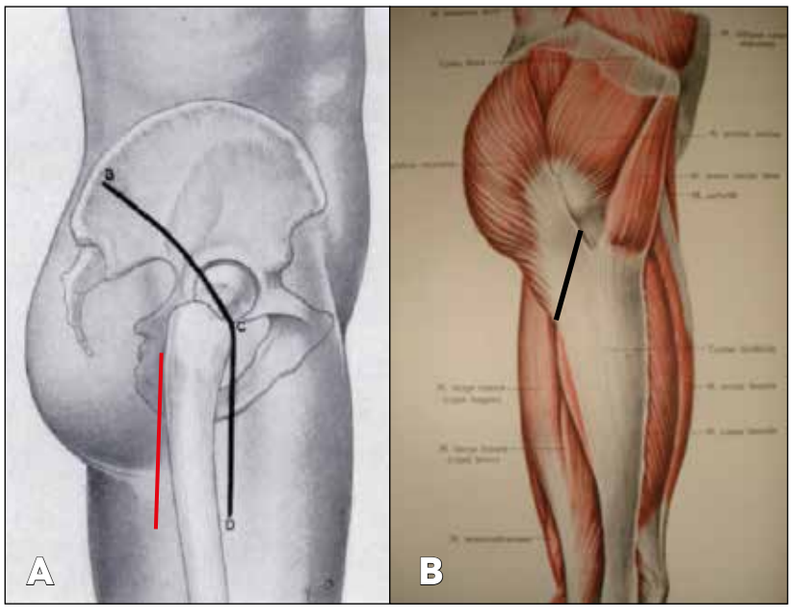

Figure 2 : (A) - Gibson incision (black line). The incision proposed by us - red line. (B) - Fascial incision.

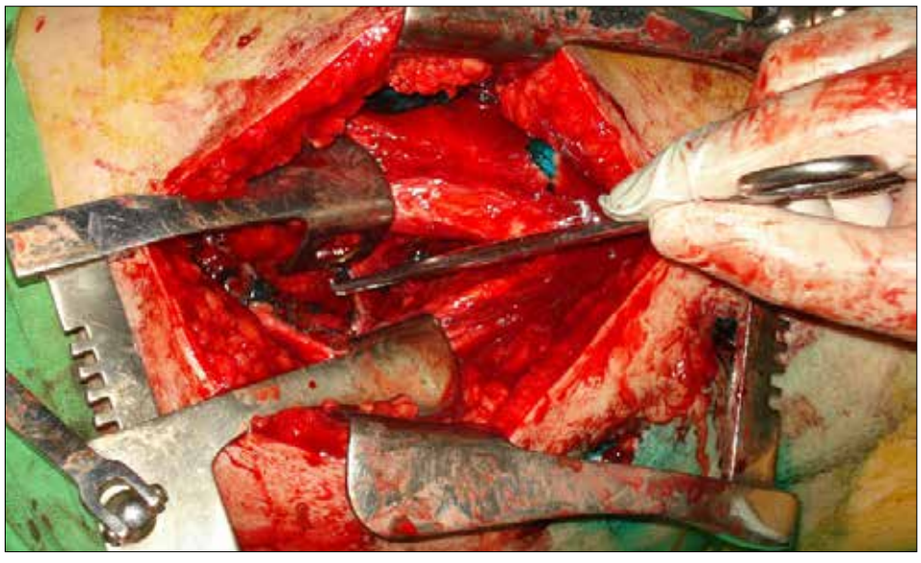

Figure 3 : View of the surgical wound — the lesser trochanter is indicated with forceps. Necrotic tissues, stained green, are visible.

Figure 4 : Specimen — resected lesser trochanter.

Figure 5 : View of the surgical wound during treatment.

Necroectomy was carried out. The wound was drained with a tube. Sutures were placed on the fascia, subcutaneous tissue, and skin. The wound healed primarily (Figure 5).

The patient began walking without pain. Discharged on 02/03/2010.

DISCUSSION

In the literature available to us, we found surgical approaches to the lesser trochanter used in tumors in this area. The approach was performed from the anterior-medial surface (1971) [1]. R.E. Zhitnitsky (1976) [2] described the Gibson approach for surgical treatment of tumors in the region of the lesser trochanter and the posteroinferior surface of the femoral neck. In this approach, access to the lesser trochanter is through the distal part of the Gibson approach. The A. Gibson surgical approach is a modification of Kocher's approach, published by him in 1950 [3]. The skin incision for this approach begins at the posterior superior iliac spine and the anterior angle of the greater trochanter. The author then describes the now well-known sequential approach to the hip joint, without mentioning anything about the lesser trochanter. This approach to the hip joint was also described by V.D. Chaklin in 1964 [4]. Amr S. (1998) described a modification of the A. Gibson approach, but this modification also related to access to the hip joint [5].

In the sectional anatomy atlas by Torsten B. Moeller (2000), a cross-section at the level of the lesser trochanter is shown (Figure 6).

The approach we used is indicated by arrows and passes, bypassing the main muscle groups of the thigh and neurovascular bundles. Particular caution is required when separating the m. quadratus femoris from the femur, as the sciatic nerve runs immediately behind it.

Thus, this case is of interest from two perspectives. On one side, it involves chronic osteomyelitis of the lesser trochanter — a rarely encountered localization. The etiology of the disease is unclear. Possibly, a sudden abduction of the thigh led to detachment from the attachment site of the m. iliopsoas, followed by self-infection of the hematoma and subsequent development of osteomyelitis of the lesser trochanter. The fistulous tract extended from the lesser trochanter along the posterior-lateral surface of the femur and exited into the subcutaneous space between the m. tensor fasciae latae and m. gluteus maximus. Interestingly, the pus did not spread under the m. gluteus maximus or under the m. tensor fasciae latae, as described by V.F. Voyno-Yasenetsky (2000) [7]. Presumably, this is why the incisions made along the patient's residence achieved their purpose.

On the other hand, this is a surgical approach to the lesser trochanter that can be considered a modification of the A. Gibson approach and allowed for atraumatic resection of the lesser trochanter and debridement of this area. ■

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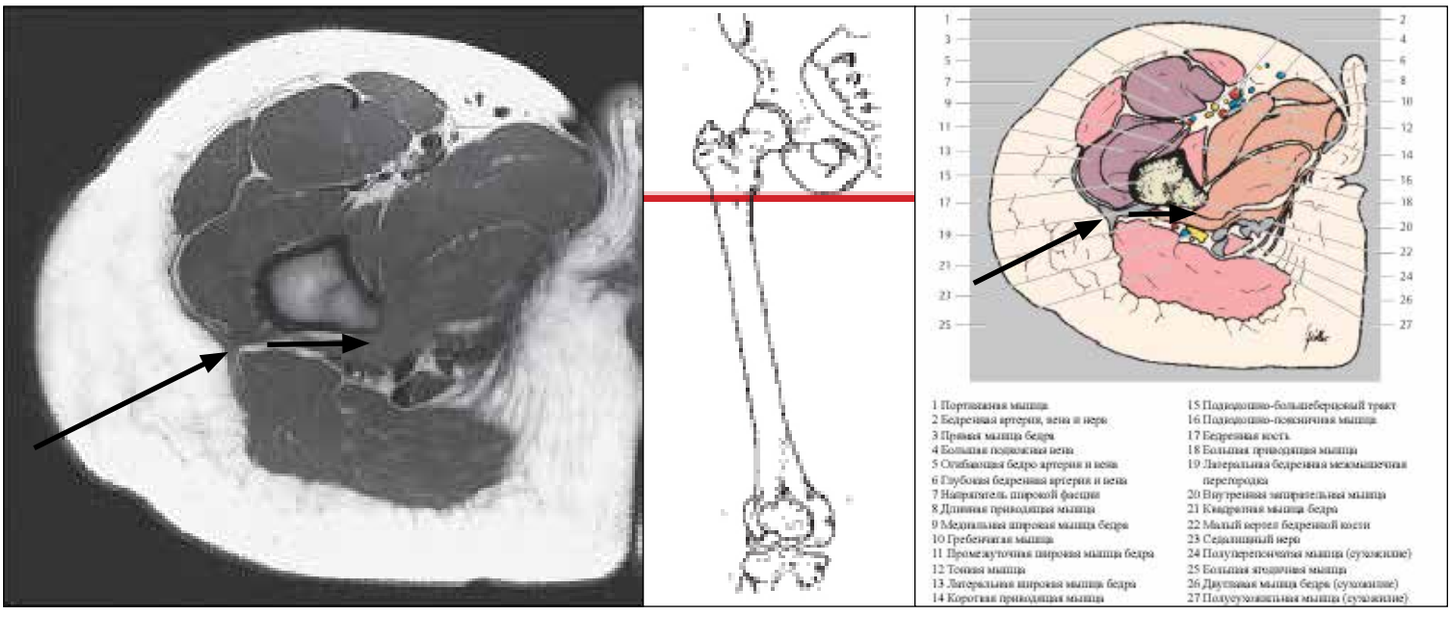

Figure 6 : Computed tomography slice at the level of the lesser trochanter and its diagram (arrows indicate the approach to the lesser trochanter).

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THE SAMPLE'S JOURNEY IN ORTHOPEDIC IMPLANT INFECTIONS

FROM THE OPERATING ROOM TO THE MICROBIOLOGY LAB

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INTRODUCTION

Implant-related infections (IRIs) represent one of the most feared complications in orthopedic and trauma surgery [1]. These infections can affect joint prostheses, internal fixation devices, and other biomaterials, often leading to prolonged treatments, multiple surgeries, and poor functional outcomes [2]. One of the main challenges in diagnosing these infections lies in the behavior of the causative microorganisms, which frequently reside within biofilms — structured communities that adhere to implant surfaces and resist both antibiotics and immune responses [3-5].

Correct identification of the responsible pathogens is fundamental to plan adequate antimicrobial therapy and surgical strategies [6]. However, microbiological diagnosis is highly dependent on the quality of the sample collection and handling process. The pre-analytical phase — often underestimated — includes all steps from intra-operative sampling to laboratory processing, and each step carries a risk of error that may compromise the final diagnosis [7].

In this review, we describe the current procedures for intra-operative sampling and biofilm-targeted pretreatment strategies prior to culture analysis. We emphasize the critical impact of false negatives (missed infections) and false positives (contaminants misidentified as pathogens), both of which can lead to inappropriate therapy, extended hospital stays, unnecessary surgeries, and increased costs. Analysis estimated that a single false negative in prosthetic joint infection can incur more than €49.000 in additional patient costs, while a single false positive may generate over €8.500 in unnecessary treatments and follow-up expenses [8]. The following sections cover best practices for sampling, handling and transport of explanted materials, chemical biofilm disruption techniques, and workflow optimizations to minimize diagnostic errors. The goal is to provide a clear guide to support clinicians, microbiologists, and healthcare teams in optimizing diagnostic accuracy in implant-related infections.

SAMPLING: CURRENT INTRA-OPERATIVE PRACTICES

Accurate intra-operative sampling underpins reliable microbiological diagnosis in IRIs by balancing two objectives: maximizing pathogen recovery (high sensitivity) and minimizing contamination (high specificity).

Sampling must follow a strict, stepwise protocol. The World Association against Infection in Orthopaedics and Trauma (WAIOT) "10-rules" procedure, reported in Figure 1, begins with synovial fluid sampling by fine needle joint aspiration prior to surgery and/or, at surgery, immediately after skin incision—thus avoiding the risk of dragging skin flora into the joint—followed by immediate transfer of the fluid into sterile containers or blood culture bottles. Any purulent exudate at the incision site is likewise collected and sent for culture. Next, a biopsy of the synovial membrane or joint capsule is obtained using sterile instruments for each specimen [9, 10].

Once tissue sampling is complete, prosthetic components or osteosynthesis devices are explanted, usually from 3 to 6 samples [7]. Before handling the device, the surgical team should change gloves and switch to a fresh instrument set. The removed hardware is placed directly—never resting on the operative field or trays—into dedicated sterile, hermetically sealed transport containers [11, 12]. Finally, periprosthetic tissues, bone sequestra or osteolytic fragments at the implant–bone interface are sampled in the same manner. Each specimen—fluid, soft tissue, implant, bone—must be collected with sterile instruments and immediately sealed [13] amcli.it.

The Italian Society of Orthopaedics and Traumatology (SIOT) guidelines reinforce these principles, emphasizing

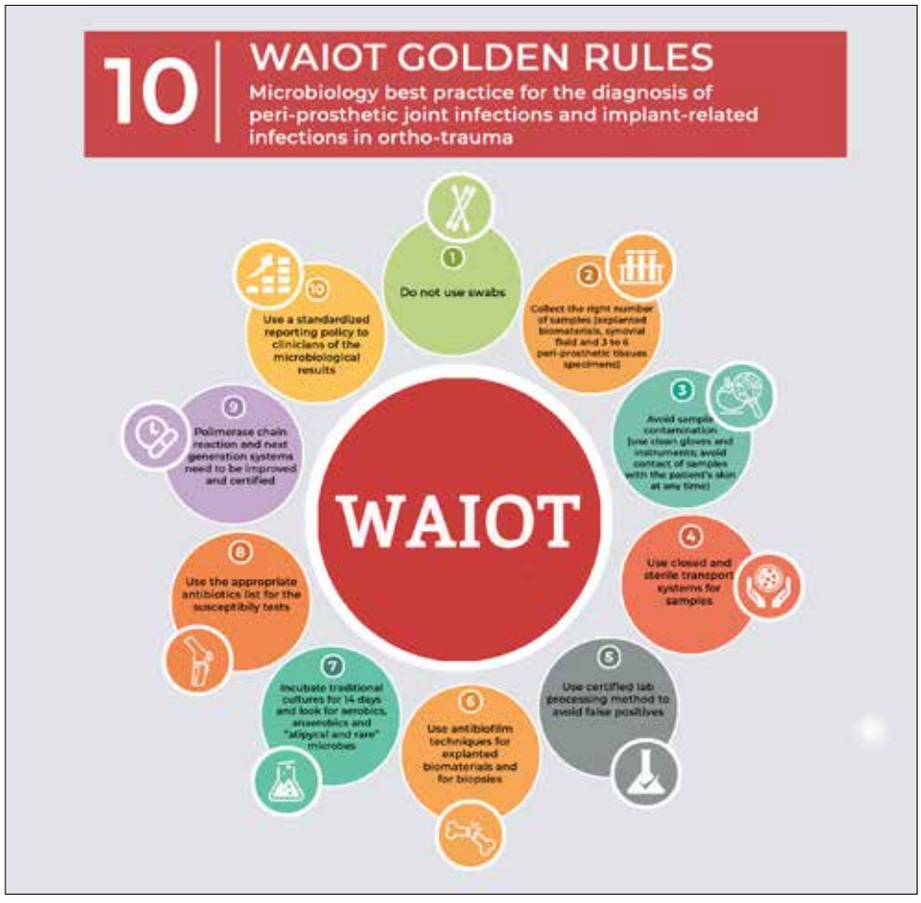

Figure 1 : The 10 WAIOT golden rules.

Figure 2. Intra-operative Sampling Workflow
Stepwise guide to the "sample's journey" in implant-related infections:
(1) synovial fluid aspiration via small incision;
(2) collection of purulent exudate if present;
(3) synovial membrane or joint capsule biopsy;
(4) prosthesis or hardware explant following glove and instrument change;
(5) direct placement of the implant into hermetic transport containers;
(6) periprosthetic tissue and bone sampling with fresh instruments; and
(7) specimen labeling and immediate transfer to the microbiology laboratory at 4 °C.

gloves and instrument changes between each sampling step and strict avoidance of any intermediate handling or surface contact [https://old.giot.it/wp-content/uploads/2018/04/04_Art_LINEE_Guida-1.pdf]. The Italian Association of Clinical Microbiologists (AMCLI) pathway mirrors this sequence—synovial fluid first, then capsule, then implant components, and finally periprosthetic tissue or bone—providing detailed instructions on container choice, labeling, and rapid transfer to the microbiology laboratory [amcli.it].

Adherence to these recommendations (schematized in Figure 2), dedicated tools per specimen, strict asepsis, immediate sealing, and a clear sampling order, lays the groundwork for reliable downstream transport, storage, pretreatment, and culture, thereby reducing both false negatives and false positives.

HANDLING, STORAGE, AND TRANSPORT OF SAMPLE

Proper handling and transport of intra-operative specimens are critical to preserving pathogen viability and preventing overgrowth of contaminants. As soon as each sample is collected, it should be sealed in its dedicated sterile, hermetic container in the operatory room [World Health Organization, 2012. Guidance on Regulations for Transport of Infectious Substances 2013-2014, World Health Organization. Switzerland. Retrieved from https://coilink.org/20.500.12592/crmmz2 on 25 May 2025. COI: 20.500.12592/crmmz2.]. Clear labeling directly on the container—indicating patient identifiers, anatomical site, date and time of collection, and collector's initials—ensures accurate tracking A standardized request form, detailing relevant clinical information such as recent antibiotic therapy and the patient's comorbidities, must accompany every specimen [14].

Tissue, bone, and explanted implant components should be kept at 4 °C from collection until they reach the laboratory, if transit exceeds 2 hours. [15, 16]. If immediate transport is not possible, refrigerated storage at 4°C for up to 24 hours is accept-

able, though longer delays increase the risk of bacterial death and false-negative cultures [17-19]. Synovial fluid specimens, when inoculated directly into blood-culture bottles in the operating room, may be held at ambient temperature and processed according to the manufacturer's incubation protocol. Freezing any clinical material is strictly discouraged, as ice crystal formation damages cellular structures and compromises culture yield [20].

For transport, specimens must be placed in rigid, secondary container and clearly separated from any non-clinical items. Courier services or laboratory porters should be notified in advance of time-sensitive shipments to prevent unintended delays. Upon arrival at the microbiology laboratory, each batch of samples is checked against its request form, and a chain-of-custody log is signed to document receipt. Any deviations—such as temperature excursions or prolonged transit times—are recorded promptly.

By ensuring immediate sealing and labeling, strict temperature maintenance, rapid delivery, and meticulous documentation, the integrity of the sample "journey" is preserved, maximizing culture sensitivity and reducing diagnostic errors (Figure 3).

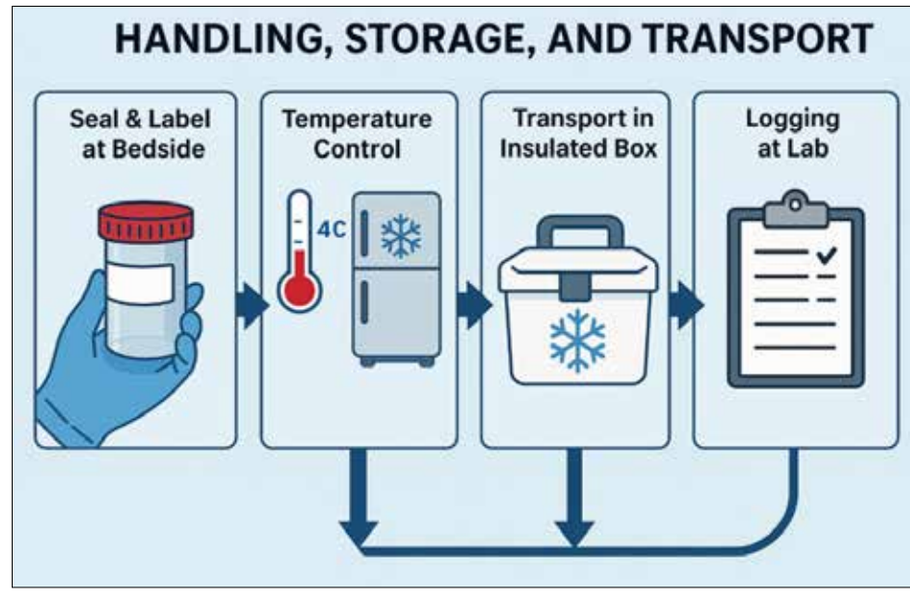

Figure 3. Handling, Storage, and Transport Workflow
Infographic summarizing the post-collection phase:
(1) bedside sealing and labeling of each specimen in sterile, hermetic containers;
(2) maintenance of tissue, bone, and implant samples at 4 °C (up to 24 h) and ambient transport for inoculated blood-culture bottles;
(3) placement in rigid, insulated secondary boxes with cold packs; and
(4) logging and chain-of-custody documentation upon arrival in the microbiology laboratory.

PHYSICAL OR CHEMICAL ANTIBIOFILM PRETREATMENT TECHNIQUES

Routine cultures of biofilm- and implant-related infections may fail or yield false culture-negative results in a significant number of patients, with figures ranging from 5% to 42% in Prosthetic Joint Infections. (PJIs) [21]; to increase the sensitivity, pretreatment of samples have been proposed to liberate biofilm-embedded bacteria. Validated antibiofilm strategies include sonication and chemical biofilm debonding with dithiothreitol (DTT).

Physical antibiofilm pretreatment with Sonication

Implanted components are submerged in sterile fluid and exposed to low-frequency ultrasound waves (typically 40–50 kHz for 5–10 minutes) [22]. Cavitation disrupts the extracellular polymeric matrix, releasing bacteria into suspension for culture [23, 24]. The SIOT recommends sonication exclusively for explanted hardware (excluding cement), with quantitative thresholds (≥50 CFU/mL sonicate or ≥200 CFU/mL concentrated sonicate) indicating infection [25]. Advantages include wide availability in high volume orthopedic surgery centers and proven efficacy [26]; limitations are equipment cost, operator dependency, maintenance of the sonicator, potential bacterial damage if parameters are not strictly controlled [27], and the need to manually sort the sample, a step that can itself introduce cross-contamination. Moreover, phenotypic changes of some pathogen following sonication have been reported [28]. It is also worth noting that some well-known experts did not find a superiority of sonication over tissue samples collected according to strict rules [29].

Chemical antibiofilm pretreatment with Dithiothreitol

Dithiothreitol (DTT) is a reducing agent that cleaves disulfide bonds within the biofilm matrix. Per standard protocols, tissue or explant samples are incubated in 0.1% DTT (≈25 mM) for 15 minutes at room temperature, then vortexed and cultured [30]. According to SIOT guideline, DTT pretreatment can be applied both to prosthetic material and periprosthetic tissue, as shown by various studies [31]. Evidence demonstrates that DTT treatment increases sensitivity—up to 85% in some series—without impairing microbial viability [6]. Advantages include its relative low-cost, the possible implementation in all hospitals without the need for specific equipments, and the applicability to all types of explanted materials (fluids, tissues, metallic and polymeric implants), making the procedure less operator-dependent, more streamlined, and reducing cross-contamination from manual handling. Care must be taken to respect concentration and contact-time parameters, as excessive exposure can have bactericidal effects [32].

To further standardize and secure this workflow and minimize contamination, completely closed systems, like MicroDTTect®, integrate DTT elution within a sterile, single-use, specifically designed closed cartridge : implants or tissues are loaded intra-operatively, sealed, transported and then processed without any open handling, yielding up to 98 % diagnostic sensitivity and specificity while minimizing hands-on time, contamination risk and logistical complexity [8].

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METHOD	DESCRIPTION	KEY FEATURE(S)
Sonication 	Uses ultrasonic waves to physically disrupt biofilm structure, releasing bacteria for culture examination. 	• Effective physical disruption; requires ultrasonic device. • Multi-step procedure: contamination risk. • May induce phenotypic change in some microorganisms. • Suitable for implants.
Dithiothreitol (DTT) 	Chemical agent that reduces disulfide bonds in biofilm matrix, breaking it down chemically. 	• Chemical disruption targeting biofilm matrix. • Suitable for implants, tissues, organic fluids analysis.
MicroDTTect 	A closed-circuit system combining DTT chemical treatment with sample collection to disrupt biofilm and reduce contamination risk. 	• Chemical disruption targeting biofilm matrix. • Completely closed circuit reduces contamination risk. • Suitable for implants, tissues, organic fluids analysis.

Figure 4: Comparison of Antibiofilm Pretreatment Techniques
Infographic overview of three key biofilm disruption methods for implant-related infections.

The 2018 International Consensus Meeting (ICM) on hip and knee PJIs specifically endorses sonication and DTT technologies to minimize culture-negative cases [33].

Using physical disruption (sonication) or chemical biofilm dissolution (DTT or MicroDTTect®), laboratories can dramatically improve microbial recovery from both tissue and prosthetic materials (Figure 4). In the next section, we will review culture protocols and diagnostic considerations once samples have been pretreated.

MICROBIOLOGICAL CULTURE AND DIAGNOSTIC CONSIDERATIONS

Optimal sampling, transport, handling and antibiofilm pretreatment are key preliminary steps to cultural examination, that remains the diagnostic cornerstone for implant-related infections. However, accurate interpretation of culture results requires attention to technique, incubation conditions, and the clinical context.

Quantitative and Qualitative Culture

Explanted tissue and synovial fluid should be plated onto solid media and inoculated into blood-culture bottles (BCBs). BCB systems enable larger sample volumes, continuous growth monitoring, and in-built antibiotic neutralization—often yielding faster and more sensitive detection than agar alone [34, 35].

Release of bacteria by sonication fluid or DTT eluates must be quantified: recovery of at least 50 CFU/mL of sonicate or DTT eluate is considered significant, whereas lower counts or growth only in enrichment broths demand clinical correlation before labeling an infection. [36-38] [https://old.giot.it/wp-content/uploads/2018/04/04_Art_LINEE_Guida-1.pdf].

To capture slow-growing organisms (e.g., Cutibacterium acnes), incubation should extend to 14 days, with a subculture check at day 5 and a final readout at day 14 [13, 21, 39-41].

Culture-Negative Scenarios

When microbiological cultures remain negative despite a high clinical and intra-operative suspicion of infection, several steps are strongly recommended. Surface swabs should be avoided to reduce contamination risk and repeat sampling—preferably multiple tissue specimens and synovial fluid—should be performed immediately [42]. At the time of explantation, all removed materials (hardware, tissue, fluid) should undergo antibiofilm pretreatment—sonication of implants whenever feasible, or chemical elution with dithiothreitol (DTT) for both biotic and abiotic samples—and, where possible, inoculation directly into blood-culture bottles to maximize recovery [43]. Cultures must be incubated for more than 14 days when anaerobic or fastidious organisms are suspected [40]. Parallel testing using different media and methods can further enhance yield. Finally, if cultures remain sterile, molecular diagnostics—broad-range or targeted PCR and next-generation sequencing (NGS)—may be employed, albeit with caution, since these methods can detect non-viable microbial DNA and require careful interpretation in the clinical context [44].

Molecular and Rapid Diagnostics

Molecular assays can play a crucial adjunct role in culture-negative scenarios, after prior antibiotic exposure, or when fastidious or biofilm-embedded organisms are suspected. Broad-range PCR targeting the bacterial 16S rRNA gene offers an unbiased approach, capable of detecting unexpected or slow-growing pathogens directly from synovial fluid, sonication fluid, or DTT eluate [45]. Its main advantages are high sensitivity and the ability to uncover rare organisms; however, it carries a significant risk of false positives from contaminant or non-viable DNA and does not distinguish live from dead bacteria, necessitating rigorous laboratory controls.

Targeted multiplex PCR panels—such as FilmArray or custom real-time qPCR assays—provide results within hours and can simultaneously identify predefined pathogens and key resistance genes [46]. This rapid turnaround enables earlier, more focused antimicrobial therapy, but panels are inherently limited to the organisms and resistance markers they include and may miss atypical or emerging pathogens [47, 48].

Next-generation sequencing (NGS) and metagenomic techniques hold the promise of comprehensive, culture-independent profiling of bacteria, fungi, and resistance determinants in a single assay [49, 50]. These methods eliminate panel restrictions and can reveal a full spectrum of pathogens and resistance genes. However, their high cost, need for specialized equipment and bioinformatics expertise, and longer turnaround times currently preclude routine implementation in most clinical laboratories. As these technologies mature, decrease in cost, and become more standardized, they may gradually transition from specialized referral centers to broader diagnostic use [51].

Reporting and Interpretation

Laboratory reports must strike a balance between speed and accuracy. A preliminary report—issued around day 5—alerts clinicians to any initial growth, even at low levels, with an antibiogram pending. The final report, at the end of the incubation period, should classify isolates as:

- Definitive pathogens (e.g., Staphylococcus aureus, Pseudomonas aeruginosa, Enterobacterales at significant counts)
- Possible contaminants (e.g., coagulase-negative staphylococci, Cutibacterium spp. from a single specimen; annotate “possible contaminant—interpret clinically”)
- No growth

By integrating quantitative culture thresholds, antibiofilm-enhanced methods, extended incubation, and judicious molecular testing, laboratories can deliver nuanced, timely data that directly inform appropriate antimicrobial therapy and surgical decision-making in implant-related infections [9].

CRITICAL ISSUES AND COMMON PITFALLS

Even the best protocols can be undermined by errors at any stage of the diagnostic pathway. Below are the most frequent missteps—and their downstream consequences—that teams must vigilantly guard against:

1. **Inadequate or Contaminated Sampling**
   Collecting too few specimens or missing key sites (e.g., the prosthesis–

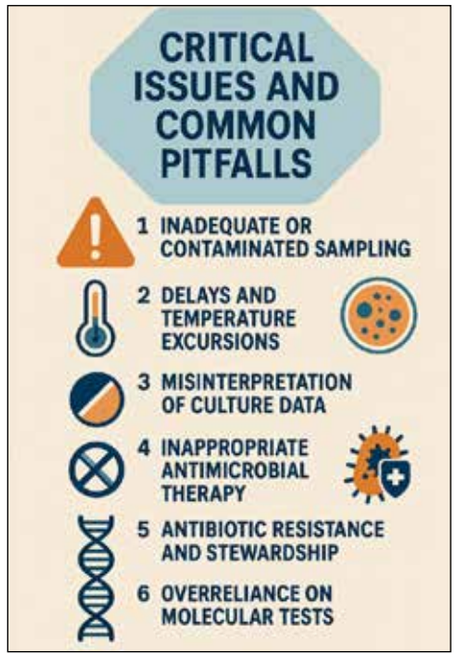

Figure 5. Critical Issues and Common Pitfalls in IRI Diagnosis
Illustration of six frequently encountered challenges that can compromise microbiological diagnosis of implant-related infections:
(1) inadequate or contaminated sampling leading to false negatives/positives;
(2) delays and temperature excursions causing loss of viable pathogens;
(3) misinterpretation of low-level growth without quantitative thresholds;
(4) inappropriate antimicrobial therapy fueling patient harm and resistance;
(5) antibiotic resistance undermining stewardship efforts; and
(6) overreliance on molecular tests without clinical correlation.

bone interface) increases false negatives, leaving infections undetected. Conversely, non-sterile instruments or lapses in asepsis can introduce skin or environmental flora, leading to false-positive cultures. Both errors misguide therapy: undiagnosed infections may persist or recur, while contaminants can prompt unnecessary antibiotic courses.

2. **Delays and Temperature Excursions**
Prolonged transport or breaches in the 4 °C cold chain can kill fastidious or anaerobic bacteria, at once lowering sensitivity and increasing false negatives.

3. **Misinterpretation of Culture Data**
Low-level growth of organisms such as coagulase-negative staphylococci or Cutibacterium spp. often represents contamination rather than genuine infection. Without quantitative thresholds (e.g., ≥50 CFU/mL in DTT or sonicate) and clinical correlation, these isolates can be mistaken for pathogens, leading to overtreatment.

4. **Inappropriate Antimicrobial Therapy**
False-positive results drive unnecessary antibiotic regimens, which not only expose patients to toxicity and side effects but also foster antibiotic resistance in the hospital environment. False negatives, by contrast, may delay or omit needed therapy, increasing the risk of sepsis, implant failure, and complex re-operations.

5. **Antibiotic Resistance and Stewardship**
Inaccurate diagnoses undermine antimicrobial stewardship: overuse of broad-spectrum agents for presumed infections fuels resistance, while under-treatment allows biofilm-embedded organisms to persist and evolve. Reporting must therefore distinguish true pathogens from likely contaminants and guide narrow-spectrum, biofilm-active therapy.

6. **Overreliance on Molecular Tests**
While PCR and NGS can rescue culture-negative cases, they can also detect DNA from dead or contaminant organisms, risking false positives. Likewise, targeted panels may miss unexpected pathogens. Molecular findings must always be interpreted in concert with culture, histology, and the patient's clinical picture.

By anticipating these pitfalls, schematically reported in Figure 5 —and embedding quantitative culture criteria, strict time-and-temperature controls, clear reporting language, and tight coordination between surgeons, microbiologists, and infectious-disease specialists—teams can minimize both false positives and false negatives, ensure appropriate therapy, and curb the rise of antibiotic resistance in implant-related infections.

Illustration of six frequently encountered challenges that can compromise microbiological diagnosis of implant-related infections:

1. inadequate or contaminated sampling leading to false negatives/positives;
2. delays and temperature excursions causing loss of viable pathogens;
3. misinterpretation of low-level growth without quantitative thresholds;
4. inappropriate antimicrobial therapy fueling patient harm and resistance;
5. antibiotic resistance undermining stewardship efforts; and
6. overreliance on molecular tests without clinical correlation.

CONCLUSIONS

Successful diagnosis of implant-related infections hinges on rigorous attention to each step of the sample's journey—from precise, aseptic intra-operative collection through rapid, cold-chain transport, to targeted biofilm disruption and extended culture protocols. When surgeons, microbiologists, and infectious-disease specialists collaborate closely—adhering to consensus-driven guidelines, using sonication or DTT (including closed-system devices), and reserving molecular assays for truly culture-negative cases—they can sharply reduce both false negatives and false positives. This integrated, multidisciplinary approach not only ensures accurate pathogen identification and tailored antimicrobial therapy but also supports antimicrobial stewardship, minimizes patient morbidity, and optimizes clinical outcomes in the management of implant-related infections. ■

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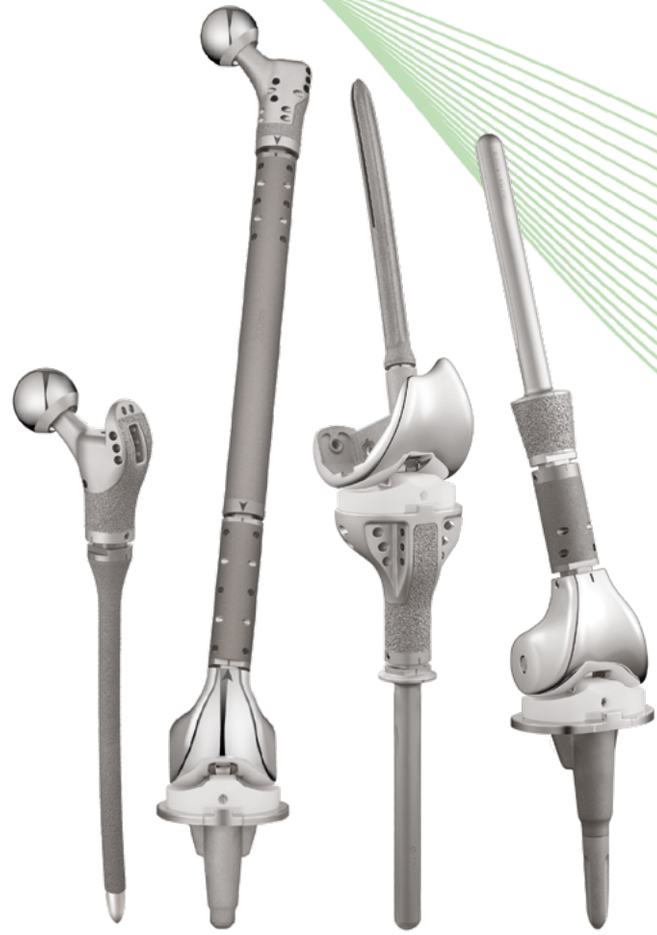

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BIOFILM-RELATED INFECTIONS: HOW TO IMPROVE LABORATORY DIAGNOSIS

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INTRODUCTION

Infections involving biofilms are increasingly recognized as a major burden in clinical practice, particularly in the context of medical devices such as prosthetic joints, catheters, and heart valves. In these scenarios, bacteria organize themselves into complex communities attached to surfaces and encased in a self-produced matrix. This matrix protects the bacteria not only from the immune system but also from antibiotics and, crucially, from diagnostic methods traditionally used in microbiology laboratories. Diagnosing these infections is not straightforward. Standard cultures often yield negative results even when infection is present, and clinicians are left with uncertainty that can delay appropriate treatment. Therefore, improving the laboratory's ability to detect biofilm-associated infections is essential for better patient outcomes. Biofilm Infections Are Hard to Detect.One of the primary reasons biofilm infections are so elusive is that the bacteria embedded in the matrix are in a low-metabolic, often non-replicating state. This makes them much less likely to grow in conventional culture media. In addition, prior exposure to antibiotics further reduces the yield of standard cultures. This leads to a classic clinical paradox: a patient may present with signs of infection, but cultures from blood, tissue, or synovial fluid may come back negative. In such cases, unless the laboratory adopts specific protocols aimed at disrupting the biofilm, the true etiology of the infection may remain hidden.

BREAKING THE BIOFILM: SONICATION AND DTT

To overcome the challenge of poor culture sensitivity, several techniques have been developed to physically or chemically disrupt the biofilm matrix and release the bacteria into a form that can be more easily detected.

Sonication is perhaps the best-known technique in this context. It involves placing explanted devices—such as joint prostheses—into a sterile container filled with fluid and then exposing them to ultrasound waves (Figure 1). The vibrations break up the biofilm and release the embedded bacteria into the surrounding fluid, which is then cultured. This method was validated by Trampuz et al. [1] and confirmed by Portillo et al. [2].

An alternative to sonication is the use of dithiothreitol (DTT), a chemical agent capable of breaking disulfide bonds in the biofilm matrix. When applied to explanted devices or tissue samples, DTT can effectively disrupt the biofilm and release viable bacteria into solution. Its effectiveness was shown by Drago et al. [3] and later supported by Karbysheva, S et al. [4].

BIOFILMS IN BIOLOGICAL FLUIDS AND THE ROLE OF DTT IN DIAGNOSTIC ENHANCEMENT

Biofilm formation is not restricted to the surfaces of implanted devices; increasingly, evidence shows that bacteria can form biofilm-like aggregates directly in biological fluids such as synovial fluid, cerebrospinal fluid, and bronchoalveolar lavage. These aggregates are typically embedded in host-derived extracellular matrices such as fibrin or hyaluronic acid, making them difficult to detect with traditional culture methods. This phenomenon is particularly relevant in prosthetic joint infections (PJIs), where biofilm aggregates in synovial fluid can lead to false-negative cultures and underdiagnosis [5].

Dithiothreitol (DTT), a mucolytic and reducing agent, has emerged as a valuable tool in this context. It acts by breaking disulfide bonds within the extracellular polymeric substance (EPS) of the biofilm, as well as in the host-derived matrix, thereby releasing bacteria into suspension without compromising their viability. This chemical disruption improves the recovery of pathogens from samples such as synovial fluid, as schematized in Figure 2 [6].

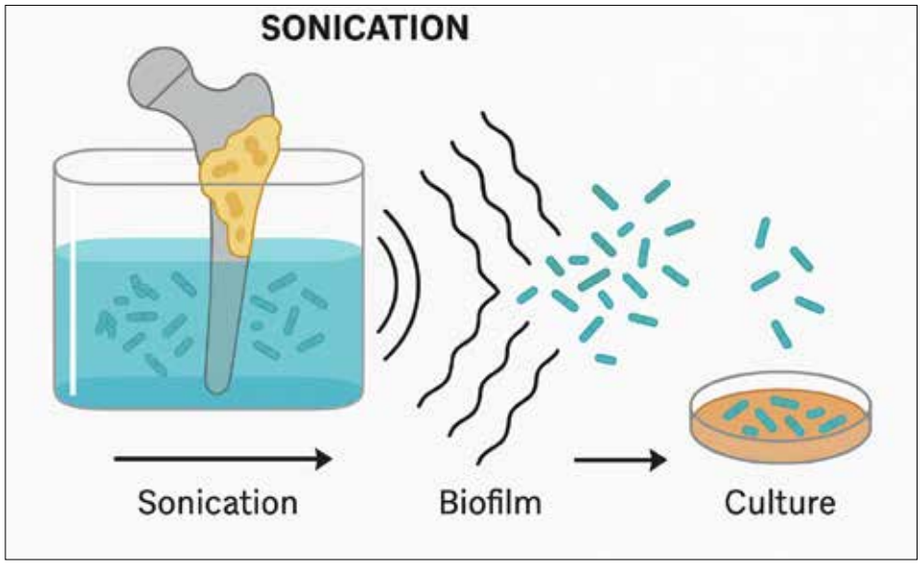

Figure 1 : Illustrates the sonication process and subsequent bacterial release for culturing.

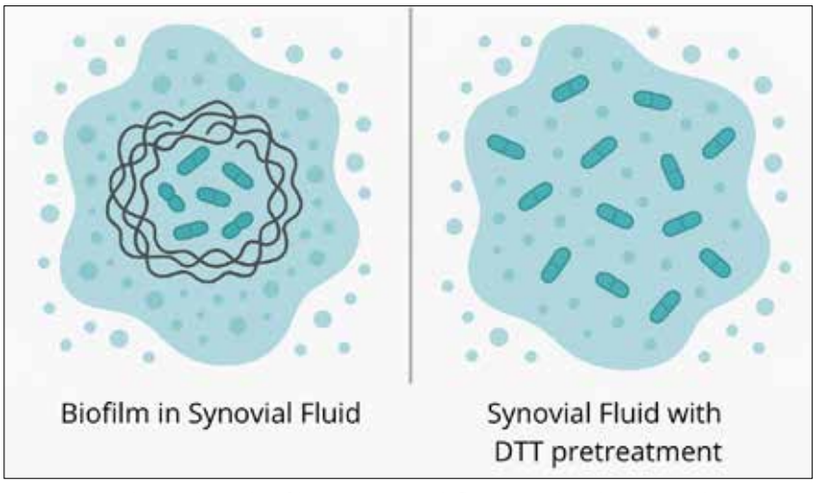

Figure 2 : Shows how biofilm in synovial fluid can be disrupted by DTT to improve pathogen recovery.

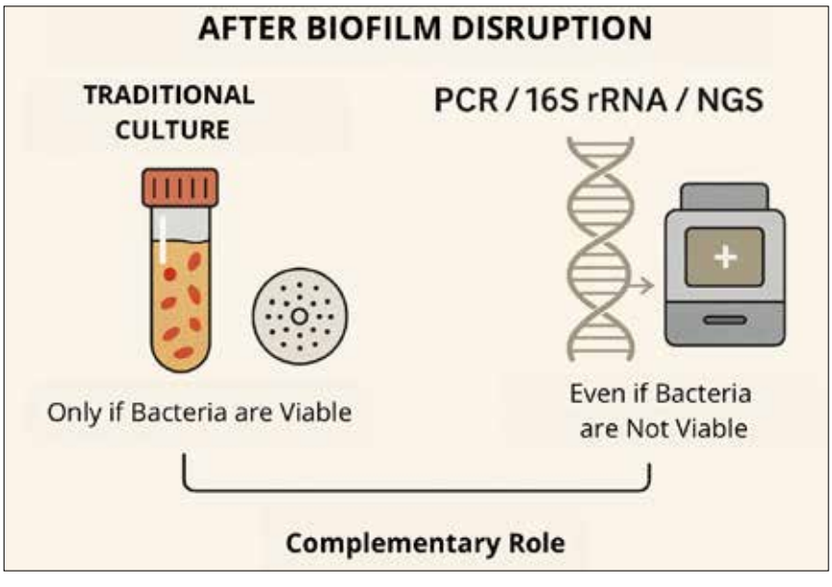

Figure 3 : Culture detects viable bacteria, while molecular methods identify pathogens even when non-viable. Combined use improves diagnostic accuracy.

The ability of DTT to disaggregate biofilm structures in liquid matrices offers a practical and cost-effective enhancement to microbiological workflows in routine laboratories, and its application is expanding beyond orthopedic infections to include other biofilm-prone clinical contexts.

CULTURE VS. MOLECULAR TECHNIQUES: A COMPLEMENTARY ROLE

Once the biofilm has been disrupted, the next step is to detect and identify the bacteria. Traditionally, this has been done using culture methods, which remain the gold standard for antimicrobial susceptibility testing. However, culture has its limits—especially in patients pretreated with antibiotics, or when dealing with slow-growing or fastidious organisms.

This is where molecular methods come into play. Techniques like PCR, 16S rRNA sequencing, and multiplex PCR panels allow for the direct detection of bacterial DNA, even when the organisms are not viable (Figure 3). These methods have shown increased sensitivity in several studies, including work by Tsang et al. [7] and Tande et al. [8].

PUTTING IT ALL TOGETHER: DIAGNOSTIC ALGORITHMS

An ideal diagnostic strategy for biofilm-associated infections should incorporate a combination of mechanical or chemical biofilm disruption techniques—such as sonication or dithiothreitol (DTT)—with both culture-based and molecular diagnostics. This integrated approach enhances diagnostic sensitivity and specificity by addressing the major limitations of each method when used alone. Biofilm disruption increases the release of viable bacteria that would otherwise remain embedded in the matrix, while molecular techniques offer the ability to detect non-cultivable or fastidious organisms and can provide

results even when antibiotics have been administered prior to sampling.

Recent evidence supports the use of such multimodal workflows. For example, Portillo et al. demonstrated that combining sonication fluid cultures with periprosthetic tissue samples significantly increased the microbiological yield in prosthetic joint infections [2].

Similarly, studies using DTT have shown improved recovery rates of pathogens in both solid and liquid clinical matrices, especially in culture-negative scenarios [9].

Molecular assays, including multiplex PCR and 16S rRNA sequencing, have proven particularly useful when culture results are negative or inconclusive, further contributing to diagnostic clarity [7, 8].

Importantly, the most recent iterations of the diagnostic criteria for prosthetic joint infection—such as those developed by the International Consensus Meeting (ICM) in 2018, 2023 and updated in 2025—explicitly include the use of sonicate fluid culture and molecular diagnostics (e.g., PCR and next-generation sequencing) as part of their scoring algorithms and supportive criteria. These guidelines underscore the value of combining clinical, laboratory, and microbiological data to improve diagnostic certainty and treatment decisions.

The implementation of standardized diagnostic algorithms that leverage biofilm-disruptive techniques and multiple detection platforms is increasingly seen as a best practice in microbiology laboratories dealing with device-associated infections. Such workflows require close interdisciplinary collaboration among surgeons, infectious disease specialists, and microbiologists, as well as adequate infrastructure and training to ensure proper sample collection, processing, and interpretation.

LOOKING AHEAD: FUTURE DIRECTIONS IN BIOFILM DIAGNOSTICS

As scientific and technological innovation accelerates, the field of biofilm diagnostics is poised for a profound transformation. The traditional reliance on culture methods is gradually being complemented—and in some cases challenged—by cutting-edge tools that offer the potential for faster, more sensitive, and more comprehensive pathogen detection.

One of the most promising areas is metagenomics, which allows for untargeted sequencing of all microbial DNA in a clinical specimen. Unlike targeted PCR, metagenomics does not require prior knowledge of the organism, making it particularly valuable in polymicrobial infections or cases with rare or fastidious pathogens. Preliminary studies have shown its ability to identify pathogens in culture-negative prosthetic joint infections and other implant-related infections, although cost, turnaround time, and data interpretation remain challenges to widespread adoption.

Closely related to this are proteomics and metabolomics, which focus on identifying specific bacterial proteins or metabolic signatures associated with biofilm presence and activity. These approaches may not only detect the presence of infection but also help characterize the physiological state of the pathogens—whether dormant, active, or resistant—thus providing valuable information for therapeutic decisions.

Another emerging frontier involves biosensors, which are engineered to detect microbial components or biofilm-specific markers in real time. These compact, point-of-care devices could one day allow clinicians to identify biofilm-related infections intraoperatively or even bedside, facilitating earlier and more targeted interventions.

Machine learning and artificial intelligence (AI) are also making inroads. By integrating complex data from laboratory tests, clinical parameters, and imaging, AI-driven algorithms can help predict the likelihood of biofilm infection, suggest optimal diagnostic workflows, or even flag atypical cases that warrant molecular testing.

Additionally, microfluidics—the manipulation of fluids in miniaturized channels—is being applied to develop lab-on-a-chip systems that combine biofilm disruption, DNA extraction, amplification, and detection in a single, automated platform. These technologies hold promise for reducing turnaround times and minimizing sample volume requirements, making them ideal for point-of-care settings. Beyond the technological landscape, the concept of diagnostic stewardship will become increasingly important. Just as antimicrobial stewardship ensures appropriate antibiotic use, diagnostic stewardship promotes the correct selection, timing, and interpretation of diagnostic tests. This is particularly critical in biofilm infections, where unnecessary or poorly interpreted tests can lead to overdiagnosis, inappropriate therapy, or missed infections.

Ultimately, the integration of these novel technologies into routine microbiology practice will depend on validation studies, cost-benefit analyses, and collaboration among clinicians, microbiologists, engineers, and data scientists. With appropriate investment and interdisciplinary effort, the future of biofilm diagnostics promises to be not only more accurate and efficient, but also more personalized and clinically impactful.

CONCLUSION

Biofilm-related infections are difficult to detect with standard laboratory methods, but advances in biofilm disruption techniques—particularly sonication and DTT—are helping to close the diagnostic gap. When combined with both culture and molecular methods, these approaches significantly enhance our ability to identify pathogens that would otherwise remain hidden.

The future of biofilm diagnostics lies in integrated, multi-modal strategies that combine physical, chemical, and molecular techniques with clinical insight and emerging technologies. As laboratories adopt these innovations and clinicians become more aware of their utility, the diagnosis and management of biofilm infections will become more accurate, timely, and effective. ■

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TREATMENT OF ORTHOPAEDIC INFECTIONS USING CONTINUOUS LOCAL ANTIBIOTIC PERFUSION

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INTRODUCTION

One of the major challenges in treating orthopedic implant-related infections is the formation of bacterial biofilms, which significantly contribute to treatment resistance. Although systemic administration of antibiotics is the standard approach to managing bacterial infections, biofilms formed at the site of infection are known to protect bacteria from immune cells and confer high levels of resistance to antibiotics 1. As a result, systemic antibiotics often fail to achieve therapeutic efficacy in periprosthetic joint infections (PJI).

The commonly used indicator for antibiotic effectiveness, the minimum inhibitory concentration (MIC), is not clinically meaningful in the context of biofilm-associated infections [1,2]. This is because MIC represents the lowest concentration of antibiotics required to inhibit the growth of planktonic (free-floating) bacteria [2]. In contrast, to assess the efficacy of antibiotics against biofilms, the minimum biofilm eradication concentration (MBEC) must be considered. MBEC values are reported to be tens to hundreds of times higher than the MIC [3].

Achieving MBEC through systemic antibiotic administration is extremely difficult. Therefore, in many cases of implant-related infections, in addition to surgical debridement and irrigation, local administration of antiseptics or high-concentration antibiotics is required. Traditionally, antibiotic-loaded spacers, such as those made from bone cement, have been used to deliver high concentrations of antibiotics locally [2]. More recently, intra-articular catheters [4,5], intramedullary antibiotic infusion [6], and resorbable antibiotic gels [7,8] applied around implants have shown promise in enhancing local antibiotic delivery. Continuous local antibiotic perfusion (CLAP) , a technique developed primarily in Japan, has been increasingly reported as an effective technique for managing implant-associated infections. CLAP is a technique that enables the perfusion of high-concentration antibiotics directly at the site of infection. Since its first report in treating implant-related infections following trauma surgery, CLAP has been applied across various fields of orthopedic infections with promising outcomes [9-14]. A key feature of CLAP is the simultaneous use of low-flow antibiotic infusion into the infected site and negative pressure wound therapy (NPWT), which facilitates continuous drainage of hematomas and exudates after surgery. This approach allows antibiotics to circulate without stagnation within the infected area. Conventional antibiotic irrigation methods often relied on high-flow systems, which led to leakage from the surgical wound and made postoperative wound management challenging. In contrast, CLAP uses low-flow perfusion combined with sustained negative pressure drainage via NPWT, resulting in improved wound control and stability (Figure 1). In Japan, the Salem Sump tube—a double-lumen catheter originally developed for gastric lavage—is most commonly used for antibiotic perfusion and hematoma drainage in CLAP procedures. However, it is important to note that this device is not originally intended for use in joints or soft tissues. Therefore, its off-label application in such cases requires institutional approval and informed consent from the patient.

BASIC PRINCIPLES AND METHODOLOGY OF CLAP

Continuous Local Antibiotic Perfusion (CLAP) is a therapeutic technique designed to deliver high concentrations of antibiotics locally, targeting the MBEC. This method involves low-flow antibiotic perfusion into the intramedullary canal (intra-Medullary Antibiotics Perfusion: iMAP), soft tissue (intra-Soft tissue Antibiotics Perfusion: iSAP), or joint space (intra-Joint Antibiotics Perfusion: iJAP) (Table 1). By connecting a continuous negative pressure device to the iJAP or iSAP tube, sustained drainage is achieved at the infected site or within the joint, creating a negative pressure gradient that facilitates directed antibiotic perfusion (Figure 1).

For the appropriate use of CLAP, preoperative and intraoperative evaluation of the infection site is crucial. Preoperative imaging, including CT, MRI, and nuclear medicine studies, should be used to identify abscess formation, the extent of osteomyelitis, and other relevant findings. During surgery, it is important to assess for the presence of subcutaneous pockets and delineate the extent of dead space. During debridement, care should be taken to preserve as much healthy tissue as possible, and anatomical reconstruction of the soft tissue should be performed at wound closure to ensure effective perfusion with CLAP. Postoperatively, the CLAP system should be monitored daily. Based on intraoperative assessment, daily flushing of the antibiotic perfusion system should be performed as needed.

iMAP Pin	A bone marrow needle that is inserted into the infected bone to deliver high-concentration antibiotics directly into the intramedullary space.
iSAP tube	A double-lumen drain that is placed within the soft tissue infection site, allowing simultaneous high-concentration antibiotic delivery and drainage.
iJAP tube	A double-lumen drain is placed intra-articularly to enable continuous antibiotic perfusion along with drainage from the joint cavity.
NPWT	NPWT provides continuous suction and drainage from the infected area by connecting to the iSAP or iJAP tubes.
Syringe Pump	Used to continuously deliver high-concentration antibiotics such as gentamicin (typically at 1200 mg/mL) at a low infusion rate (e.g., 2 mL/hr)

Table 1: Items used for CLAP
iMAP: Intra-Medullary Antibiotics Perfusion, iSAP: Intra-Soft tissue Antibiotics Perfusion, iJAP: Intra-Joint Antibiotics Perfusion, NPWT: Negative Pressure Wound Therapy

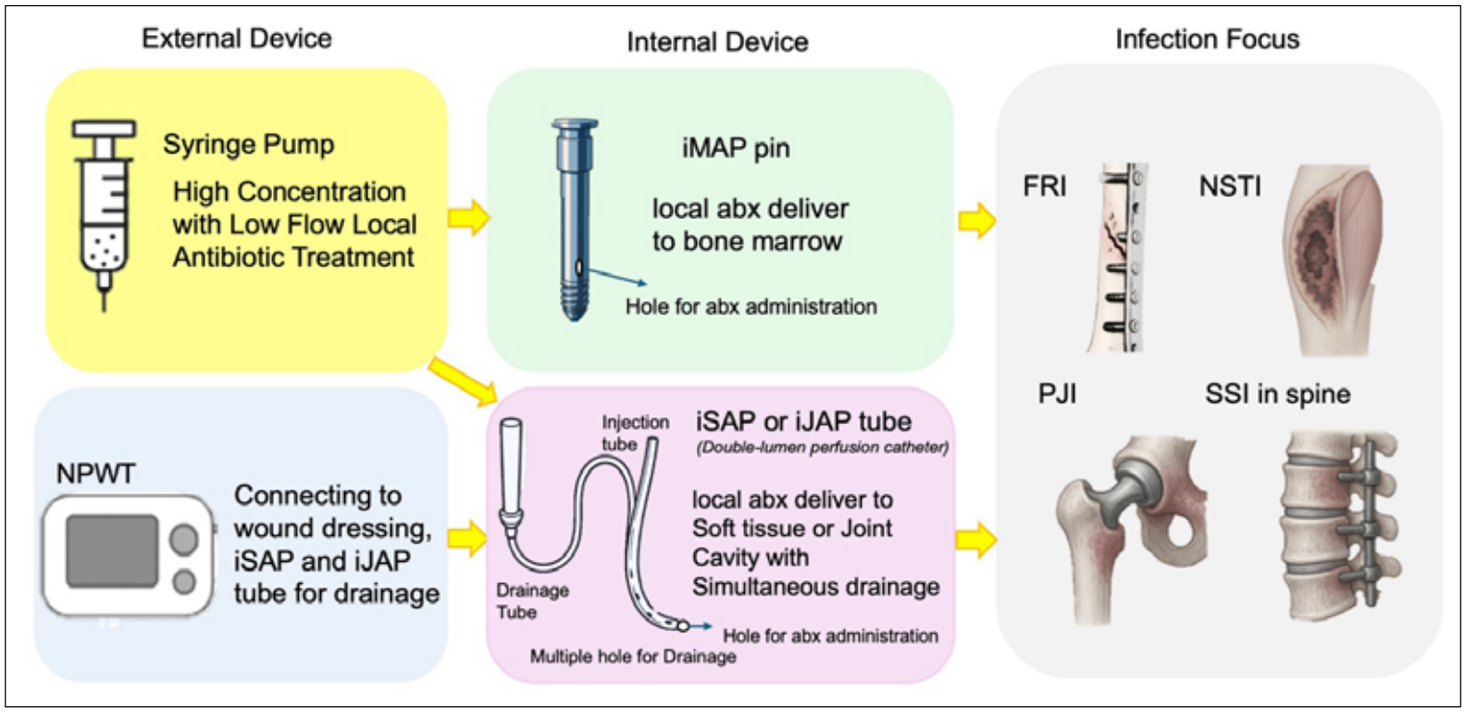

Figure 1

OVERVIEW OF RESEARCH ON CONTINUOUS LOCAL ANTIBIOTIC PERFUSION (CLAP)

In recent years, CLAP has attracted increasing attention as a novel treatment strategy for refractory infections in the field of orthopedic surgery. This approach enables the continuous local delivery of high-concentration antibiotics to infected sites, including those with biofilm formation, such as implant-associated infections, osteomyelitis, and deep soft tissue infections. By doing so, CLAP aims to achieve the Minimum Biofilm Eradication Concentration (MBEC), a therapeutic threshold that is difficult to attain with systemic antibiotic administration alone.

Published reports on CLAP span a wide range of clinical scenarios, including fracture-related infections (FRI), periprosthetic joint infections (PJI), postoperative spinal infections, necrotizing fasciitis, pediatric Brodie abscesses, and infections following frozen bone grafts. The technique has been applied in both acute and chronic infections, as well as in bacterial and fungal infections, including those caused by multidrug-resistant organisms such as MRSA. Many studies emphasize the preservation of implants, even in cases where implant removal or revision surgery would have been considered necessary under conventional treatment approaches. Favorable clinical outcomes have also been reported in retrospective cohort studies on chronic osteomyelitis, multicenter studies on postoperative spinal infections, and fungal PJIs.

The application of Continuous Local Antibiotic Perfusion (CLAP) for fracture-related infections (FRI) has gained momentum as a treatment strategy aimed at achieving both bone union and implant retention. Particularly in diaphyseal infections and nonunions—common and challenging scenarios—CLAP has shown promising results. Maruo et al. reported a bone union rate of 95% and an implant retention rate of 88% using iMAP for early FRI, demonstrating its effectiveness in avoiding reoperations [12]. Furthermore, Sawauchi et al. described successful healing of a tibial nonunion using a combination of CLAP and bone grafting [15]. In the treatment

of periprosthetic joint infections (PJI), CLAP has been increasingly adopted as an adjunct to the Debridement, Antibiotics, and Implant Retention (DAIR) procedure, including for fungal infections [9,14]. Choe et al. were the first to report the successful use of CLAP in combination with antifungal therapy for fungal PJI, suggesting its potential in infection control and implant preservation [9,14,16-19]. Additional reports include Zenk et al., who demonstrated the utility of CLAP combined with DAIR in chronic TKA PJI [9,14,20].

CLAP has also drawn attention as a treatment option for surgical site infections (SSI) following spinal instrumentation surgery [21,13]. It has shown high rates of implant retention and reduced need for reoperation, with early intervention identified as a key factor for success. Takahashi et al. reported that CLAP enabled implant preservation and demonstrated its effectiveness as an initial treatment strategy. A multicenter retrospective study further confirmed an 82% infection control rate, highlighting early introduction as a predictor of success [13].

Efficacy of CLAP has been demonsotrated in several case reports including refractory spondylitis [22], post-open fracture infections [23] and chronic osteomyelitis [24], necrotizing fasciitis [25], gas-forming vertebral osteomyelitis [26], frozen bone autograft infection [27], and Brodie's abscess in pediatric patients [28], confirming its flexibility and scalability as a strategy for localized infection control.

As indications for CLAP continue to expand, evaluating its safety—particularly regarding bone toxicity and renal function of high concentration gentamycin—has become an urgent priority. Yamamoto et al. conducted in vitro assessments of the cytotoxic effects of high-concentration antibiotics on osteocytes [29], while Fujihara et al. investigated risk factors for renal impairment during CLAP therapy [30]. These studies represent ongoing efforts to establish safety benchmarks through both basic and clinical research. Furthermore, with the accumulation of Japanese case reports and review articles, international dissemination of knowledge on CLAP is beginning to emerge.

LIMITATIONS, CHALLENGES, AND FUTURE DIRECTIONS

Despite the promising results of CLAP in treating orthopedic infections, several limitations and challenges remain. First, there is currently a lack of standardized protocols regarding antibiotic selection, dosage, duration of administration, and infusion rate. In addition, the use of CLAP requires close monitoring of renal function and serum antibiotic concentrations to ensure patient safety. The placement of iMAP pins or iSAP/iJAP catheters demands careful preoperative planning and a high level of technical expertise, along with sufficient knowledge of CLAP itself. Most importantly, the current evidence supporting CLAP is primarily based on retrospective studies, and randomized controlled trials have yet to be conducted. Therefore, future research should focus on establishing a consensus on appropriate antibiotic agents, optimal concentrations, treatment duration, and clear indications for implant retention.

In summary, CLAP represents a promising therapeutic option for managing refractory orthopedic infections. It offers several advantages, including implant retention, targeted local therapy with reduced systemic toxicity, continues drainages. However, most of the current evidence is based on case reports and retrospective studies. Future challenges include the need for prospective clinical trials, standardization of treatment protocols, and long-term safety assessments. ■

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INFECTED NONUNION FRACTURE NECK OF FEMUR WITH SEVERE HIP JOINT DESTRUCTION IN A CHILD

A CASE REPORT ON LATE COMPLICATIONS AND MULTIMODAL MANAGEMENT

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INTRODUCTION

Femoral neck fractures in children are uncommon but carry a significant risk of complications, particularly when complicated by infection or delayed union [1]. Pediatric femoral neck fractures are rare and associated with a high risk of complications, particularly when infection and nonunion developed [2]. Septic arthritis, epiphysitis, and chronic osteomyelitis are rare but devastating outcomes that may result in joint destruction and limb shortening [3].

This case illustrates a complex course of an infected nonunion in a child and explores the challenges of treatment, especially when advanced therapies such as orthobiologics are declined.

CASE PRESENTATION

A 10-year-old male presented with persistent left hip pain, limited mobility, sinus infection discharge, and limb length discrepancy. Over a year prior, he had sustained a fracture of the neck of the left femur after falling from a height. The fracture was treated with internal fixation, which later became infected. The implants were removed, but the patient's infection persisted.

Clinical Findings and Imaging

Limb examination: Pain in the groin area that occasionally radiate to the medial side of thigh, limping gait, Left lower limb 4 cm shortening due to resorption of proximal femur and growth disturbance, Limitation of Lt hip motion.

X-ray (AP and lateral views) (Figure 1): showed Widening of the hip joint space, Resorption of the femoral head and neck, Proximal migration of the greater trochanter and Cavitation and sclerosis of upper femur; suggestive of chronic osteomyelitis.

MRI: Confirmed findings consistent with septic arthritis, epiphysitis, and chronic osteomyelitis.

Laboratory Investigations

CBC: W.B. Cs= 19.000, ESR= 35 and CRP= 18, Renal and liver function tests: Normal, HbA1c and fasting blood glucose: Normal, Vitamin D, calcium, alkaline phosphatase: Normal, Blood and synovial fluid cultures: pseudomonas bacterial infection resistant to many antibiotics, Plasma protein examination showed hypoalbuminemia.

Management

The patient underwent: Extensive surgical debridement and lavage, correction of hypo-albuminemia, Empirical post culture sensitive IV antibiotics, Valgus osteotomy of the proximal femur to improve joint mechanics and compensate for deformity (Figure 2).

The orthopedic team also considered orthobiologics (e.g., bone graft substitutes, growth factors, or stem-cell-based therapies) as an adjunct to enhance bone healing. However, the family declined all these interventions.

Also, due to significant limb shortening, a custom-made orthopedic shoe was prescribed to compensate for the length discrepancy and improve gait.

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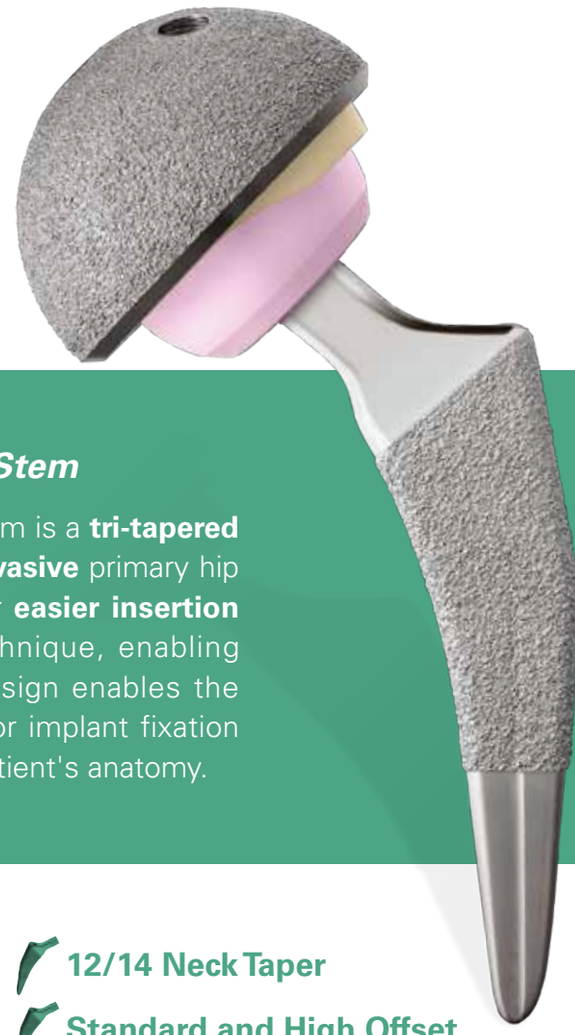

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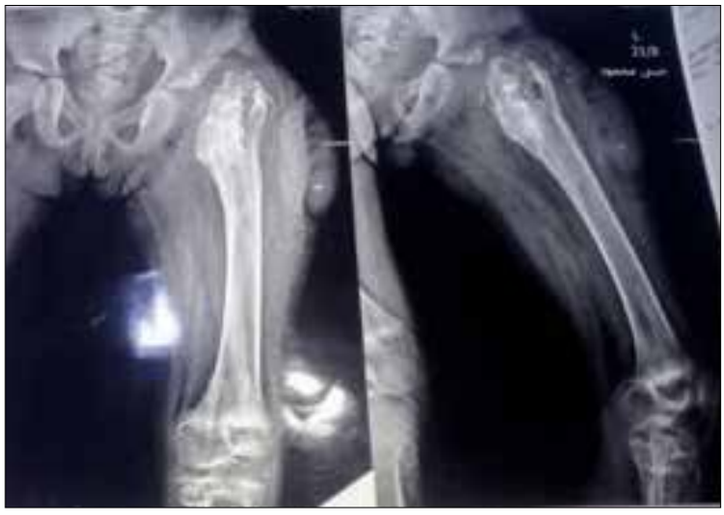

Figure 1: A Choi type V post septic arthritis sequel (this classification will be mentioned below).

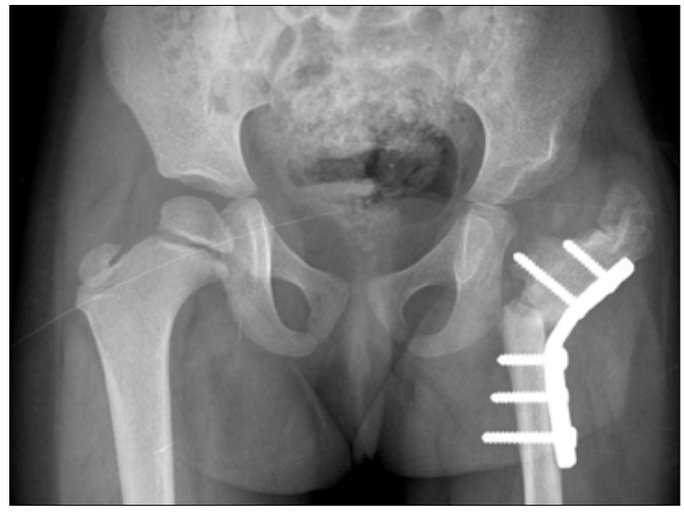

Figure 2: Valgus osteotomy of proximal left femur.

Classification used and Plan of management in septic hip cases

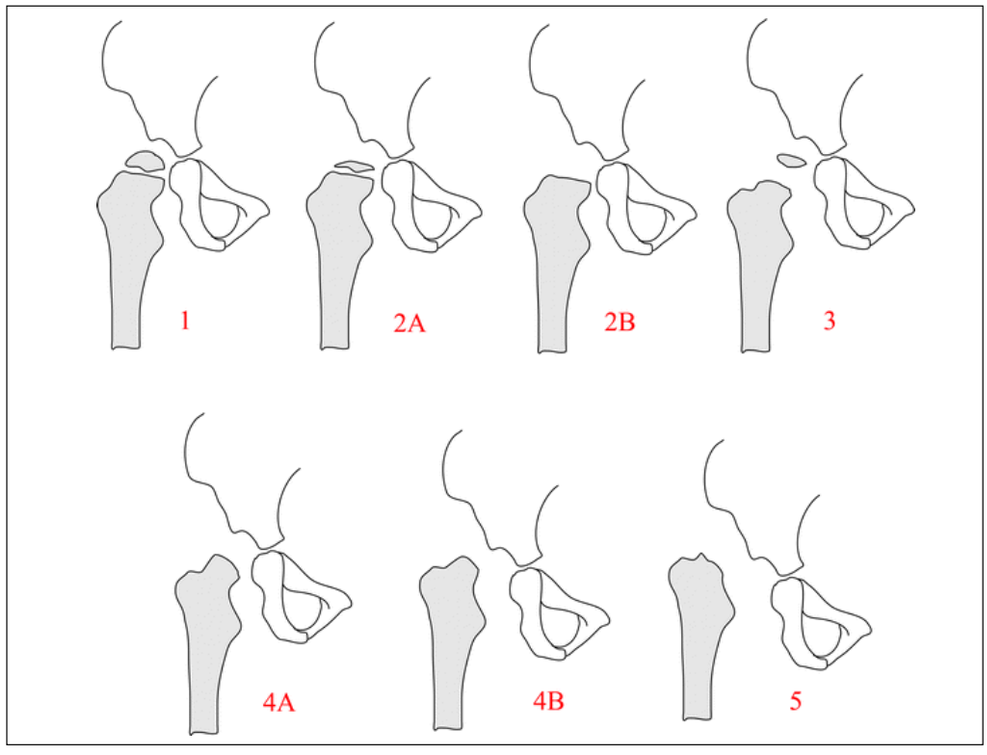

Figure 3: Choi (2006) classification of post-septic hip sequel [4]

Type 1: no residual deformity up to mild coxa magna, it needs no reconstruction.
Type 2A: coxa brevia with deformed head, it needs observation till skeletal maturity.
Type 2B: progressive coxa vara or coxa valga with asymmetric premature closure of proximal femur physis, it needs surgical intervention to prevent subluxation as epiphysiodesis of remaining physis.
Type 3: slipping at femoral neck with sever anteversion or retroversion, it needs femoral osteotomy to correct version and neck shaft angle.
Type 4A: complete destruction of femoral epiphysis with stable neck segment.
Type 4B: complete destruction of femoral epiphysis with unstable neck segment, it needs greater trochanter arthroplasty.
Type 5: complete destruction of femoral head and neck up to intertrochanteric line with dislocation of the hip, it needs arthrodesis, Ilizarov hip reconstruction or epiphyseal transfer.

Detection of sequelae

As femur head is purely cartilaginous more susceptible to direct destructive activity of pus and inflammatory products, also increased intra-capsular pressure complicated by avascular necrosis of femur head, these lead to absorption of femur head and neck resulting in sever shortening and disability.

Outcome and Follow-Up

Following surgery and rehabilitation, the patient reported improvement in pain and joint mobility. Inflammatory markers normalized, and infection was controlled. He remains under orthopedic and physiotherapy follow-up. While limb shortening persists. He is currently managed non-surgically with a shoe lift. Future surgical plan for limb length discrepancy may be considered as the child grows.

DISCUSSION

This case reflects a rare but serious cascade of complications from pediatric femoral neck fractures, emphasizing: The risk of infection and nonunion following internal fixation [5]. The devastating consequences of chronic joint infection in a skeletally immature child, including growth plate involvement (epiphysitis), osteomyelitis, and femoral head and neck resorption [6].

Many surgical interventions were described to overcome the resorption of femoral head and neck like Harmon arthroplasty of greater trochanter (Figure 4), L'Epsicopo arthroplasty, Modified Albee arthroplasty (Figure 5), and others [7,8].

The challenge of managing limb length discrepancy, especially when growth potential remains.

The use of orthobiologics—which may include platelet-rich plasma (PRP), bone morphogenetic proteins (BMPs), or stem cells—was considered to promote healing. However, due to family refusal, this modality was not utilized, potentially affecting long-term outcomes. The most important thing is the correlation of hypo-albumeneamia [12, 13].

CONCLUSION

Pediatric femoral neck fractures complicated by infection require multidisciplinary care. Early intervention, infection control, and reconstructive techniques like valgus osteotomy can salvage joint function. When advanced treatment like orthobiologics is declined, supportive options such as orthopedic shoe modification may play an essential role in maintaining mobility and quality of life. ■

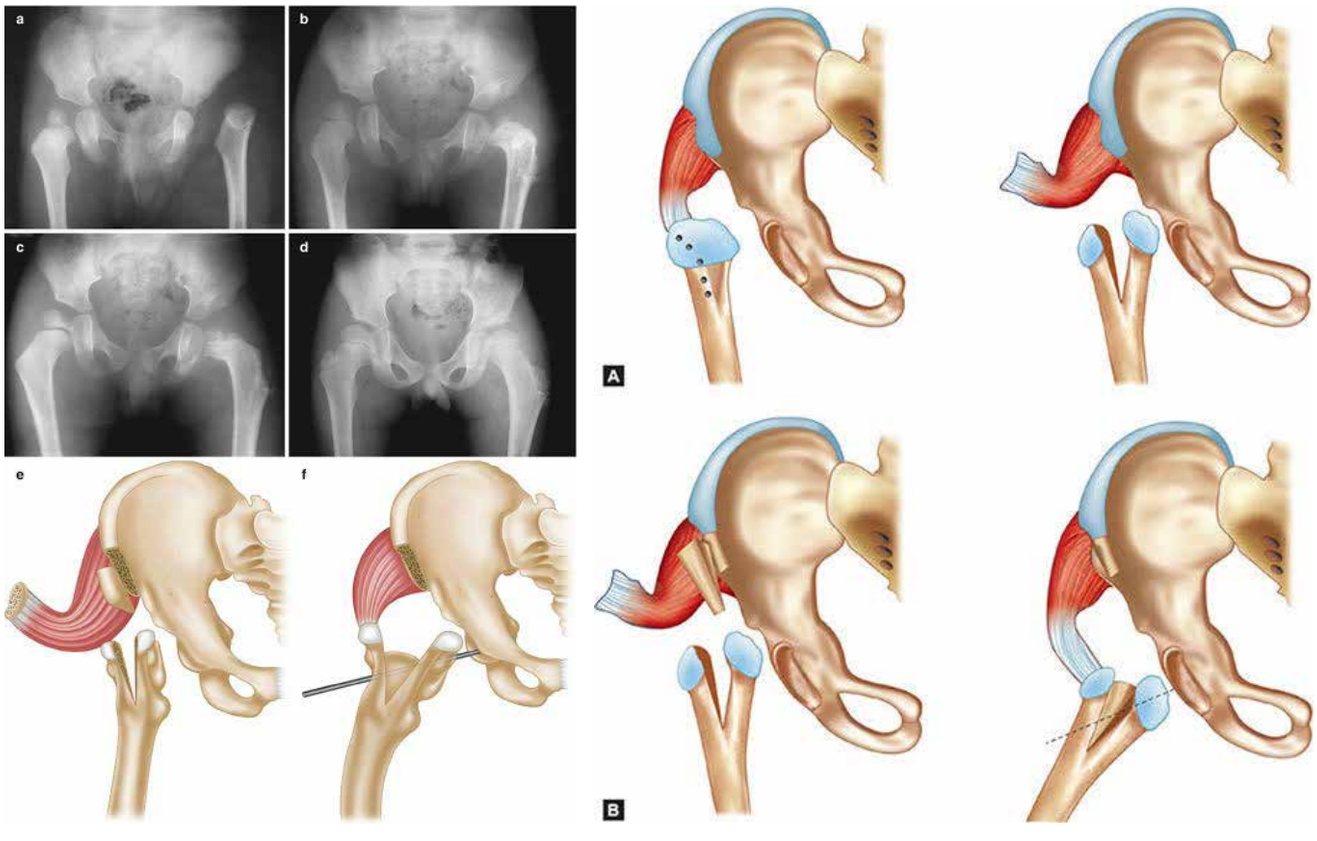

Figure 4: Harmon arthroplasty of greater trochanter (Musculoskeletal Key, Fastest Musculoskeletal Insight Engine, Septic Arthritis In Children, 2010) [9, 10]

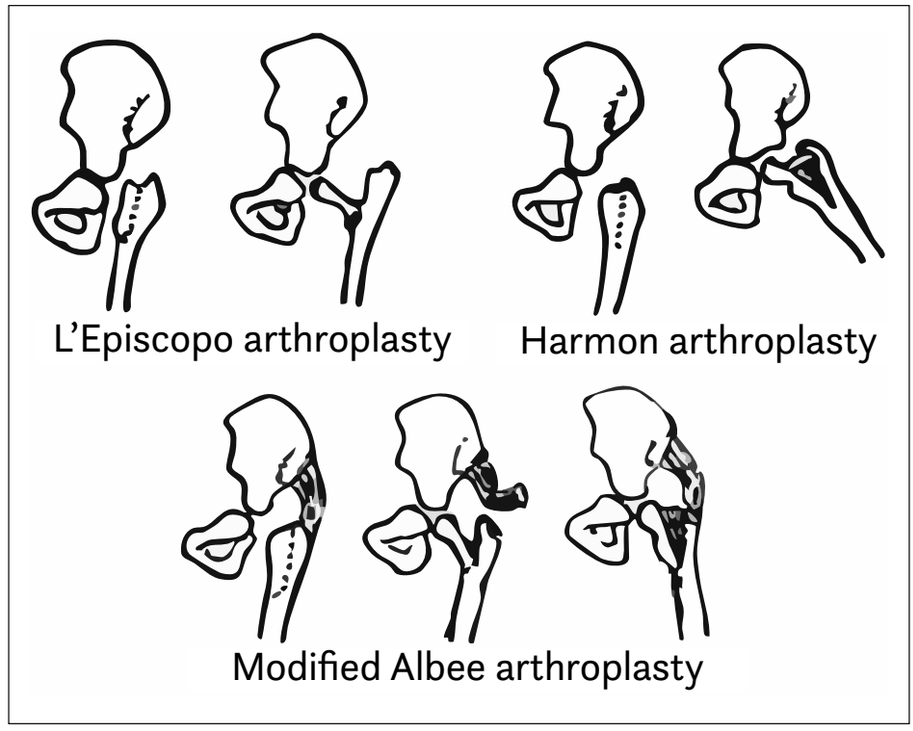

Figure 5: Other arthroplasties for the greater trochanter [11]

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