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Narrative Review

A classification of articular cartilage grafting and regeneration developed using an artificial intelligence narrative review

Joseph Bernstein[a,b,*] and James L. Carey[b,c]

[a] Corporal Michael J. Crescenz VA Medical Center, Philadelphia, PA, United States
[b] University of Pennsylvania, Department of Orthopaedic Surgery, Philadelphia, PA, United States
[c] Penn Center for Cartilage Repair and Osteochondritis Dissecans Treatment, Philadelphia, PA, United States

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ABSTRACT

Introduction: Cartilage grafting, in contrast to bone grafting, lacks a standardized classification system. We hypothesized that a robust classification system for cartilage grafts could be developed effectively with artificial intelligence (AI)-assistance.
Objectives: To synthesize properties identified through an AI-augmented narrative review and thereby generate a classification of cartilage grafting techniques.
Methods: Twenty-four cartilage-related search terms were identified by the authors based on their clinical experience. These terms were used to query 6 large language models. Each AI was prompted to list properties relevant to cartilage grafts, based on its determination of what published researchers have reported. The resulting properties were consolidated by the authors and then submitted to the AIs for suggestions to name the properties, using Greek-based roots to describe each property. The output was synthesized by the authors into a final 5-category system.
Results: A classification with 5 primary categories of cartilage graft properties was devised. The categories were as follows: providing load-bearing and force-dissipating capacity (termed "chondrodynamic"); providing a smooth and resilient surface ("chondrolissic"); filling the defect volume ("chondroplerotic"); integrating with defect margins ("chondrosyndetic"); and supporting cellular activity ("chondrobiotic").
Conclusions: We present a novel 5-category classification system for cartilage grafting and regeneration developed through an AI-assisted narrative review and synthesis. This study may fill important gaps. While the risks of AI are real (especially source fabrication, also known as "hallucination"), with further validation and consensus-building, the proposed framework can be used in clinical and research settings and guide the future use of AI in knowledge aggregation and application.

Investigation performed at the Corporal Michael J. Crescenz VA Medical Center/ University of Pennsylvania, Department of Orthopaedic Surgery.

* Joseph Bernstein, Corporal Michael J. Crescenz VA Medical Center, 3900 Woodland Ave, Philadelphia, PA 19104.
Email address: orthodoc@upenn.edu (J. Bernstein).

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Introduction

Background

Articular cartilage has the remarkable ability to bear loads, glide smoothly, and dissipate forces. Once damaged, however, cartilage does not have the capacity to repair itself.[1] As a result, cartilage defects are often addressed with grafting, repair and regeneration procedures.[2]

Bone defects also at times require grafting. Bone grafts have historically been classified according to their properties[3]: osteogenic grafts supply living bone-forming cells; osteoinductive grafts stimulate progenitor cells to differentiate into bone-forming cells; and osteoconductive grafts provide a scaffold for the ingrowth of new bone.

By contrast, no comparable classification exists for cartilage grafting. The present study aims to fill that defect by offering a classification system for cartilage grafts. One approach to constructing a classification would begin with a narrative review of the literature to identify the properties that researchers report when evaluating grafts. These properties could then be grouped by shared themes.

Contemporary methods for conducting a literature review and synthesis can be enhanced through artificial intelligence (AI). With its broad assimilation of information and exceptional recall capabilities, AI offers unique potential for both wide-ranging review and deep synthesis. To be sure, the use of AI can be risky too, as chatbots may conjure up sources that are not real or incompletely digested, generating plausible yet fictional responses.[4] This risk, however, can be mitigated by close supervision of the AI by human scholars. Thus, this study attempts to leverage the capabilities of AI—under close human supervision—to develop a robust and practical classification of cartilage grafts.

This study asks whether the properties of cartilage grafts known to experienced orthopedic surgeons but augmented by an AI-assisted narrative review of the literature can be synthesized to thereby generate a classification of cartilage grafting and regeneration techniques.

Methods

A set of 24 cartilage-related search terms, derived from the authors' experience in clinical practice and scientific research, was created to guide the AI-assisted narrative review. The list of search terms comprised the following:

- Abrasion arthroplasty
- Autologous chondrocyte implantation
- Cartilage defect
- Cartilage defect augmentation
- Cartilage defect biologic implant
- Cartilage defect bioengineered cartilage
- Cartilage defect graft
- Cartilage defect growth factors
- Cartilage defect hyaline cartilage restoration
- Cartilage defect hydrogel-based implants
- Cartilage defect implant
- Cartilage defect injection
- Cartilage defect osteochondral allograft
- Cartilage defect osteochondral autograft
- Cartilage defect patch
- Cartilage defect platelet-rich plasma
- Cartilage defect repair
- Cartilage defect scaffolds
- Cartilage defect stem cell therapy
- Cartilage defect synthetic cartilage replacement
- Cartilage tissue engineering
- Chondral repair implant
- Matrix-induced autologous chondrocyte implantation (MACI)
- Minced/particulated cartilage allograft
- 3D printed cartilage constructs.

Six large language models (LLMs), including ChatGPT-4o (OpenAI), Claude Sonnet 4 (Anthropic), Gemini 1.5 Pro (Google DeepMind), Grok-4 (xAI), Perplexity Sonar (Perplexity AI), and DeepSeek-V3.1 (DeepSeek), were given the 24 terms and prompted to compile a comprehensive set of cartilage graft properties based on reported research outcomes (See Appendix 1). All models were consulted in June 2025. Each AI system responded without being informed that other systems were queried, and their responses were compiled into a master list of cartilage graft properties (referred to below as the "Master List"). The authors (JB, JC), both Sports Medicine fellowship-trained board-certified orthopedic surgeons with more than 20 years' experience each, then reviewed this Master

List and grouped the properties into 5 categories based on their understanding of biological attributes, structural and functional roles, and biomaterial characteristics.

Copies of the Master List were submitted to each LLM in parallel without redaction, prompting it to construct its own classification scheme for cartilage grafts. The AIs were told that this was intended to echo, but not necessarily replicate, the tripartite framework used for bone grafts. The LLMs were directed to focus on intrinsic graft properties and to formulate no more than 6 discrete categories, a limit informed by the authors' experience with classification systems. The LLMs were instructed to describe these categories in standard English, avoiding (for the time being) novel terminology, and to define each category by its core property (eg, "serving as a scaffold"). Each AI system was encouraged to apply its own methods of inference and synthesis in generating a proposed classification.

The authors reviewed the resulting AI-derived classification schemes and used them to inform their final, human-derived system. Overlapping or closely related properties were consolidated through discussion and expert judgment, resulting in 5 final categories. In this framework, each category was defined by a short English phrase describing the relevant graft property. The 2 authors worked independently on the initial grouping process and then came together to compare and reconcile their results, in the manner of a collaborative partnership where individual work informs but does not predetermine the joint product. No disagreements requiring adjudication were encountered, but a trusted colleague was available to serve as a tiebreaker if needed.

Once the underlying framework of the classification was established, the authors submitted their phrase-based taxonomy to the 6 AI systems and requested proposed names for each category. The AI systems were instructed to use the prefix *chondro-* combined with Greek-rooted suffixes reflecting the nature or purpose of each property. These name suggestions were reviewed and refined by the authors to yield the final classification terminology.

The complete methodological workflow is summarized in Figures 1 and 2. The diagram illustrates a human-led process of integrating LLM synthesis. As shown, the process is sequential, not parallel; thus at no point were the humans and the AI simultaneously operating on identical inputs.

Results

The 6 LLMs generated a total of 436 graft properties for the Master List (see Appendix 2). This list included repeated or closely related terms; nothing was removed or altered by the authors.

In the second round of analysis, each LLM was provided with a copy of the full Master List and was prompted to propose a classification system based on graft characteristics. From these independent syntheses, 11 distinct graft property categories emerged (Table 1).

After human review of the AI-generated property groupings and suggested Greek-based terms (Table 2), a final classification of 5 categories was produced as follows:

- Chondrodynamic, referring to the property of bearing loads appropriately.[1]
- Chondrolissic, referring to the property of having a smooth top layer,[5] recapitulating the lamina splendens.
- Chondrosyndetic, referring to the property of integrating into surrounding tissues.[6]
- Chondroplerotic, referring to the property of filling the defect's precise dimensions.[7]
- Chondrobiotic, referring to the property of matrix synthesis and cellular activity.[8]

Discussion

The primary contribution of this work is a process: an AI-assisted narrative review employed to develop a standardized classification system for cartilage grafting and regeneration. To that end, we compiled a comprehensive Master List of cartilage graft properties by querying 6 widely used LLMs. We then synthesized those properties, guided by both AI-derived groupings and our own biological and clinical understanding, into a final 5-category classification.

Limitations

Our work has acknowledged limitations. First, any novel classification system is inherently provisional until it is subjected to a process of validation. In the case of predictive classifications, such validation would be empirical. For instance, patients whose disease is classified as "mild" should be shown to fare better than those labeled "severe" a failure to demonstrate such a distinction undermines the very premise of the classification. By contrast, for conceptual classification schemes like the one proposed here, there is no method of empirical validation. Rather, validation depends on community adoption. As Sterner et al[9] have argued, the measure of a classification rests not on prior proof but on its utility for coordinating communication within the relevant community. Until such consensus emerges, this framework remains only a starting point for discussion and refinement.

Second, the classification as proposed may be incomplete. Key properties relevant to cartilage graft performance may have been omitted, whether due to gaps in the literature, failure on our part to master the literature, or other oversights.

Relatedly, the grouping of properties and the selection of category names, though grounded in the authors' clinical experience, are inevitably subjective. The resulting classification is interpretive and idiosyncratic; alternative schemes may be equally valid, or even preferable. At the same time, such interpretive flexibility is often useful when first attempting to organize a heterogeneous domain.

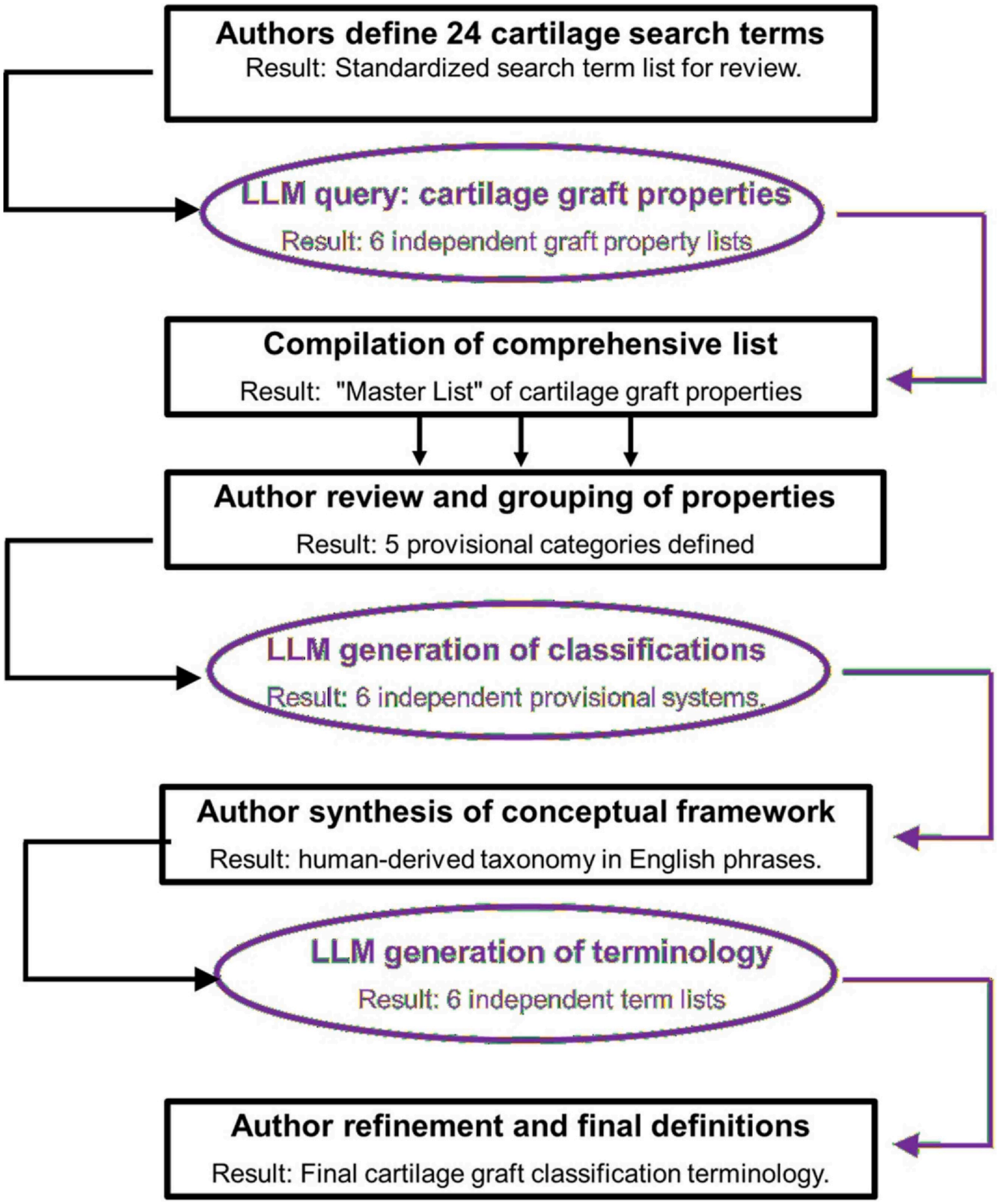

Fig. 1. Methodological workflow for the development of the cartilage graft classification system. The diagram illustrates a sequential, human-led process of integrating large language model (LLM) synthesis. The boxes indicate steps requiring author-driven analysis or synthesis; the purple ovals represent steps involving LLM generation. Critically, the process begins and ends with a human-led step.

Third, the classification does not account for changes in graft properties over time. For example, at the time of surgery, MACI is typically glued to the base of a defect.[10] A cartilage defect is often deeper than 3 mm, while the MACI construct is approximately 1 mm thick. In terms of chondroplerosis, MACI could reasonably be characterized as incomplete at the moment of implantation. However, over time, the construct is expected to generate new matrix, filling the defect. At that point, the graft would meet criteria for being chondroplerotic. Similarly, some grafts may improve their integration postoperatively, while the mechanical properties of others may decline. Accordingly, without incorporating the temporal dimension, the classification cannot capture how graft properties evolve. Future refinements can readily incorporate time-dependent characteristics.

Relatedly, the proposed framework is not intended to function as a direct clinical decision algorithm. Rather, it is meant to organize thinking about the properties of cartilage grafts and regenerative strategies. In this respect, it is analogous to Urist's well-known classification of bone graft properties as osteogenic, osteoinductive, and osteoconductive. That framework does not dictate a specific treatment choice but helps clinicians consider whether a given graft material possesses the properties needed to address a particular defect (see Table 3). The present classification is intended to serve a similar conceptual role for cartilage grafting and regeneration.

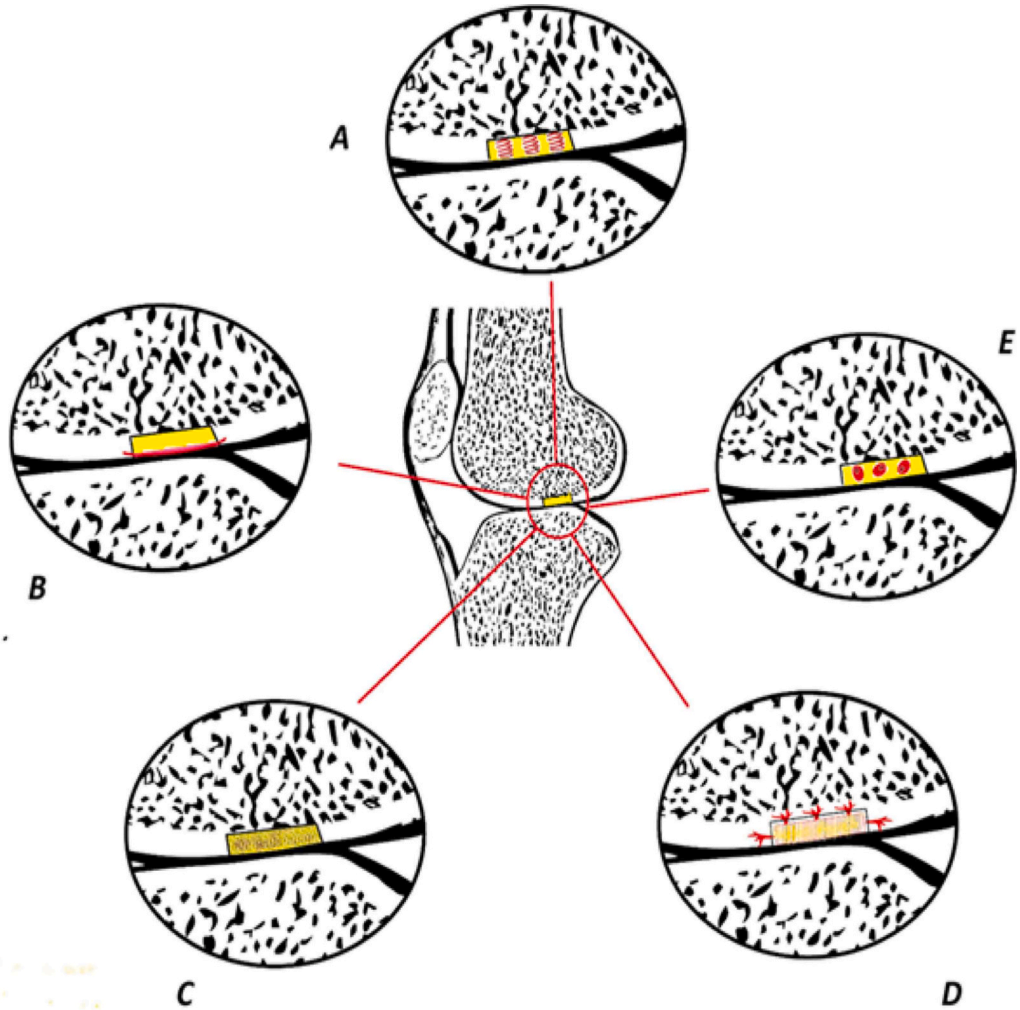

Fig. 2. Schematic representation of 5 desirable properties of a cartilage graft: **A,** Springs embedded in the graft signify *chondrodynamics*, the capacity to absorb and return load. **B,** A smooth surface of the graft represents *chondrolissis*, denoting a low-friction articulating interface. **C,** Graft material filling the entire defect illustrates *chondroplerosis*, the restoration of cartilage volume. **D,** Connections at the margins reflect *chondrosyndesis*, the integration of the graft with surrounding native cartilage. **E,** Embedded synthetic cells indicate *chondrobiosis*, the presence of biologically active or engineered cellular components.

Table 1
The list of property descriptions, sorted by the frequency of mention.

	Perplexity	Gemini	Chat GPT	Claude	Deepseek	Grok
Load bearing	X	X	X	X	X	X
Integrative	X	X	X	X	X	X
Bioactive	X		X	X	X	X
Scaffolding		X	X	X	X	X
Biocompatible	X	X				
Matrix formative	X		X			
Remodels	X		X			
Stimulates differentiation		X		X		
Mimics native cartilage					X	X
Supports surgical handling		X				
Has viable cells				X		

Some may question our use of an AI-assisted narrative review, rather than a systematic review, to develop the classification system. Systematic reviews include assessment of evidence quality or adjustments for bias, among other features[11] and that was not provided here. However, such criticism may be less applicable in the present context. Our aim was not to establish what is true about

Table 2
The list of properties, with Greek root defined.

Property	Coined term	Greek root
Load-bearing	**Chondrodynamic**	*dynamis* (δύναμις) = power, force
Offering a smooth, protective layer	**Chondrolissic**	*lissos* (λισσός) = smooth
Attaching/integrating with surrounding cartilage	**Chondrosyndetic**	*syndesis* (σύνδεσις) = binding together
Space-filling	**Chondroplerotic**	*plerosis* (πλήρωσις) = filling, completion
Biologically active	**Chondrobiotic**	*bios* (βίος) = life

Table 3
An assessment of 3 cartilage repair procedures using the classification categories.

	Chondrodynamic (load-bearing)	Chondrolissic (offering a smooth layer)	Chondrosyndetic (integrates to surrounding tissues)	Chondroplerotic (space-filling)	Chondrobiotic (matrix synthesis and cellular activity)
Microfracture	*Early: Poor; Late: Satisfactory	Early: Poor; Late: Satisfactory (concern for intra-lesional osteophytes)	Early: Poor; Late: Good	Early: Satisfactory; Late: Satisfactory	Good
Fresh osteochondral allograft	Early: Good; Late: Excellent	Early: Excellent; Late: Excellent	Early: Poor; Late: Poor	Early: Good; Late: Good (concern for contour mismatch, especially patellofemoral)	Satisfactory
Autologous chondrocyte implantation	Early: Poor; Late: Good	Early: Poor; Late: Good	Early: Poor; Late: Good	Early: Satisfactory; Late: Good (concern for hypertrophy)	Excellent

* All assessments represent the authors' opinions.

cartilage grafting properties, but rather to identify what properties investigators have considered worth studying. A property that appears only in a low-quality study is still a property that someone found meaningful enough to investigate. The signal we were extracting was the existence and naming of categories, not the validity of findings within them. Evidence appraisal would be essential if we were drawing clinical conclusions from the literature; it is less relevant when the literature is being used as a map of the investigative terrain rather than as a source of ground truth. When the goal is to map the literature and identify key concepts (as it is in this study), the expediency of an AI-assisted narrative review is justified. Systematic reviews, by contrast, are resource-intensive and better suited to settings where appraisal of the evidence is critical.

Our use of AI for literature review and synthesis may represent not merely a potential limitation, but also a source of controversy. To our knowledge, this is the first paper in the orthopedic surgery literature to incorporate LLMs as an explicit partner in the investigative process. In this context, AI is not a mere tool, like a statistical analysis program; it is a generative collaborator. This distinction is foundational: a regression analysis performed by hand, however slowly it may progress, will ultimately yield the same result as one executed by machine. LLMs, conversely, function less deterministically, possibly inventing results rather than discovering a result waiting to be found.

With that independence comes potential pitfalls. To start, because they operate less deterministically, LLMs, asked the same question twice, will not produce 2 identical answers. In addition, the data sets on which LLMs are trained are neither disclosed nor subject to scrutiny. There is no audit trail.

Furthermore, AI chatbots are optimized to be engaging, to give the user what (the model supposes) the user wants. Accordingly, they are prone to hallucinating[4]—what may be called, in medical terms, "pseudologia fantastica,"[12] or more plainly, "making things up."

An additional and related objection deserves mention with regard to an AI review of the literature. LLMs may have access only to abstracts rather than full papers, increasing the risk that they will extrapolate confidently from incomplete information. This is a serious limitation in many applications: responses might seem particularly reliable when a verifiable source can be cited (even though the source did not assert what was claimed). In our case, however, the task of generating a list of graft properties relies predominantly on data that are usually stated plainly and completely in abstracts. That is, because the models were retrieving descriptors rather than making inferences, the risk and ramifications of confabulation here are correspondingly smaller, though not absent.

Moreover, using multiple systems, as we did, can offer protection against rogue responses, as isolated hallucinations would stand exposed as outliers. To be sure, however, if the seed of an errant response lies within the data set on which all models are trained, what appears to be confirmation of a consensus may instead reflect an echo chamber of ignorance. In sum, AI-based analysis remains a black box.

Against that backdrop, using LLMs for thought synthesis offers more than the familiar advantages of computers, such as speed and scale. Beyond that, with blanket immersion, total recall, and vast computational capacity,[13] LLMs can elucidate the subtle "patterns and relationships that may not be readily apparent,"[14] enabling forms of insight otherwise elusive.

Assisted by those capabilities, the authors organized isolated descriptions of graft properties into a 5-category classification scheme based on biological, clinical, and material considerations. We further used the LLMs to suggest candidate names for each category, aiming for terminology rooted in Greek etymology and clinical relevance. This iterative, human-directed and AI-assisted process culminated in a novel, practical classification system for cartilage grafts, intended to enhance clarity, communication, and research in the field. The 5 resulting categories—chondrodynamics, chondrolissis, chondroplerosis, chondrosyndesis, and chondrobiosis—together represent the full complement of processes that would occur with true cartilage regeneration and restoration[15] (Fig. 1).

Conclusion

As David St Hubbins observed, there is a fine line between clever and stupid.[16] This study operates near that boundary, where innovation risks tipping into inanity. We acknowledge that hazard, but argue that the price of experimentation here is particularly affordable; we are in an entirely safe domain with very low likelihood of patient harm.

The use of AI as a generative partner in knowledge synthesis is untested in orthopedics. Exploring this potential is worthwhile not only to improve the efficiency of established workflows but, more importantly, to expand the frontier of research that can be undertaken. We acknowledge that this may not be an unmitigated positive effect; for example, the ease with which a researcher can perform regression analyses with computer statistical analysis programs may have led to a proliferation of studies that lack an ex ante articulated hypothesis. Nonetheless, such a criticism is not an argument against the use of AI, but rather an argument for its judicious application.

Notably, in this study, AI did not replace human judgment. All synthesis, adjudication, and interpretation remained under human control, within a task structure that is relatively resistant to the hallucination risks that are understandably of concern.

Whether the 5-category system offered here proves clinically useful remains to be determined. The principal test of the framework will be whether it helps clinicians and researchers think more systematically about the properties of cartilage grafts and regenerative strategies. If it proves helpful in that regard, it will have served its purpose. At the same time, the process described here suggests that LLMs, when closely supervised, may assist scholars in synthesizing complex literatures and generating specific classifications.

Trial and error implies error. We offer this work in that spirit.

Informed consent

Not applicable. This study did not involve human participants or identifiable patient information or images.

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Declaration of Competing Interest

The authors have no competing interests.

Declaration of generative AI and AI-assisted technologies in the manuscript preparation process

During the preparation of this work the author used ChatGPT, Claude, Gemini, Grok, Perplexity, and DeepSeek, as described in detail in the Methods section above. After using these tools, the authors reviewed and edited the content as needed and take full responsibility for the content of the published article.

Appendix A. Supporting information

Supplementary material associated with this article can be found in the online version at doi:10.1016/j.jcjp.2026.100317.

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