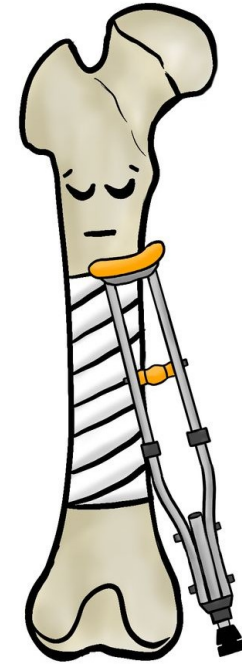


بِه نام خدا

بررسی مکانیزم بازسازی استخوان

- بیومکانیک سیستم های اسکلتی عضلانی
- ارائه دهنده: مهدیه محمد حسین زاده
- استاد راهنما: علی فخاری راد
- دانشگاه علوم تحقیقات
- دانشکده علوم و فناوری های پزشکی
- مهندسی پزشکی
- نیمسال تحصیلی اول ۴۰۴-۴۰۵



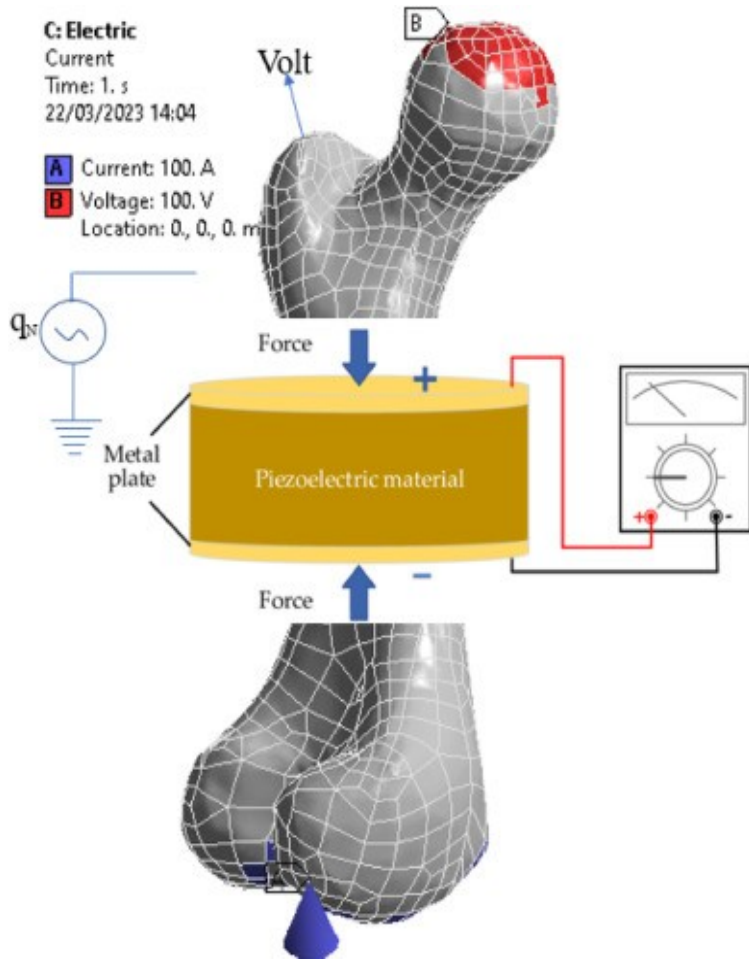


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مقدمه

استخوان یک بافت طبیعی پیزوالکتریک است که هنگام اعمال نیرو، سیگنال‌های الکتریکی تولید می‌کند و همین سیگنال‌ها نقش مهمی در رشد، بازسازی و ترمیم استخوان دارند. این ویژگی الکترومکانیکی عمدتاً از ساختار منظم کلاژن و هیدروکسی‌آپاتیت ناشی می‌شود. مواد پیزوالکتریک مصنوعی با تقلید این رفتار قادرند محیط الکتریکی لازم برای تحریک سلول‌های استخوان‌ساز را ایجاد کنند.



اثر پیزوالکتریک:

وارد شدن نیرو = تولید بار الکتریکی = تحریک سلول‌های استخوانی



مواد غیر آلی

مواد غیرآلی

(IPMs)

BaTiO₃ ،PZ ،ZnO ،KNN

مزایا: ضریب پیزوالکتریک بالا، استحکام مکانیکی خوب، شباهت به استخوان طبیعی

معایب: برخی سمی، تولید دشوار، زیست سازگاری محدود

کاربرد در استخوان: تحریک سلول های استخوانی، افزایش معدنی سازی، اما نیازمند اصلاح برای ایمنی بلندمدت



مواد غیر آلی

6/2



مواد کامپوزیتی

8/21



مواد آلی

1

مواد آلی

مواد آلی

(OPMs)

PVDF، PHB/PHBV، PLLA

مزایا: زیست تخریب پذیر، انعطاف پذیر، زیست سازگار، مناسب برای داربست های استخوانی

معایب: ضریب پیزوالکتریک پایین تر نسبت به معدنی ها، شکنندگی یا هزینه ی تولید بالا

کاربرد در استخوان: داربست های زیست تخریب پذیر، ترکیب با نانوذرات برای افزایش خاصیت ضدباکتری و استخوان سازی



6/21

مواد غیر آلی



7/21

مواد آلی



8/21

مواد کامپوزیتی

مواد کامپوزیتی

مواد کامپوزیتی

(CPMs)

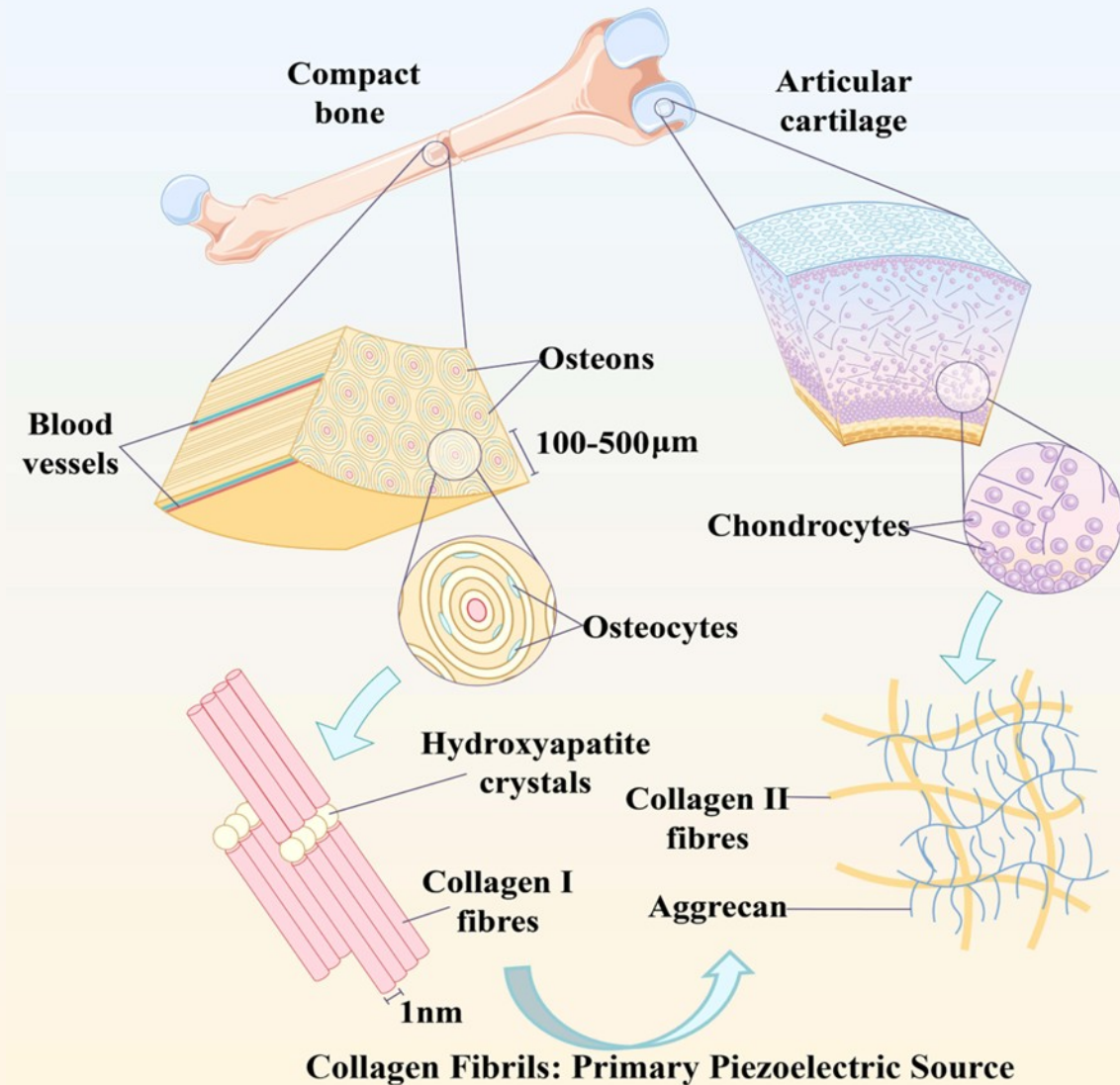
BTO/PLLA ،PVDF+MWCNT

مزایا: ترکیب خواص معدنی و آلی، زیست سازگاری بالا، قابلیت ضدباکتری و ضدالتهاب، انعطاف پذیری مکانیکی

معایب: پیچیدگی در تولید، نیاز به طراحی دقیق برای حفظ خواص الکتریکی و زیستی

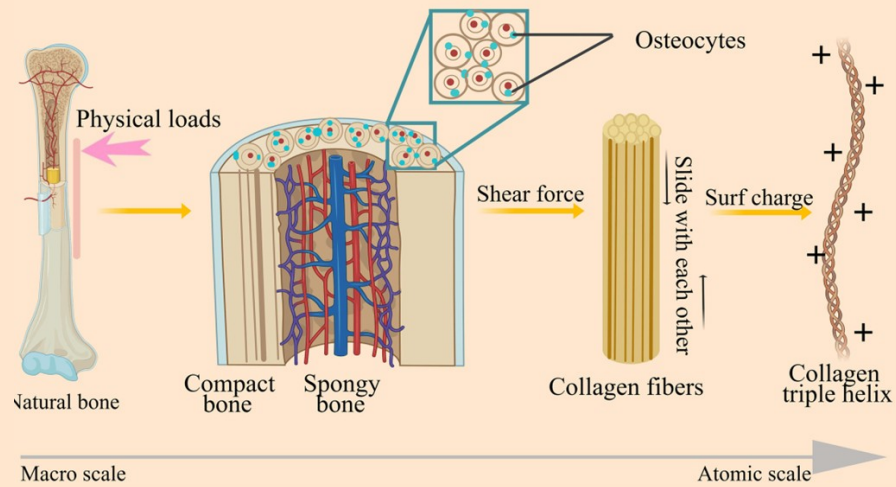
کاربرد در استخوان: داربست های چندمنظوره با توانایی تحریک سلولی، افزایش بیان ژن های استخوان ساز، معدنی سازی بهت

پیزوالکتریک استخوان

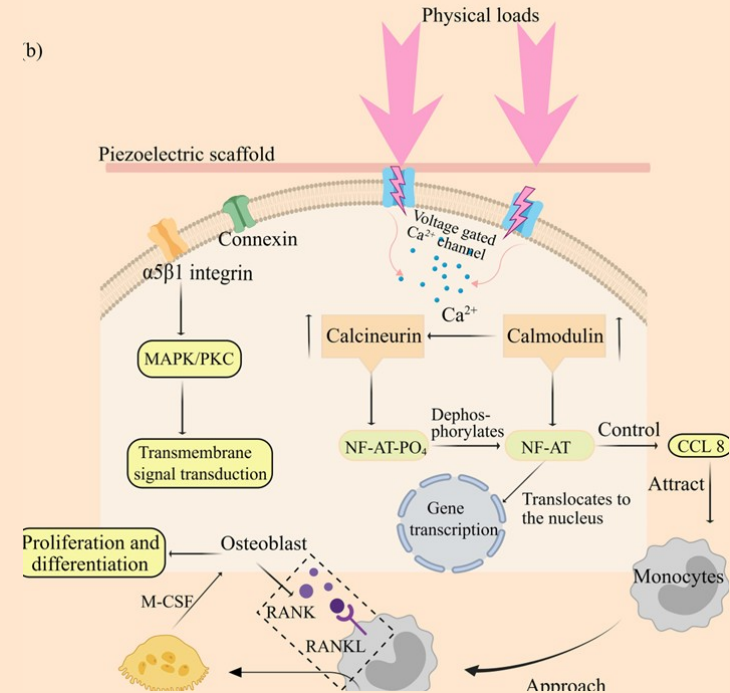


- هیدروکسی آپاتیت مسئول استحکام و سختی استخوان است.
- کلاژن با ساختار سه مارپیچه و آرایش فیبری خود منبع اصلی خاصیت پیزوالکتریک استخوان است

پیزوالکتریک و فرآیند استخوان سازی

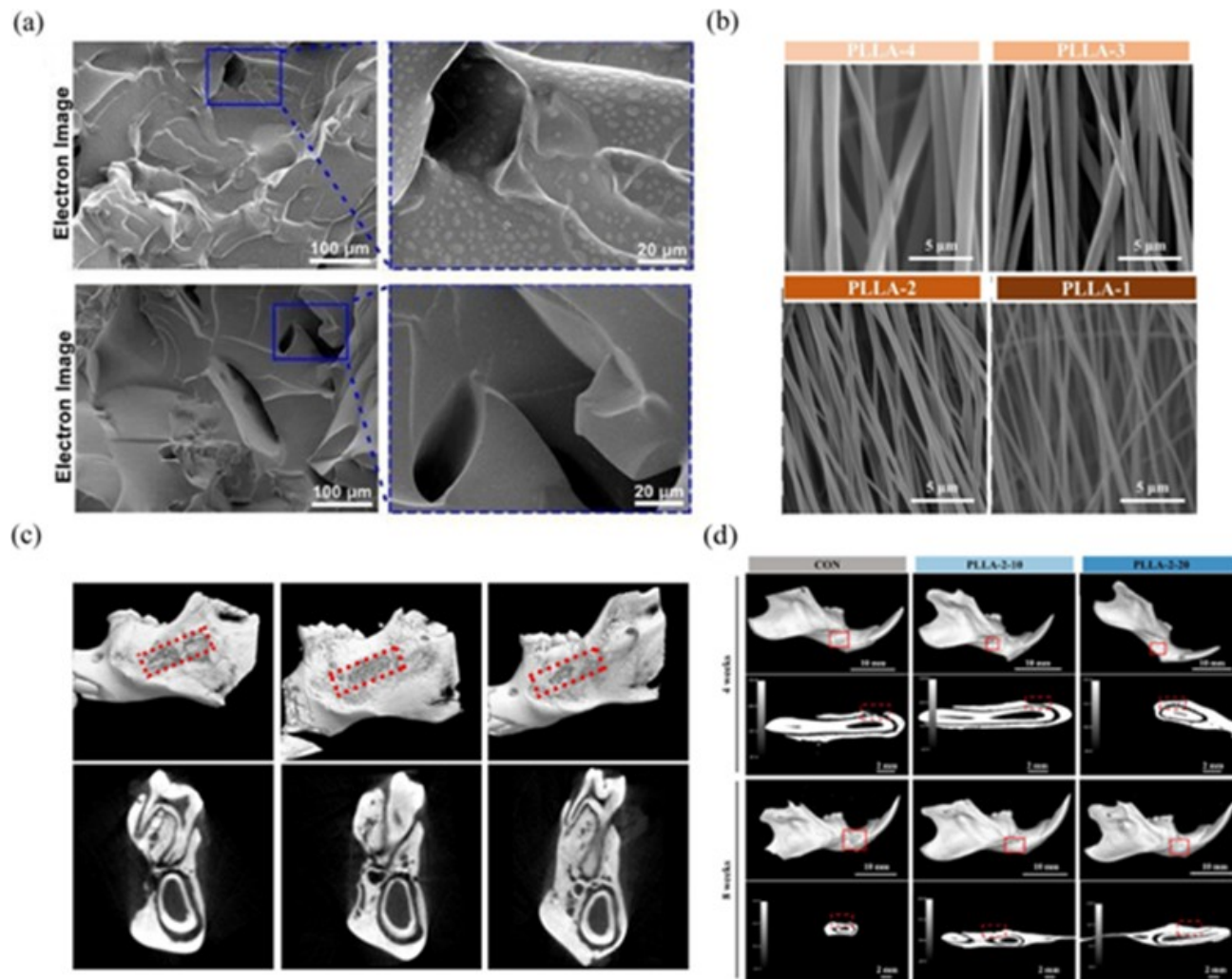


تبدیل نیرو به بار الکتریکی در کلارژن؛ مبنای پیزوالکتریسته استخوان



ورود کلسیم → بار الکتریکی → فشار

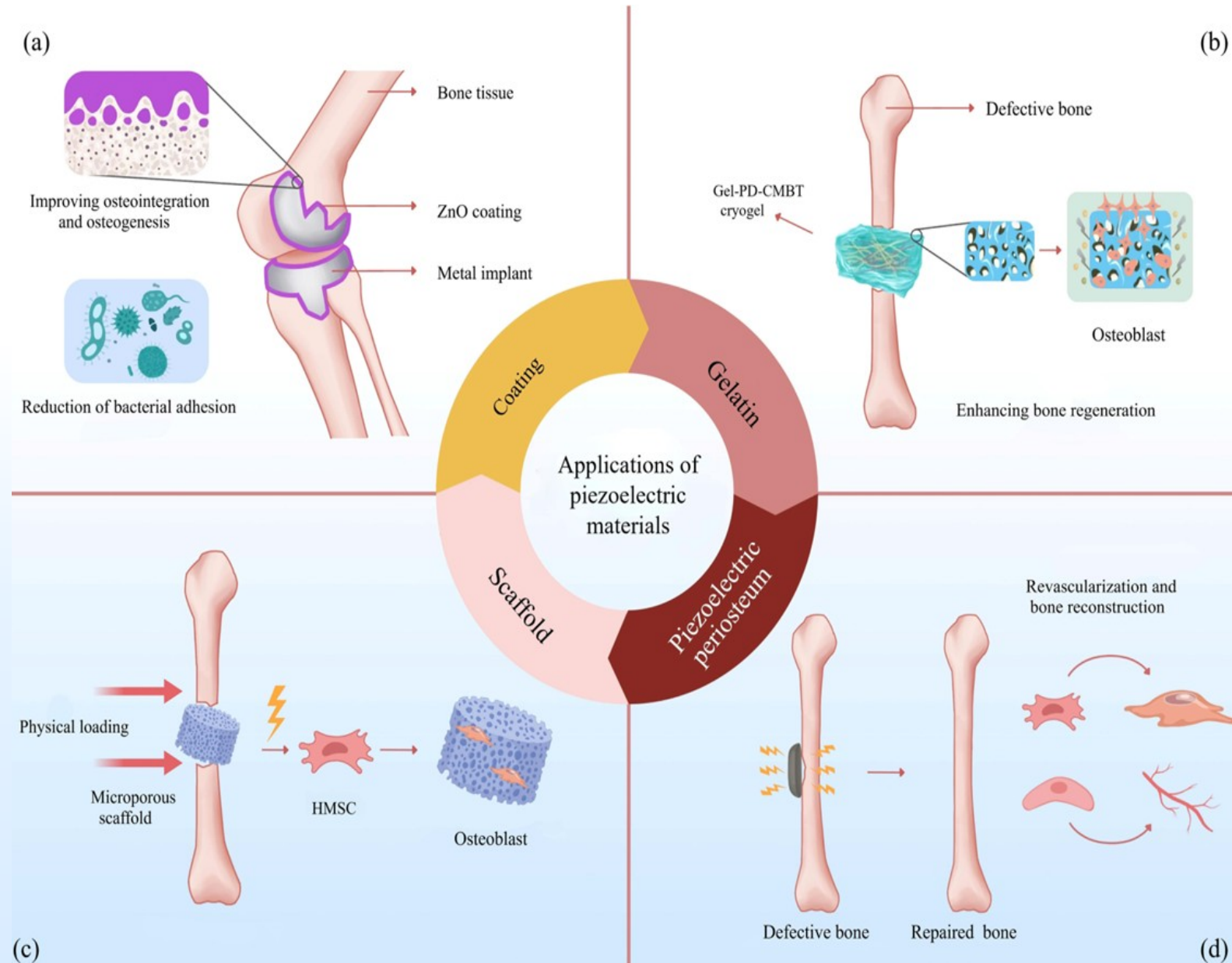
استخوان سازی → فعال شدن ژن ها →



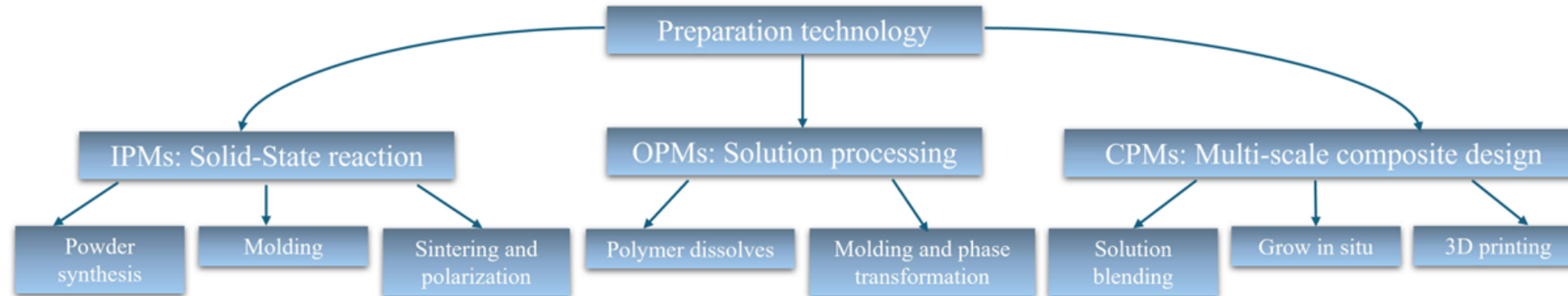
- (a) هیدرژل ساده و هیدرژل با نانوذرات BTO
 (b) نانوالیاف PLLA با غلظت‌های مختلف
 (c) بازسازی استخوان: گروه GeIMA+BTO بهترین ترمیم
 (d) غشای پیزوالکتریک → استخوان جدید در ۴ و ۸ هفت

کاربرد مواد پیزوالکتریک در فرآیند بازسازی استخوان

- پوشش ZnO روی ایمپلنت فلزی
- هیدروژل‌های پیزوالکتریک
- داربست‌های نانوالیافی پیزوالکتریک
- پریوستیوم پیزوالکتریک



اماده سازی مواد پیزوالکتریک



Comparative analysis of PMs preparation technologies for bone repair:

Technique	Materials	Key steps	Bone repair advantages	Limitations
Solid phase sintering	IPMs (BaTiO ₃ , PZT)	Ball milling → Pressing → Sintering → Poling	High d ₃₃ (>150 pC/N), Thermal stability	Brittle, Limited shape complexity
Electrospinning	OPMs/CPMs (PVDF, PLLA/BT)	Solution prep. → Fiber spinning → Stretching	ECM-mimetic porosity, High surface area	Low thickness control, Scalability issues
3D Printing	CPMs (PCL/KNN, PLLA/GO)	Bioink design → Layer-by-layer deposition → Curing	Customized geometry, Multi-scale pores	Resolution-piezoelectricity trade-off
Solvent Casting	OPMs/CPMs (PHBV, PCL/rGO)	Dissolution → Casting → Drying	Low cost, Simple process	Weak piezoelectric phase orientation



دانشگاه علم و فناوری ایران

چالش های موجود در این پژوهش

کنترل دشوار فاز پیزوالکتریک و جهت گیری الیاف در روش های ساخت

تفاوت عملکرد

پایداری پایین سیگنال پیزوالکتریک

احتمال سمیت یا التهاب ناشی از برخی نانوذرات و کامپوزیت ها.

دشواری انتقال نتایج آزمایشگاهی به شرایط بالینی
in vivo → clinica

چشم‌انداز آینده

توسعه کامپوزیت‌های چندفازی با استحکام بالا و پیزوالکتریسته تقویت‌شده.

حرکت به سوی ایمپلنت‌های فعال و شخصی‌سازی‌شده برای ترمیم نقص‌های بزرگ استخوان

ترکیب مواد پیزوالکتریک با هیدروژل‌ها یا نانوذرات برای کنترل التهاب و تقویت رگ‌زایی.

استفاده از چاپ سه‌بعدی و نانوفناوری برای ساخت داربست مشابه پریوستیوم واقعی.

ایجاد مواد هوشمند با تولید سیگنال الکتریکی خودکار در پاسخ به حرکت.

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