

Graphene–DNA Composites as Hydration-Based Boundary Lubricants in Joint-Like Environments

Chur Chin

Department of Emergency Medicine, New Life Hospital, Bokhyun-dong, Buk-gu, Daegu, South Korea.

***Corresponding Author:** Chur Chin, Department of Emergency Medicine, New Life Hospital, Bokhyun-dong, Buk-gu, Daegu, South Korea.

Received Date: January 09, 2026; **Accepted Date:** January 16, 2026; **Published Date:** January 23, 2026

Citation: Chur Chin, (2026), Graphene–DNA Composites as Hydration-Based Boundary Lubricants in Joint-Like Environments, *J. Biomedical Research and Clinical Reviews*, 12(1); DOI:10.31579/2692-9406/245

Copyright: © 2026, Chur Chin. This is an open-access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.

Abstract

Graphene-based materials have attracted increasing interest for biomedical and tribological applications; however, their behavior in biological fluids differs fundamentally from that of crystalline solids. When functionalized with DNA and introduced into aqueous environments, graphene forms a soft, hydrated, polyelectrolyte composite whose lubrication properties are governed by classical soft-matter physics rather than lattice vibrational dynamics. In this work, we present a physically grounded framework for understanding the lubrication potential of graphene–DNA composites in joint-like environments. We argue that the dominant and most plausible mechanism is boundary lubrication via hydrated polymer brushes, in which DNA chains retain strongly bound hydration layers that generate steric and electrostatic repulsion under load while maintaining low shear resistance. This mechanism is analogous to natural joint lubricants such as lubricin and hyaluronic acid and is independent of phonons or Brillouin-zone concepts.

Additional contributions may arise from electro-responsive rheological effects under low-frequency electric or electromagnetic fields, shear-induced alignment of DNA chains during motion, and limited tribo-film formation in bulk suspension. The role of graphene in these processes is primarily passive, providing mechanical robustness, surface anchoring, and conductive pathways for charge redistribution. We further clarify that low-frequency fields can modulate polymer conformation, ionic distributions, and fluid flow, but cannot excite graphene phonons in biologically relevant conditions. Overall, this work reframes graphene–DNA composites as classical hydration-based bio lubrication systems and identifies both their potential and their biological limitations in joint lubrication applications.

Key words: graphene–DNA composite; boundary lubrication; hydration lubrication; polymer brush; synovial fluid; electro-responsive rheology; soft matter physics; tribology; bio lubrication

Introduction

1. Physically Plausible Mechanisms of Lubrication in Graphene–DNA Systems

When graphene is functionalized with DNA and introduced into an aqueous or biological environment, its physical behavior transitions from that of a crystalline solid to that of a soft, hydrated, polyelectrolyte composite. In this regime, lubrication phenomena are governed by classical soft-matter and tribological principles, rather than solid-state phonon dynamics [1–3].

A. Boundary Lubrication via Hydrated Polymer Brushes

DNA is a highly charged polyelectrolyte that, when tethered or adsorbed onto a surface, can behave as a polymer brush extending into the surrounding

fluid [4]. Such brushes are characterized by: High water retention due to strong hydration of charged phosphate groups • Strong steric and electrostatic repulsion under compression Very low shear resistance when sliding occurs These properties form the basis of hydration lubrication, a mechanism shown to produce ultra-low friction coefficients even under high load [5–7]. When DNA is bound to graphene sheets, the resulting graphene–DNA composite may adsorb onto cartilage or cartilage-mimicking surfaces, forming a hydration lubrication layer. This mechanism is conceptually analogous to naturally occurring joint lubricants such as lubricin and hyaluronic acid, which rely on hydrated polymeric domains rather than fluid film hydrodynamics [6–8]. Importantly, this lubrication mechanism is well

established, entirely classical, and independent of phonons or vibrational excitations [7].

B. Electro-Responsive Rheology Under Low-Frequency Fields

Low frequency electric or electromagnetic fields can interact with charged polymer systems by influencing ion distributions and polymer conformations [9]. In graphene–DNA composites, such fields may:

- Reorient DNA chains through electrophoretic or dielectrophoretic forces
- Modulate counterion condensation along the DNA backbone
- Slightly alter local viscosity, slip length, or interfacial friction in this context, graphene does not act as a phonemic medium but rather as a conductive scaffold that can locally amplify electric fields and facilitate charge redistribution at the interface [10,11].

The resulting effects are:

- Electrostatic or electrohydrodynamic in origin
- Small in magnitude
- Reversible and dependent on field strength and orientation

These responses are fundamentally non-vibrational and should be understood within the framework of classical electrostatics and polymer physics [9–11].

C. Shear Alignment During Joint Motion

Even in the absence of externally applied fields, shear forces generated during joint motion can induce polymer alignment. DNA chains within a hydrated graphene–DNA layer may partially align along the direction of shear, while maintaining their hydration shells [12]. Such shear-induced alignment can reduce friction by:

- Lowering entanglement resistance
- Preserving hydration-mediated repulsive forces
- Promoting stable sliding interfaces

Graphene contributes mechanical robustness, surface anchoring, and load distribution, enhancing the durability of the lubricating layer [13]. Notably, no wave excitation or electromagnetic stimulation is required for this mechanism to operate.

D. Viscosity Modification and Tribolium Formation in Bulk Suspension

When dispersed in synovial-fluid-like media, graphene–DNA composites may act as nano-scale tribological additives, slightly modifying bulk rheology or forming transient tribofilms under load [14]. However, several significant challenges remain, including:

- Long-term clearance from the joint space
- Potential immunogenic or inflammatory responses
- Aggregation or protein corona formation

These limitations represent major translational barriers rather than fundamental physical constraints [14,15].

E. Potential Immunomodulatory Effects and Cytokine Regulation

Beyond lubrication, graphene-based materials in hydrated biological environments may exert secondary bioelectromagnetic and immunomodulatory effects. Recent studies suggest that graphene can support surface phonon–polaritons and plasmon phonon hybrid modes in the terahertz (THz) and mid-infrared frequency ranges when coupled to electromagnetic fields [16–18]. While such modes are strongly damped in aqueous media and cannot propagate as coherent lattice excitations, their associated near-field electromagnetic fluctuations may still influence biological processes at interfaces. In inflammatory conditions, excessive release of cytokines such as interleukins (e.g., IL-6, IL-1 β) and interferons (e.g., IFN- γ) contributes to cytokine storm syndromes and severe tissue damage [19,20].

Experimental and theoretical work indicates that low-intensity electromagnetic fields in the THz and sub-THz regime can modulate cytokine expression, macrophage activation, and inflammatory signaling pathways, including NF- κ B and JAK–STAT signaling [21–23]. In this context, graphene surfaces—particularly when functionalized with

biomolecules such as DNA—may act as local electromagnetic field concentrators, enhancing weak external or endogenous fields through surface polaritonic coupling [16,18]. These localized fields could indirectly influence cytokine production by:

- Modulating ion channel activity and membrane potential
- Affecting hydration dynamics and protein–water interactions
- Altering receptor clustering and signal transduction at cell membranes

Such effects may contribute to attenuation of excessive cytokine release, thereby helping to reduce inflammation and limiting cytokine storm severity under certain conditions.

Importantly, this mechanism does not imply direct excitation of graphene phonons within tissues; rather, it reflects field-mediated, near-surface interactions consistent with classical electrodynamics and soft biological matter [17,22]. While these immunomodulatory effects remain exploratory and highly context dependent, they suggest that graphene–DNA composites could offer dual functionality in joint like environments: (i) mechanical lubrication via hydration-based boundary layers, and (ii) potential anti-inflammatory modulation through weak electromagnetic coupling. Further in vitro and in vivo studies are required to quantify these effects, establish safety limits, and distinguish beneficial immunoregulation from unintended immune activation.

F. Exploratory Clinical Case Illustration

To provide preliminary clinical context for the proposed physical mechanisms, we describe an exploratory single-patient observation in which low-frequency field exposure was associated with symptomatic and structural improvement in end stage ankle osteoarthritis. This case is presented for hypothesis-generating purposes only. An 84-year-old female patient had a complex medical history including right pontine infarction (2021), atrial fibrillation, and a recent episode of acute pyelonephritis. She also suffered from left ankle end-stage osteoarthritis with associated avascular necrosis, resulting in chronic pain, limited mobility, and functional impairment. Laboratory findings at the time of evaluation showed evidence of systemic inflammation and medical comorbidity, including white blood cell count of 14,000/ μ L, erythrocyte sedimentation rate (ESR) of 33 mm/hr, and blood urea nitrogen/creatinine of 22.4/1.19 mg/dL. Given her advanced age, neurological history, infection risk, and cardiovascular comorbidities, surgical intervention was considered high risk. A noninvasive low frequency electromagnetic wave intervention was therefore applied locally to the affected ankle joint. The treatment was administered for 4 consecutive weeks, at a duration of 1 hour per day, under close clinical monitoring. Following the treatment period, the patient demonstrated clinically meaningful improvement in ankle pain and joint function, accompanied by improved weight bearing tolerance. Radiographic and/or imaging-based assessment showed partial improvement in joint space narrowing, consistent with enhanced synovial lubrication rather than structural cartilage regeneration (Figure 1). No acute adverse events, arrhythmia exacerbation, or infectious complications were observed during the intervention period. From a mechanistic standpoint, these observations are consistent with the physical framework proposed in this study. Low-frequency electromagnetic fields are expected to influence hydration-mediated boundary lubrication, polymer conformation, ionic distribution, and interfacial fluid dynamics within synovial environments, rather than acting through phonon excitation or quantum vibrational modes. In the presence of graphene–DNA-like hydrated interfaces (either endogenous or exogenously introduced), such field modulation could plausibly enhance synovial fluid lubrication efficiency, reduce interfacial friction, and attenuate mechanically driven inflammation. It is emphasized that this single case does not establish

causality, nor does it demonstrate cartilage regeneration or disease reversal. Instead, it supports the biophysical plausibility that low-frequency field modulation of hydrated joint interfaces may yield functional benefits even in

advanced degenerative disease. Controlled clinical trials and well-defined material delivery studies are required to determine efficacy, dose–response relationships, durability, and safety.



Figure 1. Following the treatment period, the patient demonstrated clinically meaningful improvement in ankle pain and joint function, accompanied by improved weight bearing tolerance. Radiographic and/or imaging-based assessment showed partial improvement in joint space narrowing, consistent with enhanced synovial lubrication rather than structural cartilage regeneration.

2. Role of Low-Frequency Waves: A Clarification

If low-frequency electromagnetic or acoustic waves are applied to such systems, their effects are expected to act on: • DNA chain conformation • Ionic clouds and electrostatic screening • Bulk or interfacial fluid flow They do not act on graphene phonons, Brillouin-zone modes, or any quantum vibrational states [2,3].

Therefore, the correct physical description is field modulated polymer hydration lubrication, not phonon excitation.

3. Conceptual Framework Shift

While solid-state physics concepts such as phonons, Γ -points, and Brillouin zones are essential for crystalline materials, they are not applicable once graphene is functionalized with DNA and immersed in a biological fluid. The appropriate theoretical framework instead involves: • Soft matter physics • Polymer brush lubrication theory • Electrostatics and electrohydrodynamics • Rheology and hydration forces Within this framework, graphene–DNA composites can be meaningfully discussed as classical bio lubrication systems, rather than quantum or vibrational materials.

References

- Bhushan B. (2013). Introduction to Tribology. 2nd ed. New York: Wiley.
- Pop E, Varshney V, Roy AK. (2012). Thermal properties of graphene: Fundamentals and applications. *MRS Bull.*;37(12):1273–1281.
- Balandin AA. (2011). Thermal properties of graphene and nanostructured carbon materials. *Nat Mater*;10(8):569–581.
- Milner ST. (1991). Polymer brushes. *Science*;251(4996):905–914.
- Raviv U, Klein J. (2002). Fluidity of bound hydration layers. *Science*;297(5586):1540–1543.
- Klein J. (2013). Hydration lubrication. *Friction*;1(1):1–23.
- Israelachvili JN, Wennerström H. (1996). Role of hydration and water structure in biological and colloidal interactions. *Nature*;379(6562):219–225.
- Jay GD, Waller KA. (2014). The biology of lubricin: Near frictionless joint motion. *Matrix Biol.* 39:17–24.
- Rubinstein M, Colby RH. (2003). Polymer Physics. Oxford: Oxford University Press.
- Novoselov KS, Fal'ko VI, Colombo L, et al. (2012) A roadmap for graphene. *Nature*;490(7419):192–200.
- Geim AK, Grigorieva I (2013). Van der Waals heterostructures. *Nature*;499(7459):419–425.
- Smith DE, Perkins TT, Chu S. (1996). Dynamical scaling of DNA diffusion coefficients. *Macromolecules*;29(4):1372–1373.
- Lee C, Wei X, Kysar JW, Hone J. (2008). Measurement of the elastic properties and intrinsic strength of monolayer graphene. *Science*;321(5887):385–388.
- Sanchez C, Belleville P, Popall M, Nicole L. (2011). Applications of advanced hybrid organic–inorganic nanomaterials: From laboratory to market. *Chem Soc Rev*;40(2):696–753.
- Fadeel B, Bussy C, Merino S, et al. (2018). Safety assessment of graphene-based materials: Focus on human health and the environment. *ACS Nano*;12(11):10582–10620.
- Low T, Avouris P. (2014). Graphene plasmonics for terahertz to mid-infrared applications. *ACS Nano*;8(2):1086–1101.
- Basov DN, Fogler MM, García de Abajo FJ. (2016). Polaritons in van der Waals materials. *Science*;354(6309):aag1992.
- Caldwell JD, Aharonovich I, Cassabois G, et al. (2019). Photonics with hexagonal boron nitride. *Nat Rev Mater*;4(8):552–567.
- Moore JB, June CH. (2020). Cytokine release syndrome in severe COVID-19. *Science*;368(6490):473–474.

20. Tang Y, Liu J, Zhang D, et al. (2020). Cytokine storm in COVID-19: The current evidence and treatment strategies. *Front Immunol.*; 11:1708.
21. Pall ML. (2013). Electromagnetic fields act via activation of voltage-gated calcium channels to produce beneficial or adverse effects. *J Cell Mol Med.*;17(8):958–965.
22. Blank M, Goodman R. (2009). Electromagnetic fields stress living cells. *Pathophysiology.*;16(2–3):71–78.
23. Funk RHW, Monsees T, Ozkucur N. (2009). Electromagnetic effects—from cell biology to medicine. *Prog Histochem Cytochem.*;43(4):177–264.



This work is licensed under Creative Commons Attribution 4.0 License

To Submit Your Article Click Here:

Submit Manuscript

DOI:10.31579/2692-9406/245

Ready to submit your research? Choose Auctores and benefit from:

- fast, convenient online submission
- rigorous peer review by experienced research in your field
- rapid publication on acceptance
- authors retain copyrights
- unique DOI for all articles
- immediate, unrestricted online access

At Auctores, research is always in progress.

Learn more <https://www.auctoresonline.com/journals/biomedical-research-and-clinical-reviews>