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Review article

The French Referral Centers for Complex Bone and Joint Infections (CRIOAc) 18 years after their establishment: Organization, added value, and future perspectives

Tristan Ferry^{a,b,*}, Éric Senneville^{c,d}, Johan Courjon^{e,f}, Gwenaél Le Moal^{g,h}, Harold Common^{h,i}, Véronique Dubois^{j,k}, Anne-Laure Roux^{l,m}, Benoît Brunschweiler^{d,n}, Adrien Lemaiguen^{h,o}, Jean-Yves Jenny^{p,q}, Simon Marmor^{m,r}, on behalf of the French CRIOAc Network

^a Service de Maladies Infectieuses, Hospices Civils de Lyon, Université Claude Bernard Lyon 1, 103 Grande Rue de la Croix-Rousse, 69004 Lyon, France

^b CRIOAc Lyon, Hospices Civils de Lyon, 103 Grande Rue de la Croix-Rousse, 69004 Lyon, France

^c Service de Maladies Infectieuses, CHU de Lille, Université de Lille, 2 Avenue Oscar Lambret, 59037 Lille Cedex, France

^d CRIOAc Nord-Ouest, 2 Avenue Oscar Lambret, 59037 Lille Cedex, France

^e Service de Maladies Infectieuses, CHU de Nice, Université Côte d'Azur, 151 Route Saint-Antoine de Ginestière, 06202 Nice Cedex 3, France

^f CRIOAc Sud-Méditerranée, Hôpital l'Archet 1, 151 Route Saint-Antoine de Ginestière, 06202 Nice Cedex 3, France

^g Service de Maladies Infectieuses, CHU de Poitiers, Université de Poitiers, 2 Rue de la Milétrie, 86021 Poitiers Cedex, France

^h CRIOAc (Grand Ouest), 2 Rue Henri Le Guilloux, 35033 Rennes Cedex 9, France

ⁱ Service de Chirurgie Orthopédique, CHU de Rennes, Université de Rennes, 2 Rue Henri Le Guilloux, 35033 Rennes Cedex 9, France

^j Service de Microbiologie, CHU de Bordeaux, Université de Bordeaux, Hôpital Pellegrin, Place Amélie Raba-Léon, 33076 Bordeaux Cedex, France

^k CRIOAc Grand Sud-Ouest (GSO), Hôpital Pellegrin, Place Amélie Raba-Léon, 33076 Bordeaux Cedex, France

^l Service de Microbiologie, AP-HP, Hôpital Ambroise-Paré, 9 Avenue Charles-de-Gaulle, 92100 Boulogne-Billancourt, France

^m CRIOAc Ile de France, 9 Avenue Charles-de-Gaulle, 92100 Boulogne-Billancourt, France

ⁿ Service de Chirurgie Orthopédique, CHU d'Amiens, Université de Picardie Jules Verne, 1 Rond-Point du Professeur Christian Cabrol, 80054 Amiens Cedex 1, France

^o Service de Maladies Infectieuses, CHU de Tours, Université de Tours, 2 Boulevard Tonnellé, 37044 Tours Cedex 9, France

^p Service de Chirurgie Orthopédique, CHU de Strasbourg, Université de Strasbourg, 1 Place de l'Hôpital, 67091 Strasbourg Cedex, France

^q CRIOAc Grand Est, 1 Place de l'Hôpital, 67091 Strasbourg Cedex, France

^r Service de Chirurgie Orthopédique, GH Diaconesses Croix Saint Simon, 125 Rue d'Avron, 75020 Paris, France

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Surgical complexity (bone resection/joint resection/soft-tissue reconstruction/major bone loss)
Relapsing bone and joint infection (treatment failure/persistent infection/recurrence after surgery or antibiotics)
Innovative anti-infective management (phage therapy/compassionate access/biofilm-targeted local delivery)

ABSTRACT

Background: Complex bone and joint infections (BJIs) represent a major public health challenge because of their severity, functional consequences, and the complexity of their management. In 2008, France established a nationwide network of Referral Centers for Complex Bone and Joint Infections (CRIOAc), a pioneering organization based on specialized multidisciplinary team (MDT) meetings and comprehensive national territorial coverage.

Methods: We conducted a nationwide descriptive study of the CRIOAc network, assessing its activity and evolution since its establishment, including organizational changes, funding mechanisms, scientific output, and academic activities. Data were extracted from the national CRIOAc information system, which prospectively records all cases discussed during MDT meetings. A descriptive bibliometric analysis of publications citing the seminal CRIOAc article was also performed.

Results: The network expanded from 8 coordinating referral centers at its inception to 32 accredited centers in 2024, providing nationwide coverage. It is governed by a National Scientific Committee representing all specialties and geographic regions. Since its creation, 64,859 patients have been managed within the network. The annual number of MDT meetings increased from 698 in 2011 to 1760 in 2024, while the number of surgical admissions for BJI increased from 6148 to 11,340 over the same period. The proportion of cases classified as complex remained stable at approximately 60–65%. The CRIOAc network has contributed to the development of national and international clinical guidelines, the establishment of a national inter-university diploma, the

* Corresponding author at: Service des Maladies Infectieuses, Hospices Civils de Lyon, CRIOAc Lyon, 93 Grande rue de la Croix-Rousse, 69004 Lyon, France.

E-mail address: tristan.ferry@chu-lyon.fr (T. Ferry).

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conduct of multicenter research projects, and the implementation of innovative phage-related anti-infective therapies. Bibliometric analysis demonstrates the growing international dissemination of the CRIOAc model.

Conclusions: Eighteen years after its establishment, the CRIOAc network represents a pioneering and sustainable national model for the multidisciplinary management of complex BJIs, whose core principles are now supported by the international literature. Its mission has expanded beyond specialized clinical care to encompass research, education, and the evaluation of innovative therapeutic strategies. Further integration into European collaborative networks could strengthen its contribution to improving the management of complex bone and joint infections.

Level of evidence: IV; Retrospective study.

1. Introduction

Complex bone and joint infections (BJIs) represent a major challenge in clinical practice because of their severity, associated functional impairment, prolonged and multidisciplinary management, and substantial morbidity and mortality. They mainly include implant-associated infections, chronic or recurrent infections, and infections occurring in patients with significant comorbidities or specific therapeutic constraints [1–4].

To improve the management of these challenging conditions, the French health authorities established a nationwide network of Referral Centers for Complex Bone and Joint Infections (CRIOAc) in 2008 [5]. The CRIOAc network represents a unique organizational model based on a centralized national structure dedicated to the management of complex BJIs, an approach that has few equivalents internationally. Patient management is coordinated through specialized multidisciplinary team (MDT) meetings involving, at a minimum, an infectious diseases physician, an orthopedic surgeon, and a clinical microbiologist, who together constitute the required quorum for therapeutic decision-making. Depending on the center, MDT meetings may also include radiologists, rheumatologists, psychologists, clinical pharmacists, and clinical pharmacologists. The network was designed to provide nationwide access to specialized expertise through coordinating referral centers and associated referral centers, the number of which has progressively increased through successive national accreditation campaigns conducted every five years [6].

Since 2019, the CRIOAc network has undergone further expansion and consolidation, with strengthened territorial coverage, increasing clinical activity, and the development of a nationwide information system based on data prospectively collected during MDT meetings [5].

Eighteen years after its establishment, this review aims to describe the evolution of the CRIOAc network, summarize its clinical activity, and highlight its scientific and educational contributions.

2. Material and methods

We conducted a nationwide descriptive observational study to evaluate the activity of the French CRIOAc network and to describe its organizational and funding evolution over time.

The analyses were based on data extracted from the national CRIOAc information system, which was developed to standardize and secure the collection of data generated during MDT meetings held in accredited referral centers. This information system prospectively records patient cases, including clinical, microbiological, and therapeutic characteristics, as well as the multidisciplinary decisions reached during MDT meetings (authorization by the French Data Protection Authority [CNIL No. 2012-220]).

All patient cases discussed during CRIOAc MDT meetings since implementation of the national information system were included. Each case was classified by the MDT as either a complex or non-complex bone and joint infection (BJI) according to the criteria detailed in Table 1. Cases classified as complex BJIs were assigned the French associated diagnosis code (*Diagnostic Associé Significatif*, DAS) Z76.800 within the French national hospital discharge database (*Programme de*

Médicalisation des Systèmes d'Information [PMSI]). This code was subsequently incorporated into hospital discharge coding within accredited CRIOAc centers.

Hospital admissions for BJIs were identified from the PMSI database using the national diagnosis-related group classification corresponding to surgical management of BJIs (code GHM 08C6x). Admissions for complex BJIs were identified by the presence of the associated diagnosis code DAS Z76.800.

A descriptive bibliometric analysis was subsequently performed using Google Scholar to identify publications citing the seminal article describing the CRIOAc network [5]. Both quantitative and qualitative analyses of the citing literature were conducted. Finally, we report the academic and educational activities that have been developed since the establishment of the CRIOAc network.

3. Results

3.1. Organization and evolution of the CRIOAc network

The CRIOAc network initially comprised eight coordinating referral centers in 2010–2011. It expanded to 24 centers in 2012 (9 coordinating and 15 associated referral centers), and subsequently to 30 centers in 2017 following the accreditation of additional associated centers. The most recent national accreditation campaign, effective from 2023, further expanded the network to 32 accredited centers in 2024. Their current geographical distribution (Fig. 1) provides comprehensive

Table 1
Criteria of complexity for bone and joint infections.

Criterion	Definition of complexity	Clinical examples
Host-related criterion	• Patient with severe comorbidities influencing therapeutic decision-making • Patient with severe drug allergy	• High anaesthetic risk
		• Immunosuppression • Severe diabetes mellitus • Allergies preventing the use of optimal antimicrobial therapy • Antimicrobial resistance
Microbiological criterion	Difficult-to-treat microorganism	• Rare or atypical pathogens
Surgical criterion	BJI requiring bone or joint resection and/or complex soft-tissue reconstruction	• Complex surgery requiring multiple procedures
		• Bone reconstruction or soft-tissue reconstruction • Major bone loss • Prosthetic joint infection requiring complex reconstruction • Clinical treatment failure
Evolution-related criterion	Relapsing BJI	• Persistent infection • Recurrence following surgery and/or antimicrobial therapy

BJI: bone and joint infections.

nationwide coverage.

Although the impact of the network on quality of care cannot easily be assessed using simple indicators, the progressive development of the CRIOAc network has been accompanied by the establishment of dedicated clinical pathways for patients with BJIs, including specialized inpatient units, dedicated day hospitals, and multidisciplinary outpatient clinics.

Following its recognition by the World Health Organization as a non-traditional antibacterial therapy, bacteriophage therapy has assumed an increasingly important role in the management of complex BJIs [7,8].

In 2023, CRIOAc Lyon was entrusted with a national coordination mission for the evaluation of non-conventional antibacterial therapies, including bacteriophage-related therapies [9]. As part of this mission, a dedicated national MDT meeting centralizes expert opinions to assess patient eligibility for phage-related therapies and to direct patients, whenever appropriate, toward clinical trials or the French Compassionate Access Program, introduced following the 2021 reform of compassionate access to medicinal products [10].

To account for the additional costs associated with complex BJIs, surgical admissions coded as GHM 08C6x and associated with DAS code Z76.800 receive a 12% reimbursement supplement from the French National Health Insurance system. Activity-based funding is complemented by structural funding of approximately €2 million annually. Currently this funding is allocated through national public health objectives (named OSP/OPS) (Fig. 2).

3.2. CRIOAc network activity

Since its establishment, the CRIOAc network has managed 64,859 patients.

The age and sex distribution of patients managed in 2024 is shown in Fig. 3, demonstrating a predominance of male patients (8520 vs. 5486), particularly after the age of 40 years. Most patients belonged to older age groups, with a peak incidence between 70 and 79 years.

MDT activity increased steadily throughout the study period, from 698 meetings in 2011 to 1760 in 2024 (Fig. 4A). Following an initial plateau between 2013 and 2016, the annual number of MDT meetings increased continuously from 2017 onwards, with a temporary slowdown in 2020 related to the COVID-19 pandemic. Throughout the study period, the proportion of cases classified as complex BJIs remained stable at approximately 60–65%.

Similarly, the annual number of surgical admissions for BJIs within the CRIOAc network increased from 6148 in 2012 to 11,340 in 2024. After a period of relative stability during the first years following implementation of the network, surgical activity increased markedly from 2017 onwards, with a transient decline during the COVID-19 pandemic in 2020–2021. The proportion of major surgical procedures remained stable over time, ranging from 69% to 71% (Fig. 4B).

The national CRIOAc MDT dedicated to innovative and phage-related therapies discussed 65 cases in 2023, 74 in 2024, and 62 in 2025. Since its establishment, 52 patients have received bacteriophage

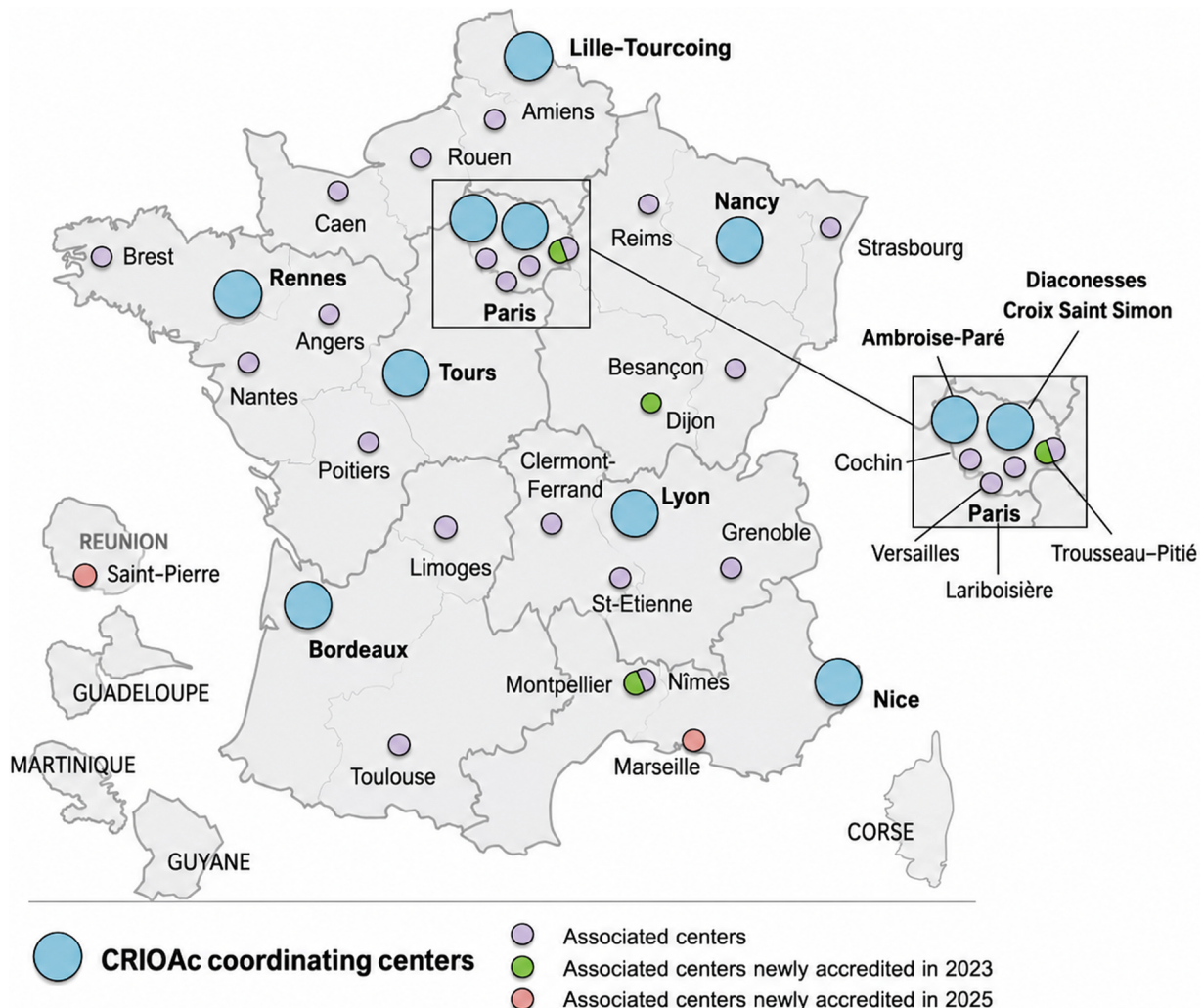


Fig. 1. Geographical distribution of the French CRIOAc network and accredited referral centers (2025).

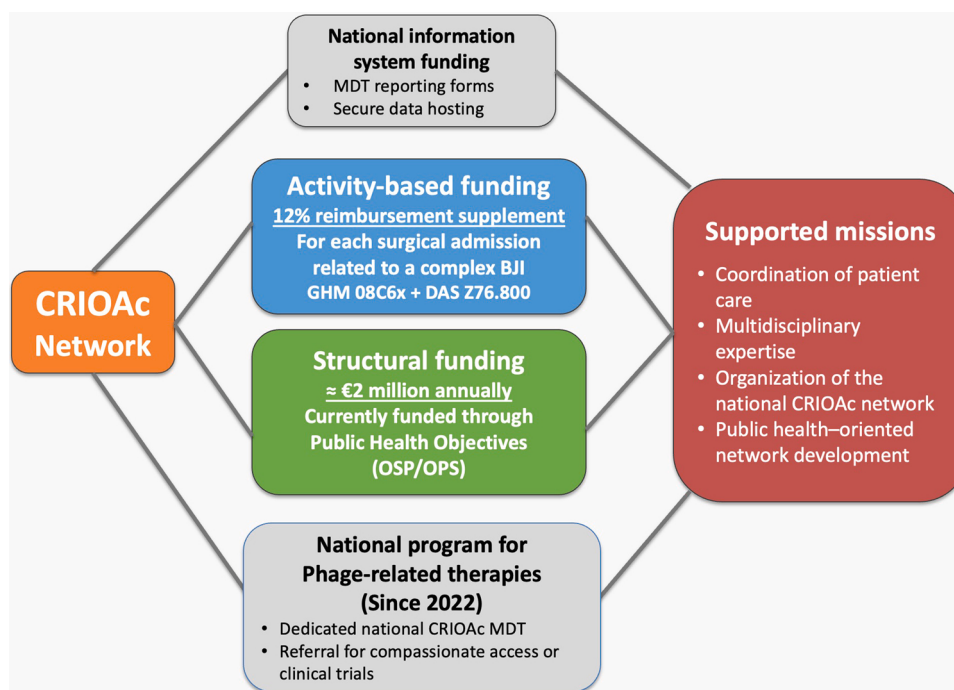


Fig. 2. The CRIOAc network is supported by a hybrid funding model combining activity-based reimbursement and structural funding to sustain multidisciplinary expertise, care coordination, and organization of the national referral network.

therapy through clinical trials, compassionate prescription, or the French Compassionate Access Authorization pathway.

3.3. Scientific and academic activities of the CRIOAc network

The scientific and academic activities of the CRIOAc network, encompassing both education and research, are coordinated by the CRIOAc National Scientific Committee (Supplementary file 1). This committee oversees the network's scientific activities, defines strategic priorities in research, education, and innovation, promotes collaboration across French regions, and liaises directly with the French Ministry of Health through the Directorate General for Health (*Direction Générale de la Santé*). It is composed of regional representatives from all specialties involved in the management of BJIs. The Chair of the Scientific Committee is elected by its members at the beginning of each term.

Beyond the standardized collection of MDT data, the national CRIOAc information system enables rapid assessment of the feasibility of both academic and industry-sponsored clinical trials by identifying potentially eligible patients at regional and national levels. The network also facilitates the dissemination of ongoing research protocols, particularly projects funded through the French Hospital Clinical Research Program (*Programme Hospitalier de Recherche Clinique*; PHRC), thereby promoting patient recruitment into multicenter studies.

Data generated through the national information system have supported numerous scientific publications. Bibliometric analysis identified 102 documents citing the seminal 2012 publication describing the CRIOAc network, including 90 indexed articles (88.2%) and 12 other documents (11.8%), such as doctoral theses, institutional reports, and professional publications. The annual number of citations increased steadily, reaching a peak of 22 citations in 2022 and remaining high in 2024 and 2025, reflecting sustained scientific interest. Most citing publications were written in English (83/102, 81.4%). Among indexed journals, the median impact factor was 3.0 (IQR, 2.4–4.4), and 16.9% of publications appeared in journals with an impact factor ≥ 5 , indicating dissemination in international journals with moderate to high visibility.

Since the establishment of the CRIOAc network, several national clinical practice guidelines on BJIs have been developed under the

auspices of the French scientific societies involved in the management of these infections (Supplementary file 2). The first milestone was the 2009 clinical practice guideline issued by the French Infectious Diseases Society (*Société de Pathologie Infectieuse de Langue Française*; SPILF) on orthopedic implant-associated infections [1]. This was followed by recommendations addressing the major clinical entities within the field of BJIs, including prosthetic joint infections, septic arthritis, and native vertebral osteomyelitis [2,3,11]. CRIOAc experts have also contributed to the International Consensus Meetings held in 2018 and 2025.

4. Discussion

Eighteen years after its establishment, the CRIOAc network has reached a high level of organizational maturity. The continuous increase in MDT activity, the growing number of patients managed, and the progressive expansion of the national referral network demonstrate its sustained integration into the French healthcare system. Beyond its role as a referral network for complex BJIs, CRIOAc has progressively shaped the field through its contributions to clinical practice, research, education, and more recently, the evaluation of innovative therapies. Notably, this nationwide multidisciplinary organization was established as early as 2008, well before the international literature recognized the value of dedicated multidisciplinary networks for the management of complex BJIs.

The importance of multidisciplinary expertise in the management of complex BJIs is now widely acknowledged internationally and has been associated with improved therapeutic decision-making, particularly regarding antimicrobial stewardship [12]. Several initiatives aimed at establishing specialized teams or referral centers have since emerged in different countries [13–15]. However, unlike the French model, these initiatives generally do not rely on a coordinated nationwide network supported by dedicated and sustainable funding. Recent international publications have increasingly emphasized the value of such organizational models and have identified the French CRIOAc network as an example of national coordination for complex BJI care, thereby retrospectively validating the organizational principles implemented in France as early as 2008 [16].

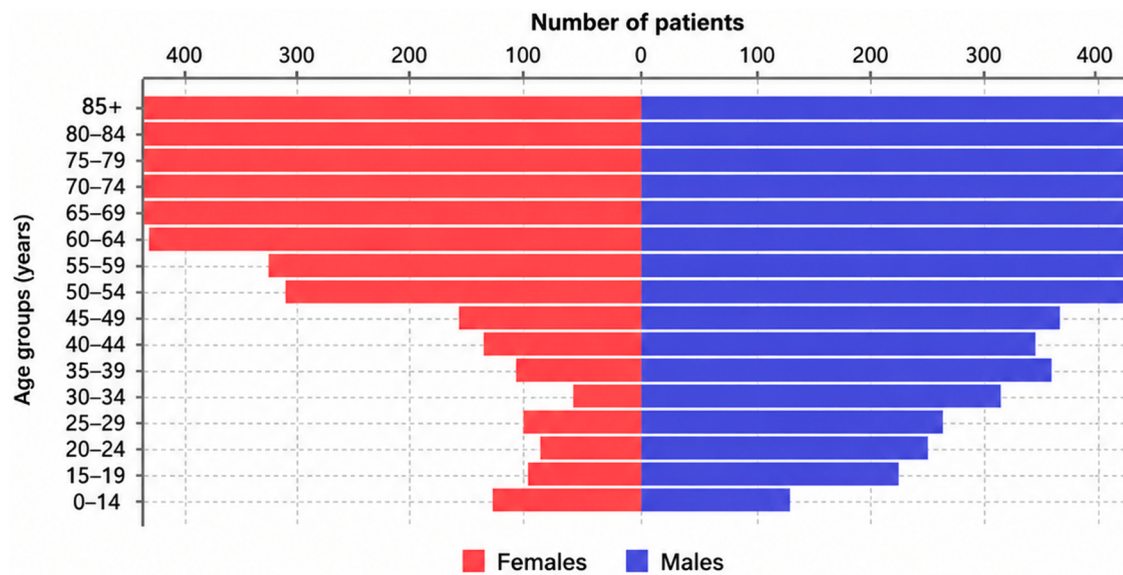


Fig. 3. Age and sex distribution of patients managed within the CRIOAc network in 2024.

The steady increase in MDT activity occurred without any substantial change in the proportion of cases classified as complex. This finding suggests that the observed increase reflects a genuine rise in referrals for specialized multidisciplinary expertise rather than a progressive broadening of the eligibility criteria for CRIOAc referral. In addition, the national information system provides a valuable tool for monitoring network performance by capturing organizational indicators such as MDT activity, compliance with multidisciplinary quorum requirements, and center-specific activity. This approach is consistent with recent studies highlighting the importance of evaluating multidisciplinary teams using organizational performance indicators alongside traditional clinical outcomes [15].

The progressive expansion of the network—from a limited number of coordinating centers to more than 30 accredited referral centers distributed across the country—has also improved equitable access to specialized expertise, with the potential to reduce both the excess

mortality and the substantial economic burden associated with complex BJIs [17–22]. Consistent with this concept, during the 2023 International Consensus Meeting, 92% of experts recommended referring patients with prosthetic joint infections to specialized regional centers, recognizing that this organization improves clinical outcomes while increasing healthcare efficiency [23]. These international recommendations closely align with the founding principles of the CRIOAc network, reinforcing the relevance of an organizational model implemented in France more than a decade earlier.

Finally, the dedicated funding strategy established by the French health authorities has probably been one of the key determinants of the network's long-term sustainability. The combination of activity-based reimbursement for complex surgical admissions and structural funding supporting network coordination, the national information system, and organizational development has provided a stable framework for the long-term implementation and expansion of the CRIOAc network.

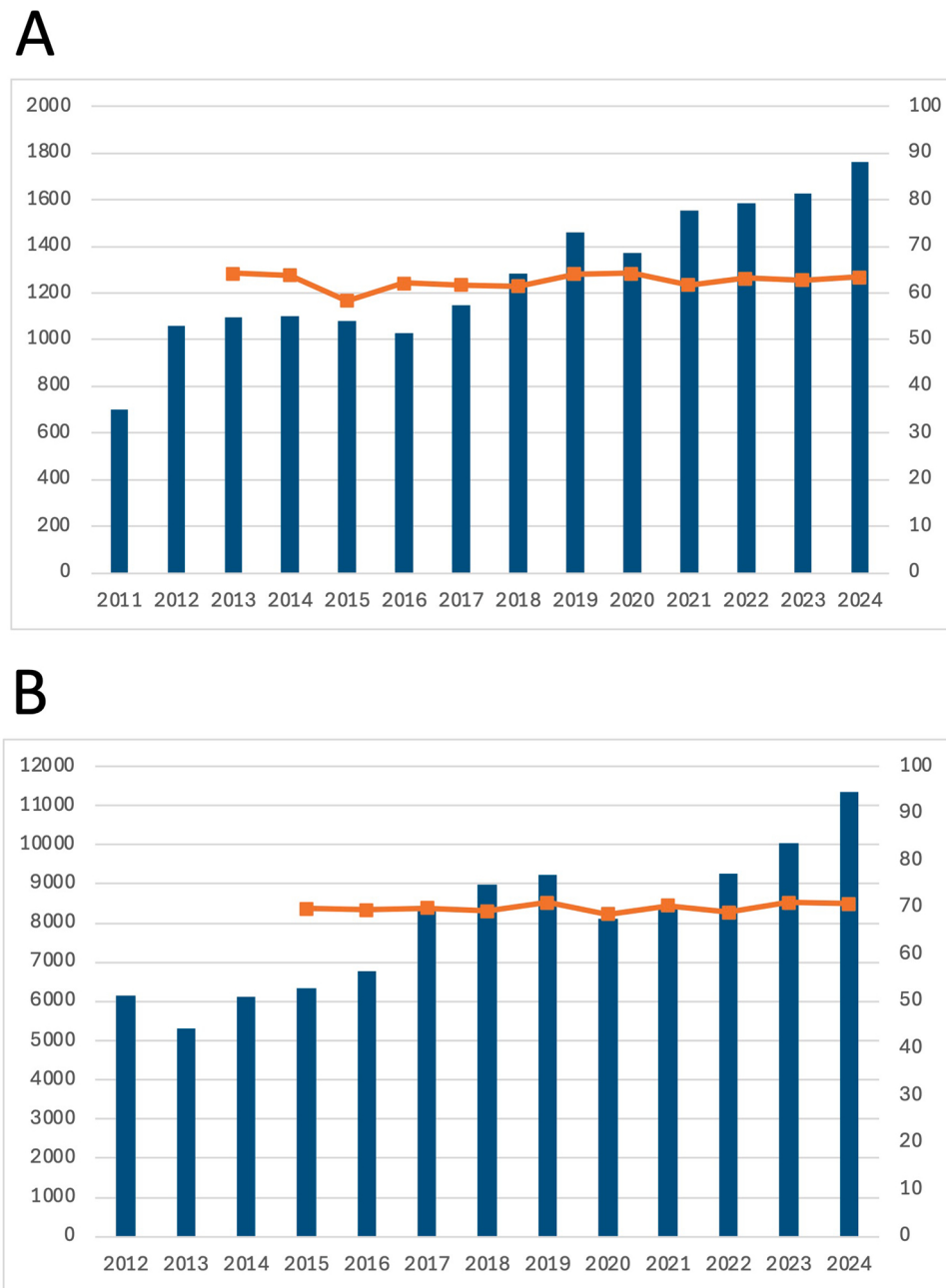


Fig. 4. Annual number of MDT (multidisciplinary team) meetings within the CRIOA network (blue) and proportion of complex BJIs (orange) (Panel A); annual number of surgical admissions for bone and joint infections (BJIs) in accredited CRIOA centers (blue) and proportion of major surgical procedures (orange) (Panel B), 2011–2024.

In parallel with its clinical mission, the CRIOA network has become an important platform for clinical research. The national information system developed around MDT meetings now represents one of the largest French databases dedicated to BJIs. Although it was not designed as a prospective cohort capturing the treatments actually administered and long-term patient outcomes, it has supported numerous epidemiological, observational, and translational studies, while also enabling the rapid identification of eligible patient populations for both academic and industry-sponsored clinical trials [24–27].

The establishment of the national inter-university diploma “Prevention and Treatment of Bone and Joint Infections”, the regular organization of national CRIOA congresses, and the increasing participation of network members in international scientific meetings have further contributed to disseminating French expertise in the field of BJIs.

Our bibliometric analysis demonstrates that the seminal publication describing the organization of the CRIOA network is now widely cited in the international literature. This growing international recognition provides opportunities for closer integration with European collaborative networks, particularly the European Bone and Joint Infection Society (EBJIS), and may facilitate the development of large multicenter collaborative studies and clinical trials [28,29].

Despite its success, the CRIOA model faces several challenges. 1) The first relates to its long-term sustainability. Population ageing, the continuous increase in the number of joint arthroplasties, and the expected rise in prosthetic joint infections are likely to increase the number of complex cases requiring specialized multidisciplinary expertise. This trend will be further amplified by the growing burden of multimorbidity and the emergence of multidrug-resistant pathogens, creating an

increasing need for the implementation and rigorous evaluation of innovative anti-infective strategies, including phage therapy, local delivery of anti-infective or anti-biofilm agents, and other non-traditional approaches [7,29–31]. 2) A second challenge concerns the collection of long-term clinical outcomes. Distinguishing between cure, sustained infection control, suppressive management, and relapse is often difficult, particularly when patients receive care across multiple institutions. Furthermore, the current lack of interoperability between the CRIOAc information system and local hospital information systems limits comprehensive longitudinal follow-up and outcome assessment over extended periods. Improving data integration across healthcare institutions will therefore be an important priority for future evaluations of the network. 3) Finally, increasing numbers of requests for expert advice regarding non-complex BJIs may place unnecessary pressure on the network by consuming substantial, unfunded medical resources. Preserving the referral role of the CRIOAc network is therefore essential. The management of non-complex BJIs should remain the responsibility of all healthcare institutions, including general hospitals and private healthcare facilities, provided that appropriate multidisciplinary expertise is available. 4) An additional challenge relates to the absence of a specific legal status defining the responsibility of the CRIOAc network for the expert recommendations issued during MDT meetings (Supplementary file 3). This creates a discrepancy between the clinical reality of multidisciplinary decision-making and the current legal framework. Although MDT recommendations are based on collective expert assessment, professional responsibility ultimately remains individual or institutional. In the event of litigation, the multidisciplinary nature of the decision does not replace the legal responsibilities of the individual healthcare professionals involved.

This last issue is particularly relevant in the field of BJIs, which remains a frequent source of medicolegal claims in reconstructive and arthroplasty surgery, as illustrated by recent data from French medical liability insurers [32]. The responsibility of a CRIOAc center could therefore be questioned when its recommendations have played a decisive role in the therapeutic strategy ultimately adopted.

This situation creates a paradox in which recognition as an expert referral center may be both protective and potentially expose the institution to greater medicolegal scrutiny. On the one hand, multidisciplinary decision-making promotes adherence to best practices, improves traceability, and strengthens the robustness of clinical decisions. On the other hand, designation as an expert center may generate higher expectations regarding the quality and appropriateness of the recommendations provided.

In this context, standardized documentation of MDT recommendations, explicit recording of residual uncertainties, and a clear definition of the respective responsibilities of the expert center and the referring institution appear essential to ensure both high-quality patient care and medicolegal security.

One of the most important recent developments of the CRIOAc network has been the progressive integration of innovative therapies targeting the biofilm locally. In this context, CRIOAc Lyon was entrusted with a national mission to coordinate the evaluation of non-traditional antibacterial therapies, including phage therapy. This mission is supported by a dedicated national MDT, which provides multidisciplinary assessment of complex cases and facilitates structured and equitable access to these innovative therapeutic approaches at the national level [7,33–36].

Beyond phage therapy, the development of other biofilm-targeted strategies, including phage-derived enzymes, antimicrobial peptides, and innovative local anti-infective delivery systems, further illustrates the progressive expansion of the CRIOAc network's field of expertise [7,37,38]. This evolution is taking place in the context of increasing antimicrobial resistance and a growing need for robust clinical evaluation of novel anti-infective therapies.

The national organization of the CRIOAc network also facilitates participation in large academic and international clinical trials

dedicated to BJIs. For example, the network is currently participating in the international ROADMAP platform trial (NCT06771050) on prosthetic joint infections, illustrating its capacity to contribute to large-scale collaborative research programs and the prospective evaluation of innovative therapeutic strategies.

Looking ahead, strengthening collaborations with European initiatives, particularly through the European Bone and Joint Infection Society (EBJIS), together with the development of digital tools enabling the use of large-scale healthcare databases and longitudinal patient follow-up, will represent important opportunities for the continued development of the CRIOAc network. Originally established as a national referral network for complex BJIs, the CRIOAc network is now well positioned to contribute to European collaborative research, education, and the evaluation of innovative therapeutic strategies, while maintaining its primary mission of providing multidisciplinary expertise for patients with complex bone and joint infections.

5. Conclusion

Eighteen years after its establishment, the CRIOAc network has established itself as a pioneering and sustainable model for the multidisciplinary management of complex BJIs in France. Recent international evidence has reinforced the relevance of the organizational principles implemented as early as 2008, based on a coordinated national referral network and multidisciplinary expertise. In the face of increasing patient complexity, antimicrobial resistance, and the growing need for innovative anti-infective therapies, the CRIOAc network is now well positioned to evaluate emerging therapeutic strategies and to contribute, through national and European collaborations, to the continuous improvement of care for patients with complex BJIs.

Author contributions

Tristan Ferry conceived and coordinated the study, drafted the first version of the manuscript, and finalized the version accepted for publication. All authors critically revised the manuscript, contributed their expertise, and approved the final version.

Declaration of Generative AI and AI-assisted technologies in the writing process

ChatGPT (OpenAI) was used exclusively to assist with language editing and stylistic improvements. All authors critically reviewed and validated the scientific content of the manuscript and take full responsibility for its final version.

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Declaration of competing interest

Tristan Ferry perceives fees from Sanofi and facilitations from MSD and is paid consultant for Erytech Pharma. Éric Senneville is paid consultant for Shionogi, Correvio, Zimmer and Menarini. Johan Courjon perceives fees from Shionogi, Correvio, and Menarini. Gwenaël Le Moal perceives fees from VIIV Healthcare SAS and Gilead. Harold Common is paid consultant for FH Ortho and perceives fees from Zimmer SERF and Stryker. Véronique Dubois perceives fees from Shionogi, MSD and Menarini. Anne-Laure Roux declares no conflict related or not to the current study. Benoît Brunschweiler perceives fees from Correvio and Stryker. Adrien Lemaignan perceives fees from Pfizer, Infectopharm France and Menarini. Jean-Yves Jenny is paid consultant for B. Braun

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Corresponding Centers

Centre Hospitalier de Versailles André Mignot, Le Chesnay – Dr Philippe Boisrenoult (Orthopedic surgeon, Coordinator), Dr Audrey Therby (Infectious Diseases specialist), Dr Marlène Amara (Clinical microbiologist);

AP-HP Hôpital Lariboisière, Paris – Dr Jawad Rahal (Orthopedic surgeon), Dr Anne-Lise Munier (Infectious Diseases specialist), Dr Béatrice Bercot (Clinical microbiologist);

AP-HP Hôpital Cochin, Paris – Prof. Philippe Anract (Orthopedic surgeon), Prof. Étienne Canoui (Infectious Diseases specialist), Dr Philippe Morand (Clinical microbiologist);

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CHU de Caen – Dr Jocelyn Michon (Infectious Diseases specialist, Coordinator), Dr Goulven Rochcongar (Orthopedic surgeon), Dr Christophe Isnard (Clinical microbiologist);

CHU de Besançon – Dr Grégoire Leclerc (Orthopedic surgeon), Dr Kevin Bouiller (Infectious Diseases specialist), Dr Isabelle Patry (Clinical microbiologist);

Hôpitaux Universitaires de Strasbourg, Illkirch-Graffenstaden – Dr Cécile Ronde-Oustau (Infectious Diseases specialist, Coordinator), Prof. Jean-Yves Jenny (Orthopedic surgeon), Dr Stéphane Klein (Infectious Diseases specialist), Dr Pierre Boyer (Clinical microbiologist);

CHU de Grenoble – Dr Patricia Pavese (Infectious Diseases specialist, Coordinator), Dr Brice Rubens Duval (Orthopedic surgeon), Dr Sandrine Boisset (Clinical microbiologist);

CHU de Clermont-Ferrand – Dr Clément Theis (Infectious Diseases specialist, Coordinator), Dr Roger Erivan (Orthopedic surgeon), Dr Tiphannie Fais (Clinical microbiologist);

CHU de Limoges – Dr Fabrice Fiorenza (Orthopedic surgeon, Coordinator), Dr Hélène Durox (Infectious Diseases specialist), Dr Nadia Hidri (Clinical microbiologist);

CHU de Brest – Prof. Séverine Ansart (Infectious Diseases specialist, Coordinator), Prof. Thomas Williams (Orthopedic surgeon), Dr Luc Quaesaet (Infectious Diseases specialist), Dr Didier Tande (Clinical microbiologist);

CHU d'Angers – Dr Pierre Abgueguen (Infectious Diseases specialist, Coordinator), Dr Florian Ducellier (Orthopedic surgeon), Dr Rachel Chenouar (Clinical microbiologist);

CHU de Poitiers – Prof. France Cazenave-Roblot (Infectious Diseases specialist, Coordinator), Dr Pierre Pries (Orthopedic surgeon), Prof. Gwenaél Le Moal (Infectious Diseases specialist), Dr Chloé Plouzeau-Jayle (Clinical microbiologist);

CHU de Nantes – Dr Raphaël Lecompte (Infectious Diseases specialist, Coordinator), Prof. Christophe Nich (Orthopedic surgeon), Prof. Stéphane Corvec (Clinical microbiologist);

CHU de La Réunion, Saint-Pierre – Dr Rodolphe Manaquin (Infectious Diseases specialist, Coordinator), Dr Xavier Bouiloux (Orthopedic surgeon), Dr Anne-Gaëlle Leroy (Clinical microbiologist).

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:<https://doi.org/10.1016/j.otsr.2026.104804>.

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