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Development of Orthopedic Implants: Tribological Insights and Biomedical Material Innovations in Mechanical Engineering

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ABSTRACT

This comprehensive review paper concentrates on tribocorrosion behavior of biomaterials and composites in the context of orthopedic implant applications. This review paper focuses on the wear behavior of hip implant materials in the context of orthopedic implant applications. It highlights the critical importance of understanding the effects of different lubrication mediums on wear characteristics and emphasizes the necessity for comprehensive tribological investigations to optimize lubrication conditions for improved implant longevity and performance. Through an in-depth analysis of engineering studies, the paper highlights the crucial role of material characterization methods such as scanning electron microscopy and X-ray diffraction in assessing the microstructure and chemical composition of biomaterials for implant suitability. Mechanical testing techniques are explored to evaluate the tensile strength, flexural strength, and hardness of biomaterials, crucial for determining their performance in implant systems. The review emphasizes the significance of materials like Polyetheretherketone (PEEK), Ultra-High Molecular Weight Polyethylene (UHMWPE), carbon fiber-reinforced resins, and titanium alloys in enhancing the mechanical properties and longevity of orthopedic implants. Furthermore, advancements in additive manufacturing techniques for creating customized structures for biomedical applications are discussed. The paper concludes by stressing the importance of interdisciplinary research in optimizing the design and performance of biomaterials for orthopedic implants, ultimately aiming to enhance implant longevity and overall performance.

Keywords: *Tribocorrosion, Orthopedic Implants, Biomaterials, Wear Behavior, Material Characterization, Additive Manufacturing*

1. INTRODUCTION

Engineering studies on tribocorrosion behavior of biomaterials and composites structures provide insights into the enhanced performance of biomaterial composites, offering potential benefits for orthopedic implant applications (Bartolomeu et al., 2019; Oladapo et al., 2021). The development of hip implant systems benefits from engineering expertise in wear estimation theories, contact pressure analysis, and frictional coefficient evaluation to enhance the longevity and performance of implants (Soemardi et al., 2021; Soliman et al., 2022).Engineers employ material characterization methods such as scanning electron microscopy (SEM) and X-ray diffraction (XRD) to analyze the microstructure and chemical composition of biomaterials, ensuring their suitability for implant applications, Mechanical testing conducted by engineers assesses the tensile strength, flexural strength, and hardness of biomaterials to determine their mechanical properties and performance in implant systems. Engineering plays a pivotal role in the fabrication of biopolymer composites for implants, utilizing additive manufacturing techniques to create customized structures for biomedical applications (Oladapo et al., 2021).

Polyetheretherketone (PEEK) is a significant material for biomedical implant applications due to its biocompatibility, mechanical properties, and potential for additive manufacturing techniques, making it suitable for advanced medical devices and implants(Oladapo et al., 2021). Ultra-High Molecular Weight Polyethylene (UHMWPE) is essential for artificial hip joint applications, offering excellent wear resistance and biotribological behavior critical for the longevity and performance of joint implants, Carbon fiber reinforcement of resins is significant for enhancing the mechanical properties and strength of biomaterial composites, improving the performance and longevity of implants in orthopedic and dental applications (De Santis et al., 2017). Titanium alloys, such as Ti6Al4V, are vital materials for implants, known for their biocompatibility, corrosion resistance, and mechanical strength, making them ideal for orthopedic and dental implant applications(Oladapo et al., 2021).

The research in last 25 years explore the development of advanced materials for biomedical applications, including polyether-ether-ketone (PEEK) composites and ultra-high molecular weight polyethylene (UHMWPE) in polymer category. Studies investigate the wear and frictional characteristics of prosthetic material combinations, highlighting the importance of lubricants like bovine serum and the impact of pin rotation on polyethylene surfaces(Wright et al., n.d.; Yang et al., 2021). The use of composite materials, such as hydroxyapatite-reinforced high-density polyethylene, is explored for tissue substitutes in hip prostheses, showcasing the advantages of these materials over monolithic structures(De Santis et al., 2017). Tribocorrosion behavior of multi-material structures like Ti6Al4V & PEEK is studied, revealing enhanced performance in biomedical applications(Bartolomeu et al., 2019).

The history of material development for total hip replacements has evolved to include a wide range of biomaterials and metallic alloys, such as ultra-high molecular weight polyethylene (UHMWPE), titanium alloys like Ti6Al4V, and polyether-ether-ketone (PEEK) (Bartolomeu et al., 2019; De Santis et al., 2017).

Researchers have explored the use of composite materials, including carbon fiber-reinforced polymers and graphene oxide-reinforced ultra-high molecular weight polyethylene (UHMWPE), to enhance the mechanical properties and biocompatibility of hip implants (De Santis et al., 2017; Spiegelberg et al., 2016). Advances in additive manufacturing techniques, such as selective laser melting, have enabled the production of complex multi-material structures like Ti6Al4V & PEEK cellular structures for hip prostheses, offering improved tribocorrosion performance (Bartolomeu et al., 2019; Verma et al., 2021). The development of novel composite materials and surface modification techniques has opened up new possibilities for enhancing the mechanical integrity, biocompatibility, and wear resistance of hip implants, paving the way for customized and advanced prosthetic solutions(De Santis et al., 2017; Pan & Yapici, 2016; Spiegelberg et al., 2016).

From this review it is evident that a diverse range of test methods and outcomes have been utilized to evaluate the performance, wear characteristics, and biotribological behavior of materials used in hip implant systems. Various types of tests and testing methods have been employed in the evaluation of hip implant materials, including pin-on-disk tribometer tests against stainless steel counterfaces, in vivo and in vitro testing, and biomechanical investigations using hip joint simulators (De Santis et al., 2017; Koh, Lee, et al., 2019; Mohamad Raffi et al., 2016; Sagbas, 2016). Wear testing on hip joint simulators has been conducted to assess the linear and volumetric wear rates of prostheses under simulated physiological conditions, with lubrication mediums like bovine serum used during testing (Koh, Lee, et al., 2019; ShenoyB & BhatN, 2018). Computational wear prediction through finite element analysis (FEA) software tools like FEBio, Abaqus, ANSYS, and COMSOL Multiphysics has enabled researchers to simulate wear behavior, loading conditions, and material properties to predict the performance of hip implant materials(Koh et al., 2019; ShenoyB & BhatN, 2018; Soemardi et al., 2021; Soliman et al., 2022).

The review of research papers highlights the need for standardized testing parameters and conditions in wear testing methodologies for orthopedic implants, emphasizing the importance of replicating clinically relevant wear mechanisms to improve the reliability of test results (Baykal et al., 2014; Savio III et al., 1994; Wang et al., 1997). Studies have indicated a gap in understanding the effects of different lubrication mediums on the wear behavior of hip implant materials, suggesting the necessity for comprehensive tribological investigations to optimize the lubrication conditions for improved implant longevity and performance (Mohamad Raffi et al., 2016; Sagbas, 2016), The review underscores the importance of continued research efforts in exploring the biotribological behavior of artificial hip joints, particularly in assessing the wear characteristics of various joint combinations like CoCrMo and UHMWPE/BHA, to enhance the design and durability of hip implant materials (Kumar et al., 2021; Mohamad Raffi et al., 2016; Sagbas, 2016; Savio III et al., n.d.; Wang et al., 1997). Future research directions may involve the development of advanced computational models to predict wear performance, the investigation of composite materials for enhanced mechanical properties, and the exploration of additive manufacturing techniques for customized hip prostheses with improved tribocorrosion resistance (Baykal et al., 2014; Li et al., 2014; Verma et al., 2021).

The review table discusses the use of metallic alloys like titanium and cobalt, as well as the mechanical properties of polyether-ether-ketone (PEEK) in hip implant systems, emphasizing the novelty of incorporating diverse materials to enhance the performance and durability of hip implants. After ten to fifteen years, most hip implants fail. Given that it influences both the mechanical and clinical performance of the entire hip implant system, material selection is a significant area of study. Hip implant failure is caused by a number of factors that mostly related to wear, including deformation, aseptic implant loosening from the particle propagation of wear debris, decreased bone remodeling density from stress shielding, and poor tissue responses from material wear debris. (Soemardi et al., 2021; Soliman et al., 2022). advanced characterization techniques such as Fourier transform infrared spectroscopy (FTIR) and thermal analysis to assess the microstructure, chemical composition, and thermal properties of hip implant materials, demonstrating a novel focus on material analysis and properties(Oladapo et al., 2021).

2. REVIEW OF BIOMEDICAL MATERIALS FOR LAST 40 YEARS

When considering a different reasons for hip prosthesis Failure/revisions, loosening of the prosthesis are the most common reason, as can be seen from the figure which shows the different reasons for the failure/revision.

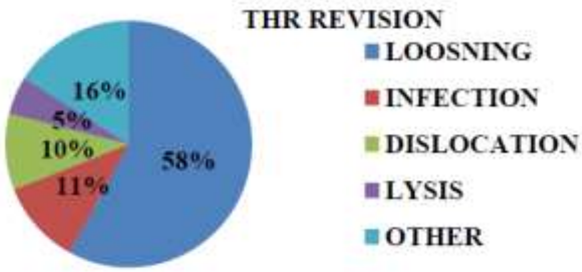

Fig 1. Reasons for the hip prosthesis revision/failure.(ShenoyB & BhatN, 2018)

Aseptic loosening, a common cause of long-term hip and knee replacement failure, occurs when normal wear on prosthetic joints produces microscopic debris particles, triggering an immune system response and osteolysis. Mechanical factors include repeated cyclic stresses on the prosthesis and the lack of a feedback system protecting natural joints against overload. These particles spread into surrounding tissues, triggering osteolysis.(ShenoyB & BhatN, 2018)

Considering a Polyether ether ketone (PEEK) as Acetabular Liner Materials in hip joint prosthesis, PEEK is a biocompatible material with a high melting point of 330-334 0C, It reduces wear debris propagation and maintains sterility even in exposure to steam, radiation, or ethylene oxide, PEEK-based acetabular components transmit wear debris at half the rate of UHMWPE/metal or UHMWPE/ceramic components. PEEK composites are used in hip, spine, joint, and trauma implants. Carbon Fiber/PEEK is an FDA-approved binary PEEK composite with higher Young's modulus than pure PEEK(Soliman et al., 2022). Under several studies, CFR-PEEK composite orthopedic implant components have demonstrated notable advantages, particularly in terms of durability(Li et al., 2014a). Biological passivity, bone blindness, and lipophilicity limit its use in orthopedic implants, BaSo4 is mixed into pure PEEK to create X-ray and MRI-compatible binary PEEK(Soliman et al., 2022).

Table: 1. Authors and their materials under study

Author	Materials																										
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	Y	Z	AA
(Soliman et al., 2022)	X	X										X														
(Soemardi et al., 2021)			X	X																						
(Chang et al., 2020)				X	X																					
(Koh, Park, et al., 2019)	X			X		X																				
(ShenoyB & BhatN, 2018)		X	X	X				X																		

(Affatato et al., 2016)				X				X	X																	
(Li et al., 2014b)				X		X																				
(Baykal et al., 2014)				X				X		X																
(Teoh, 2000)	X	X		X							X	X											X			
(Verma et al., 2021)	X	X											X	X												
(Koh, Park, et al., 2019)	X			X		X	X					X														
(Regis et al., 2018)	X					X																				
(Rasheva et al., 2010)															X									X	X	
(Guenther et al., 2015)						X		X																		
(Puértolas et al., 2019)																X										
(Kurtz et al., 2014)				X																						
(Brockett et al., 2016)	X					X																				
(Díaz & Fuentes, 2017)	X			X			X																			
(Bonnheim et al., 2019)	X					X																				
(Brockett et al., 2017)	X			X	X																					
(Y. Wang et al., 2021)																	X									
(Shrivastava et al., 2021)	X				X																					
(Diabb Zavala et al., 2021)				X																						
(Dayyoub et al., 2020)				X														X								
(S. E. Arevalo & Pruitt, 2020)	X					X																				

(Oladapo et al., 2021)	X											X										X				
(Bartolomeu et al., 2019)	X	X																								
(S. Arevalo et al., 2023)	X					X																				
(Chithambaram & Senthilnathan, 2024)																	X									
(Pulipaka et al., 2023)																	X									
(Yang et al., 2017)																	X									
(De Santis et al., 2017)	X	X										X								X			X			
(Zdero et al., 2017)				X			X																			
(Dworak et al., 2017)	X					X																				
(Panayotov et al., 2016)	X					X						X							X				X			
(Zalaznik et al., 2016)	X																									
(Garcia-Gonzalez et al., 2015)	X			X		X									X											
(Regis et al., 2017)						X																				
(Wu et al., 2015)																	X									
(Pan & Yapici, 2016)	X					X																				
(Spiegelberg et al., 2016)				X																						
(Sak et al., 2016)	X	X																								
(Li et al., 2014b)	X	X				X	X																			
(Rae et al., 2007)	X																									
(Liu et al., 2011)				X																						

(Sui et al., 2009)				X																X						
(Scholes & Unsworth, 2009)	X			X		X	X																			
(Bijwe et al., 2005)	X																								X	
(Roy Chowdhury et al., 2004)				X																X						
(Fujihara et al., 2004)						X																				
(Zhang et al., 2004)	X					X									X									X	X	
(Paulo Davim et al., 2003)	X																		X							
(Kurtz et al., 2003)				X																						
(El Kadi & Denault, 2001)						X																				
(Q. Wang et al., 1997)	X																									
(Savio III et al., 1993)				X	X																					
(Kumar et al., 2021)																					X					
(Sagbas, 2016)				X																						
(Mohamad Raffi et al., 2016)				X																		X				X
(Stolarski, 1992)	X																									
(Talbott et al., 1987)	X																							X		
(Jones et al., 1985)	X																									
(Wright et al., 1982)				X																						
(Yang et al., 2021)				X																						

We have plotted a graph using this table to explain the most significant material under study for biomedical application the coding for material is given as follows

A. PEEK

B. Titanium Alloy

C. SS316L Steel

D.Ultra High Molecular Weight Polyethelene (UHMWPE)

E. PMMA

F. CFR PEEK

G. CO-Cr Alloy /CoCrMO

H. XLPE

I. Vit E Containing XLPE

J. Non-irradiated UHMWPE

K. Glass Ceramic

L. Ceramics like Alumina, Zirconia

M. bioactive amorpphous magnesium phosphate (AMP) incorporated PEEK

N. Ti alloy and PEEK Multimaterial formed by selective laser melting

O. Short carbon fibre PEEK

P. Graphenen nanoplates (GNPs) PEEK Composite

Q. PEEK by 3D printing/Additive manufacturing

R. UHMWPE coated with PE wax

S. Glass-fibre reinforced PEEK

T. High Density Polyethelene HDPE

U. Nylon

V. irradiated UHMWPE

W. Hydroxyapatit coated PEEK/UHMWPE

Y. Graphite Filled PEEK

Z. PTFE

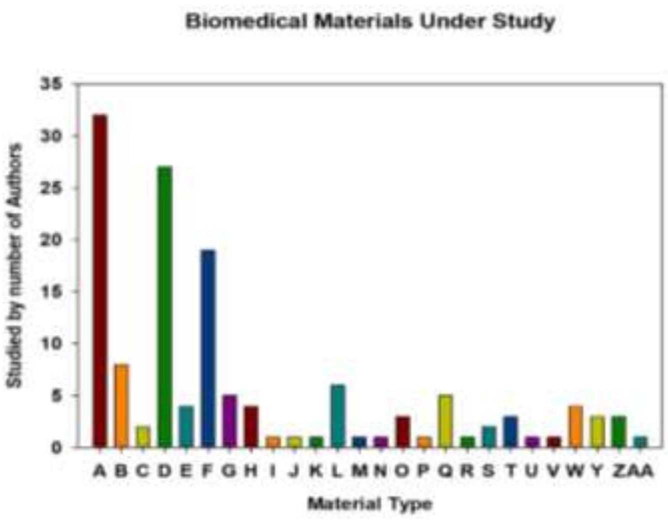

Fig 2: Authors and their materials under study

This graph can be interpreted as A. PEEK, D. Ultra-High Molecular Weight Polyethelene (UHMWPE), F. CFR PEEK and B.Titanium Alloys respectively are the highly used and most significant materials under study for biomedical implant use.

Table 2: Authors and Testing's for tribological properties

Author			Standard test equipment for Tribological Properties				
	A	B	C	D	E	F	G
(Soliman et al., 2022)		X					
(Soemardi et al., 2021)		X					
(Chang et al., 2020)	X						
(Koh, Park, et al., 2019)		X					
(ShenoyB & BhatN, 2018)	X						
(Affatato et al., 2016)	X						
(Li et al., 2014b)			X				
(Baykal et al., 2014)				X			
(Teoh, 2000)			X				
(Verma et al., 2021)		X					
(Koh, Park, et al., 2019)		X	X				
(Regis et al., 2018)			X				
(Rasheva et al., 2010)						X	
(Guenther et al., 2015)				X			
(Puértolas et al., 2019)			X				
(Kurtz et al., 2014)				X			
(Brockett et al., 2016)				X			
(Díaz & Fuentes, 2017)					X		
(Brockett et al., 2017)	X						
(Y. Wang et al., 2021)		X					
(Dayyoub et al., 2020)			X				
(Oladapo et al., 2021)		X					
(Bartolomeu et al., 2019)					X		
(S. Arevalo et al., 2023)			X	X			
(Chithambaram & Senthilnathan, 2024)			X				
(De Santis et al., 2017)			X				
(Zdero et al., 2017)			X				
(Panayotov et al., 2016)		X					

(Zalaznik et al., 2016)			X				
(Wu et al., 2015)		X					
(Spiegelberg et al., 2016)			X				
(Sak et al., 2016)					X		
(Li et al., 2014b)			X				
(Liu et al., 2011)			X				
(Scholes & Unsworth, 2009)				X			
(Bijwe et al., 2005)			X				
(Roy Chowdhury et al., 2004)			X				
(Zhang et al., 2004)						X	
(Q. Wang et al., 1997)			X				
(Savio III et al., 1993)			X				X
(Kumar et al., 2021)	X						
(Sagbas, 2016)	X		X		X		
(Mohamad Raffi et al., 2016)	X						
(Stolarski, 1992)			X				
(Wright et al., 1982)			X				
(Yang et al., 2021)					X		

We have plotted a graphs using this table to explain the most significant tribological test equipment's and most significant test for other mechanical properties under study for biomedical application, the coding for material is given as follows

A. Joint Simulator Knee or Hip Joint simulator

B. Software (FEA)

C. Pin On Disc appratus/ Pin on Plate Appratus/ Tribometer

D. Multidiractional Pin on Disc Appratus

E. Ball on Disk Appratus

F. Block on Ring Appratus

G. Rod on Rod Appratus

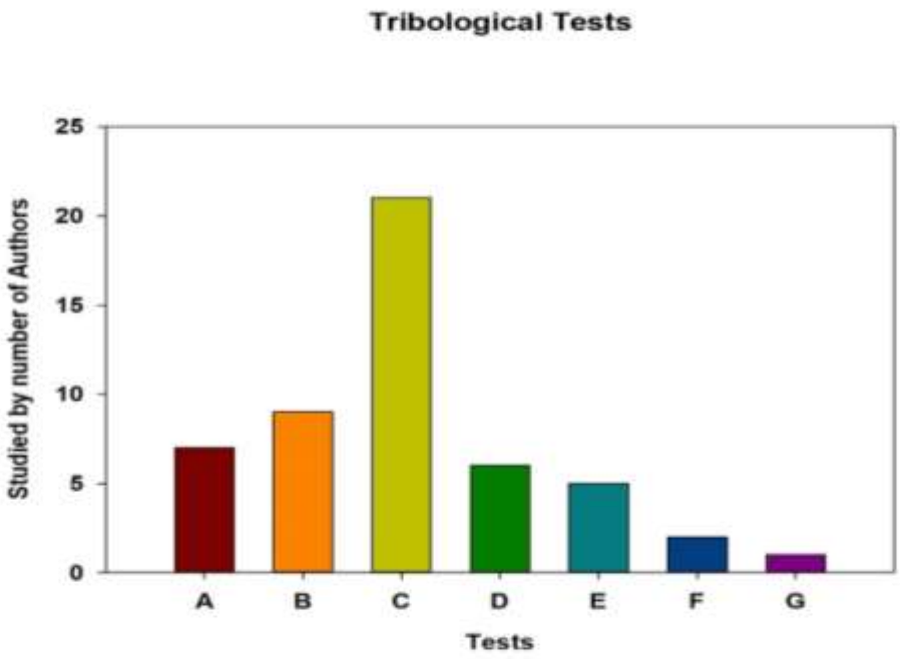

Fig 3: Authors and Tribological tests

This graph can be interpreted as C. the pin on disc is the highly used and most significant standard test under study for tribological properties of biomaterials.

Table 3: Authors and tests for mechanical properties, morphological characteristics, Nano iodization, Differential scanning calorimetry (DSC) and In-Vivo Study/ Clinical test.

Author	Tests for Mechanical Properties														Micromorphological test				Other properties		
	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	Y	Z	AA	AB	AC
(Chang et al., 2020)																					X
(ShenoyB & BhatN, 2018)																					X
(Affatato et al., 2016)																	X				
(Li et al., 2014b)	X				X							X				X					X
(Teoh, 2000)																					X
(Verma et al., 2021)														X							
(Koh, Park, et al., 2019)																					X
(Rasheva et al., 2010)													X								

(Puértolas et al., 2019)	X	X														X	X				
(Kurtz et al., 2014)																					X
(Bonnheim et al., 2019)												X									
(Y. Wang et al., 2021)	X												X								
(Shrivastava et al., 2021)		X		X																	
(Diabb Zavala et al., 2021)				X												X	X				X
(Dayyoub et al., 2020)				X											X						
(S. E. Arevalo & Pruitt, 2020)								X													
(Oladapo et al., 2021)		X	X	X											X	X	X	X			X
(Bartolomeu et al., 2019)															X	X					
(S. Arevalo et al., 2023)								X				X									
(Chithambaram & Senthilnathan, 2024)		X																			
(Pulipaka et al., 2023)		X		X										X							
(Yang et al., 2017)				X											X						
(De Santis et al., 2017)																					X
(Dworak et al., 2017)	X		X	X									X								
(Panayotov et al., 2016)																					X
(Zalaznik et al., 2016)		X														X					
(Garcia-Gonzalez et al., 2015)						X	X								X						
(Regis et al., 2017)	X	X														X		X		X	
(Wu et al., 2015)	X			X									X								

(Pan & Yapici, 2016)	X												X		X	X		X			
(Spiegelberg et al., 2016)													X		X					X	
(Li et al., 2014b)	X				X								X								X
(Rae et al., 2007)		X					X								X				X		
(Liu et al., 2011)																		X			
(Sui et al., 2009)									X												
(Bijwe et al., 2005)		X	X	X			X														
(Fujihara et al., 2004)	X																				
(Zhang et al., 2004)			X				X								X						
(Paulo Davim et al., 2003)										X											
(Kurtz et al., 2003)																		X			
(El Kadi & Denault, 2001)			X	X							X										
(Q. Wang et al., 1997)		X													X						
(Mohamad Raffi et al., 2016)															X						
(Talbott et al., 1987)				X							X		X								
(Jones et al., 1985)							X														
(Yang et al., 2021)																				X	

We have plotted a graphs using this table to explain the most significant test for the mechanical properties under study for biomedical application, the coding for material is given as follows

H. Bending test rig

I. Hardness Test

J. Flexural Strenght Test

K. Tensile Test like UTM

L . Torsional Test

M. Projectile Test

N. Impact Test

O. Nanoindentator

P. Abrasion Test

Q. CNC machining force test

R. Shear Force test

S. Fatigue Test

T. Compression Test

U. CREEP

V. Scanning electron microscopy (SEM)

W. X-Ray Diffraction (XRD)

Y. Raman Spectroscopy

Z. Fourier-transform infrared spectroscopy (FTIR)dization

AA. Nano iodization

AB. Differential scanning calorimetry (DSC)

AC. In-Vivo Study/ Clinical test

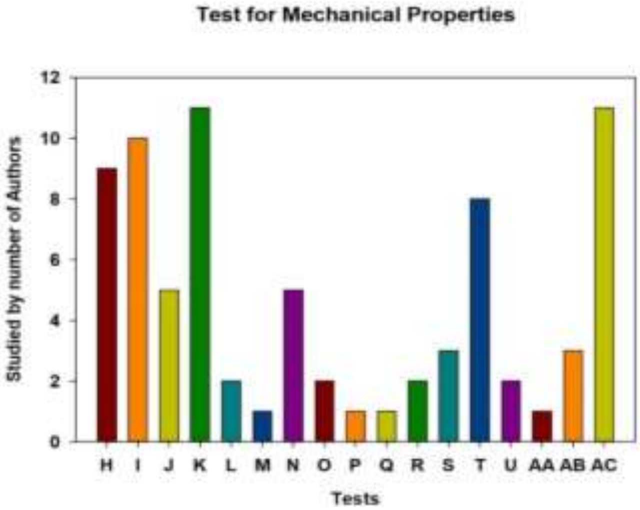

Fig 4: Authors and various tests for mechanical properties

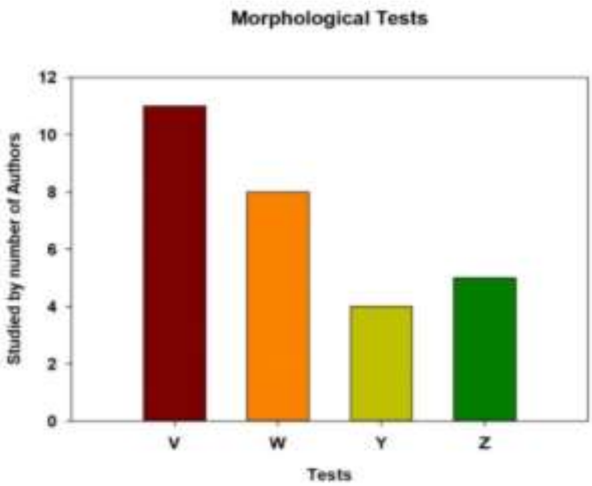

Fig 5: Authors and various morphological tests

From these two graphs it can be interpreted that K. Tensile Test like UTM AC. In-Vivo Study/ Clinical test I. Hardness Test H. Bending test rig and T. Compression Test are most significant standard test under study for Mechanical properties of biomaterials and V. Scanning electron microscopy (SEM),W. X-Ray Diffraction (XRD) are most significant morphological tests for biomaterials under study.

Table 4: Authors and testing parameters.

Author	Testing Parameters													
	A	B	C	D	E	F	G	H	I	J	K	L	M	N
(Soliman et al., 2022)	X	X	X	X				X						
(Soemardi et al., 2021)			X											
(Chang et al., 2020)	X													
(Koh, Park, et al., 2019)	X													
(ShenoyB & BhatN, 2018)	X													
(Affatato et al., 2016)	X													
(Li et al., 2014b)	X				X	X		X						X
(Baykal et al., 2014)	X													
(Teoh, 2000)	X													
(Verma et al., 2021)			X				X							
(Koh, Park, et al., 2019)	X												X	
(Regis et al., 2018)	X													
(Rasheva et al., 2010)	X													
(Guenther et al., 2015)	X													
(Puértolas et al., 2019)	X	X		X					X					
(Kurtz et al., 2014)	X													

(Brockett et al., 2016)	X													
(Díaz & Fuentes, 2017)	X													
(Bonnheim et al., 2019)								X						
(Brockett et al., 2017)	X													
(Y. Wang et al., 2021)					X									X
(Shrivastava et al., 2021)				X					X					
(Diabb Zavala et al., 2021)										X				
(Dayyoub et al., 2020)	X	X												
(S. E. Arevalo & Pruitt, 2020)											X			
(Oladapo et al., 2021)				X					X	X				
(Bartolomeu et al., 2019)	X	X												
(S. Arevalo et al., 2023)	X	X						X			X			
(Chithambaram & Senthilnathan, 2024)	X								X					
(Pulipaka et al., 2023)							X		X	X				
(Yang et al., 2017)										X				
(De Santis et al., 2017)	X	X												
(Zdero et al., 2017)	X													
(Dworak et al., 2017)					X					X				X
(Panayotov et al., 2016)								X				X		

(Zalaznik et al., 2016)	x	X												
(Garcia-Gonzalez et al., 2015)											X			
(Regis et al., 2017)											X			
(Wu et al., 2015)					X					X				X
(Pan & Yapici, 2016)	X												X	X
(Spiegelberg et al., 2016)											X			
(Sak et al., 2016)	X	X												
(Li et al., 2014b)	X	X						X						X
(Rae et al., 2007)														X
(Liu et al., 2011)	X													
(Sui et al., 2009)	X													
(Scholes & Unsworth, 2009)	X													
(Bijwe et al., 2005)	X			X					X	X				
(Roy Chowdhury et al., 2004)	X													
(Fujihara et al., 2004)					X									
(Zhang et al., 2004)	X			X										
(Paulo Davim et al., 2003)											X			
(Kurtz et al., 2003)													X	
(El Kadi & Denault, 2001)				X						X				
(Q. Wang et al., 1997)	X								X					
(Savio III et al., 1993)	X													
(Sagbas, 2016)	X													

(Mohamad Raffi et al., 2016)	X	X												
(Stolarski, 1992)	X													
(Talbott et al., 1987)										X				X
(Jones et al., 1985)				X							X			
(Wright et al., 1982)	X	X												
(Yang et al., 2021)	X						X		X				X	

We have plotted a graphs using this table to explain the most significant Test parameters under study for biomedical application, the coding for material is given as follows

A. Wear

B. Coefficiant of friction

C. Von Misses stress

D. Flexural strength

E. Bending Fatigue

F. Static Torsion

G. Creep

H. Fatigue Strength

I. Hardness

J. Tensile Strength / Youngs modulus

K. Nanomechanical Properties

L. Load Bearing capacity

M. Biomechanical Properties like Corrosion

N. Compressive strength

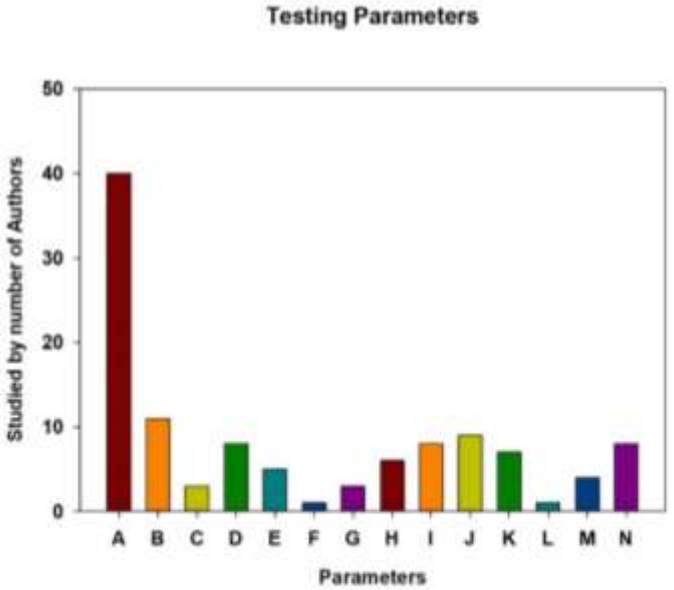

Fig 6: Authors and various testing parameters

This graph can be interpreted as A. Wear B. Coefficiant of friction is the highly used and most significant test parameter for biomaterials.

To Understanding Wear in Prosthetics, Wear is the gradual removal of substance from a solid's surface due to motion.No specific relationship exists between wear and friction. Lubricants can reduce wear on moving surfaces. Harder, smoother surfaces typically wear less than soft, rougher ones. Studies focus on material loss volumes, debris shape, and size. Wear particles can cause tissue reactions, osteolysis, and prosthesis loosening. Joint wear can be adhesive, abrasive, corrosive, or surface fatigue. Prosthesis wear mechanism combines adhesive, abrasive, and fatigue wear.(ShenoyB & BhatN, 2018)

Table 5: Authors and Lubricants under study for wear test.

Author	Lubricants for wear test (SBF)									
	O	P	Q	R	S	T	U	V	W	Y
(Chang et al., 2020)	X									
(ShenoyB & BhatN, 2018)	X									
(Li et al., 2014b)	X									
(Baykal et al., 2014)								X		
(Regis et al., 2018)	X									
(Rasheva et al., 2010)									X	
(Guenther et al., 2015)		X								
(Kurtz et al., 2014)	X									

(Brockett et al., 2016)				X						
(Díaz & Fuentes, 2017)	X									
(Brockett et al., 2017)	X			X						
(Dayyoub et al., 2020)									X	
(Bartolomeu et al., 2019)			X							
(Zdero et al., 2017)					X					
(Liu et al., 2011)	X									
(Scholes & Unsworth, 2009)	X									
(Roy Chowdhury et al., 2004)										X
(Savio III et al., 1993)		X								
(Sagbas, 2016)						X				
(Mohamad Raffi et al., 2016)	X									
(Stolarski, 1992)							X			
(Wright et al., 1982)	X								X	

We have plotted a graphs using this table to explain the most significant Lubricant for tribological test under study for biomedical application, the coding for Lubricants is given as follows.

O. Bovine Calf Serum

P. Saline Solution

Q. Phosphate buffered saline solution and hyaluronic acid

R. 25% (V/V) new born bovine serum (16 g/L protein concentration), with 0.03% (V/V) sodium ozide solution.

S. Bovine Blood-serum

T. Fluid Film Lubrication

U. Water emulsion

V. Protine serum

W. Solid Lubricant mix / PE WAX

Y. carboxymethyl cellulose / synovial fluid

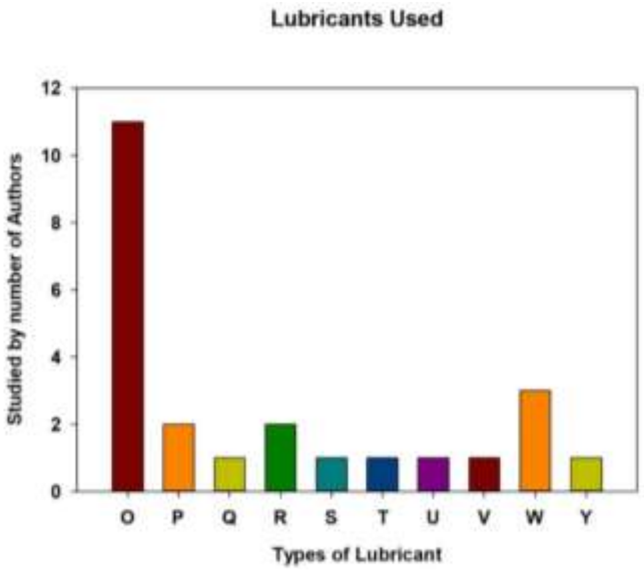

Fig 7: Authors and various Lubricants under study

This graph can be interpreted as O. Bovine Calf Serum is the highly used and most significant Lubricant used for tribological tests of biomaterials.

3. INFERENCES FROM THE LITERATURE

Emphasis on Material Selection:

Material selection plays a crucial role in the mechanical and clinical performance of hip implant systems. Factors such as wear, deformation, implant loosening, stress shielding, and tissue responses from wear debris are key considerations in ensuring the longevity and effectiveness of hip implants.

Diverse Testing Methods:

Researchers have employed a variety of testing methods, including in vivo and in vitro testing, biomechanical investigations using simulators, and computational wear prediction through FEA software tools. This indicates a comprehensive approach to evaluating the performance and wear characteristics of materials used in hip implant systems.

Focus on Wear Testing:

Wear testing on hip joint simulators has been a key area of research to assess the wear rates of prostheses under simulated physiological conditions. The use of lubrication mediums like bovine serum during testing highlights the importance of replicating real-world conditions for accurate evaluation.

Evolution of Research:

The continuity of research studies over the years, as evidenced by the references spanning from as early as 1982 to recent publications in 2023, highlights the ongoing evolution and advancement in the field of biomaterials and orthopedic implants

Collaborative Efforts:

The collaboration between multiple authors and research groups from different institutions, as indicated by the extensive list of references, suggests a collective effort towards advancing knowledge and innovation in biomaterials for biomedical applications.

Interdisciplinary Approach:

The intersection of materials science, biomechanics, and biomedical engineering in the studies referenced in the document reflects an interdisciplinary approach to address the complex challenges associated with developing biomaterials for orthopedic implants.

Focus on Mechanical Properties:

The emphasis on mechanical properties such as wear, coefficient of friction, flexural strength, hardness, and tensile strength among others suggests a significant interest in understanding the structural integrity and performance of biomaterials under different loading conditions.

Focus on Testing and Evaluation:

The document highlights the use of various testing methods to evaluate the performance, wear characteristics, and biotribological behavior of materials used in hip implant systems. These testing methods include pin-on-disk tribometer tests, in vivo and in vitro testing, biomechanical investigations using simulators, and computational wear prediction through FEA software tools. Standardized testing parameters and conditions are emphasized to improve the reliability of test results.

Importance of Tribological Investigations:

There is a recognized gap in understanding the effects of lubrication mediums on the wear behavior of hip implant materials. Comprehensive tribological investigations are deemed necessary to optimize lubrication conditions for improved implant longevity and performance.

4. CONCLUSION

- Gaining insight into the tribocorrosion behavior of biomaterials is essential to improving the durability and efficiency of orthopedic implants.
- Aseptic loosening, a major factor in the long-term failure of hip and knee replacements, results from the generation of microscopic debris during joint wear. This debris provokes immune responses and bone degeneration, emphasizing the importance of selecting materials with strong wear resistance for implants.
- Extensive research is required to better understand the complex interplay among materials, lubricants, and biological environments in orthopedic applications.
- Engineering innovations are pivotal in refining the design and functionality of biomaterials for orthopedic use.
- Detailed material analysis, including the assessment of microstructure and chemical composition, is fundamental to advancing the development of implant materials.
- Cutting-edge materials like Polyetheretherketone (PEEK) offer significant potential for biomedical purposes due to their exceptional properties and compatibility with biological systems.
- Collaborative, interdisciplinary efforts in biomaterials engineering are crucial for pushing the boundaries of orthopedic implant technology and design.

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