77th FEMTEC SCIENTIFIC CONGRESS

Artificial Intelligence in Balneology and Balneotherapy

From the integrated balneal cure to new scientific horizons

Aix-les-Bains | 4–6 November 2026 | 15-minute presentation

AUTHORS / AFFILIATIONS TO BE ADDED

TWO OPENING QUESTIONS

Two questions that define the challenge

Not AI in medicine generally — but a scientific question specific to balneology.

01 WHAT ARE WE STUDYING?

Isolated procedures — or the balneal cure as a complex, time-structured therapeutic intervention?

02 HOW CAN AI HELP?

How can AI help us understand, characterize and evaluate the balneal cure as an integrated intervention?

RESEARCH HORIZONS

Four horizons for contemporary balneology

Research questions — not four clinically validated AI applications.

01 Multimodal resource classification

Natural therapeutic resources: chemistry, mineralogy, microbiology, functionality.

02 The integrated balneal cure

Dose, procedure parameters, rhythm, duration and environmental exposure.

03 Mechanisms → outcomes

Cell biology, molecular signals, biomarkers and patient-relevant results.

04 Personalized balneotherapy

Predictive models and prospective digital-twin research.

IDENTITY OF BALNEAL MEDICINE

The cure is more than a procedure

A typical multi-week therapeutic programme has structure, repetition and context.

THERAPEUTIC RESOURCE	Mineral water · peloid · climate
DOSE & DELIVERY	Temperature · time · immersion depth
RHYTHM & DURATION	Daily timing · repeated sessions · 2–3 weeks
CO-INTERVENTIONS	Exercise · rehabilitation · other procedures

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CLIMATIC CONTEXT

Continuous exposure throughout the stay*

*Climatic presence is not equivalent to a quantified therapeutic dose; actual exposure must be measured.

A METHODOLOGICAL GAP

What is missing when we report only “mineral baths”?

The label names a procedure, but cannot reconstruct the delivered cure.

INCOMPLETE DESCRIPTION

“Mineral baths”

Without dose, timing, water profile or co-interventions

→

STRUCTURED EXPOSURE DATA

Resource profile + protocol + time + context

A prerequisite for reproducible comparisons and credible AI models

Methodological anchor: Kamioka et al., 2013 — SPAC reporting checklist.

CLINICAL ANCHOR

Clinical evidence: an integrated thermal-care programme

Forestier et al. randomized multicentre trial in knee osteoarthritis.

Participants achieving clinically important improvement at 6 months



18 days of balneal therapy + exercises and usual medical treatment; components cannot be causally separated.

Forestier et al., Ann Rheum Dis. 2010;69:660–665. DOI 10.1136/ard.2009.113209.

BIOLOGICAL ANCHOR I

From the cure to measurable molecular responses

Clinical research can investigate biological signals alongside patient outcomes.

KNEE OSTEOARTHRITIS

Balneotherapy & microRNA expression

Comparative clinical study

What can be measured?

Changes in selected microRNA expression after a balneotherapy course.

What can we NOT conclude?

Molecular changes alone do not prove clinical mediation or causation.

Giannitti et al., Int J Biometeorol. 2017;61:2153–2158. DOI 10.1007/s00484-017-1420-3.

BIOLOGICAL ANCHOR II

From mineral water to cellular pathways

A 2026 experimental study on human osteoarthritic chondrocytes.

APOPTOSIS

Cell survival

OXIDATIVE STRESS

Redox balance

INFLAMMATORY MEDIATORS

Gene expression

microRNA

Regulatory signals

Experimental cellular evidence ≠ demonstrated clinical effect of the complete balneal cure.

Fioravanti et al., Front Med. 2026;13:1800406. DOI 10.3389/fmed.2026.1800406.

THE INTEGRATION PROBLEM

The balneological data model AI would need

The challenge is connecting resource → delivered intervention → response → outcome.

RESOURCE	→	EXPOSURE	→	RESPONSE	→	OUTCOME
Mineralogy Chemistry Microbiology		Dose · timing Duration Climate		Molecular Cellular Biomarkers		Pain · function Quality of life Follow-up

AI is potentially useful at the interfaces — after careful data standardization and external validation.

RESEARCH HORIZON I

Towards a multimodal classification of natural resources

Developing—not discarding—the historical classification tradition.

PHYSICOCHEMICAL	Minerals · pH · salinity
MICROSCOPIC / IMAGING	Granularity · microstructure
BIOLOGICAL	Microbiota · organic fraction
FUNCTIONAL / SAFETY	Thermal properties · stability · contaminants

→

AI-assisted resource profiles

NOT automatic clinical indications

Gomes et al. (incl. Maraver), Applied Clay Science. 2013;75–76:28–38. DOI 10.1016/j.clay.2013.02.008.

AI: OPPORTUNITY VERSUS EVIDENCE

What AI may add — and what it cannot repair

Multimodal modelling is only as credible as the underlying science and data.

POTENTIAL CONTRIBUTIONS

- Integrate heterogeneous measurements
- Detect complex response patterns
- Model longitudinal trajectories
- Generate testable hypotheses

NON-NEGOTIABLE LIMITS

- Poorly specified interventions
- Small or biased datasets
- Confounding and causal ambiguity
- Lack of external clinical validation

RESEARCH HORIZON IV

Digital twins: an exploratory horizon

Not a validated clinical product for balneotherapy.

PATIENT

Clinical and biological profile

+

BALNEAL EXPOSURE

Resource and full cure protocol

+

UPDATED MODEL

Simulation and feedback

Clinical use would require longitudinal data, model verification, prospective testing and medical oversight.

CLIMATE CONTEXT

One additional horizon: changing climatic exposure

Climate is an evolving context of the balneal cure — not a fixed background variable.

Resort-level climate time series + **Biological and clinical trajectories**

AI may help reveal new associations — causal effects require dedicated research.

Kept deliberately brief in this presentation; a future balneology-specific research topic.

SYNTHESIS

From traditional practice to testable science

Modernization begins with a more precise characterization of balneal medicine.

DEFINE

What is the balneal cure?

→

MEASURE

Resources · exposure · responses

→

INTEGRATE

Clinical + biological data

→

VALIDATE

Reproducible, useful models

AI is a tool for advancing balneology—not a substitute for balneological knowledge.

Q&A AND MODERATED DISCUSSION

What should balneology ask of AI first?

1. Can we describe the whole balneal cure reproducibly?
2. Which biological signals genuinely track meaningful clinical benefit?
3. What data would make a multimodal resource classification credible?

Thank you

ANNEX A — REFERENCE LIST

Reference appendix · foundations

Supplementary slides — not part of the 15-minute presentation.

Forestier R et al. Spa therapy in knee osteoarthritis: a multicentre randomized trial. Ann Rheum Dis. 2010;69:660–665. doi:10.1136/ard.2009.113209

Kamioka H et al. SPAC checklist: reporting quality in spa therapy and balneotherapy trials. Complement Ther Med. 2013;21:324–332. doi:10.1016/j.ctim.2013.05.002

Gomes CSF et al. Peloids and pelotherapy: historical evolution, classification and glossary. Applied Clay Science. 2013;75–76:28–38. doi:10.1016/j.clay.2013.02.008

ANNEX B — REFERENCE LIST

Reference appendix · biology

Supplementary studies for the oral presentation and subsequent discussion.

Giannitti C et al. Can balneotherapy modify microRNA expression levels in osteoarthritis? Int J Biometeorol. 2017;61:2153–2158. doi:10.1007/s00484-017-1420-3

Fioravanti A et al. Sulfate-arsenical-ferruginous water affects apoptosis, oxidative stress, inflammatory mediators and microRNA in osteoarthritic chondrocytes. Front Med. 2026;13:1800406. doi:10.3389/fmed.2026.1800406

Antonelli M et al. Balneotherapy and cortisol levels: an updated systematic review and meta-analysis. Int J Biometeorol. 2024. PMID:38884799

ANNEX C — CRITICAL SAFEGUARDS

What the evidence does—and does not—show

Methodological safeguards to use during the moderated discussion.

CLINICAL TRIAL	A multi-component care package may be beneficial; attribution to an individual resource remains uncertain.
MOLECULAR STUDIES	Molecular and cellular changes can be measured; mediation of patient benefit is not automatically established.
RESOURCE CLASSIFICATION	Algorithmic clusters do not equal validated therapeutic indications.
DIGITAL TWINS	A conceptual research possibility, not an established personalized-balneotherapy system.

ANNEX D — BIBLIOGRAPHIC ROADMAP

Next bibliographic questions

Priority checks before treating emerging horizons as established evidence.

1. Direct AI / machine-learning studies using balneological resources or full-cure data
2. Validation of biomarker–clinical outcome links, particularly longitudinal evidence
3. Whether multimodal resource classification improves on conventional approaches
4. External validation, causal inference and sample-size constraints for predictive models
5. Dynamic climatic exposure data in balneal resorts and patient response