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Biocompatibility Driven Paradigm, a Suggested Hard Tissue Replacements Classification

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All living tissues had globalbiomechanical rules that govern their properties (mechanical, chemical, electrical,optical ….etc)

- Maximum prestrain which is simply seen when the skin is incised the resulted gap isgreater than the thickness of the incising blade(1)
- The skin could be easily measured, while in the case of bone the contract is seen by which bone could be hardly measured (2)
- Least stiffness
- Ina biological system in opposite to the mechanical systems, the stiffness is not welcomed, and the hardest tissue which is the enamel is not brittle like ceramic
- This low stiffness imparts these systems their complex servo feedback from cellular transduction to somatic feedback sensory(3)
- Loads are an integral part of the integrity of the tissue, whatever the tissue is. Without loads tissues, the tissue will get disuse atrophy(4)

Tissues had these main components

- Enforcing component
  Different types and configurations of the collagen fibres are mandated by the anatomical and functional requirements of certain anatomical regions. They are poor in the transmission of the compression but excellent to resist tension (5)

All hard tissues had this enforcing component but only in the ectodermally driven tissues we had different proteins that play this rule due to:

- Dissolution resistance
- Abrasion resistance
- Mechanical requirements

which could be said to be a mechanochemical issue.

Enamel is the only hard tissue that is engineered to be exposed to a harsh environment with a challenging mechanochemical environment(6)

- Tethering component this is achieved either through extra configuration or an alloying component in the tissues (7)
- This alloying additional component should be perceived as a tethering component and part of the matrix of the fiber-reinforced composite
- Strain gauge (strain could be mechanical, chemical, electrical,cellular ….etc.) that guide remodeling (8)
- Security tag component which is the initiator of the chemical messaging of the damage repair cascade (9)

This figure shows qualitatively the classification of loading on the bone the normal remodeling capacity of the tissue will be the driving factor in the disuse atrophy in the 2nd and 3rd cases the mechanochemical transduction is maintaining the tissues in optimum status and the security tag concept is the best fit for the 4th condition. In the 4th case, the damage could be range from a stress fracture to frank fracture and shattering bone into multiple pieces

Hard tissues are fibers reinforced composite with extremely complex anisotropicity on nano, micro, and macro scale(10). They had both viscoplastic and viscoelastic mechanical properties. (11, 12)

Their structures are not designed for durability but rather to accommodate any changes in the loading conditions owing to their fascinating remodeling capacity

Hard tissues could be classified into

a) Without remodeling capacity
   - With non-changeable structure, only enamel,middle ear ossicles, and part of the bony labyrinth are not changing throughout life (13, 14)
   - With changeable structure, the dentine had several mechanisms that replace its diminished strength with continuous exposure for loads(fatigue)(15)

b) With remodeling capacity which is bone and cartilage (16)

All hard tissues could be classified according to their origin that gives the resultant structure its unique properties (17)

a) Ectodermal
b) Ectomesenchymal
c) Mesenchymal
    - Intramembranous
    - Endochondral: loading is an integral part of development, maintenance, and physiology

There is no well-defined theory that describes bone damage, but there are some observations that give strong insights into the bone mechanical properties (18)

Hard tissue replacement could be defined as hardware that is replacing on ore more mechanical functions of the osseous structure. Hard tissue replacement is a gigantic subject. The developments in different engineerings`disciplines and their applications are now not limited to biomechanics but include biomechatronics applications (18)

Any bone management (including osteotomies protocols and rules of designs and material selections) should be approved or at least reviewed by the orthopedic community due to their intimate walk with bone cartilage and ligaments(19)

Decision-making to approve and management should be based on sound biologic pieces of evidence that respect anatomy, physiology, and biomechanics of the living tissues. A review of previous failures should be one of our guides to avoid future problems.(20)

It is sad to see the suggestion from maxillofacial surgeon suggesting the use of silicone or PMMA or even titanium as bearing surfaces for TMJ, and the saddest is to see reported cases of this disastrous maneuver (21)(22)

The rationale of this classification

After a thorough and impartial view of different hardware replacements, we could point to three main criteria that could be used to judge any device. According to the next three criteria (interaction, stiffness, and tribology) any device had these goals

- Interact well with the bone
- Don't affect physiology or growth
- Don't produce harmful products that would compromise its implementation implantation status

The biocompatibility of any replacement depends upon these factors

1) Interaction with the body environment.

This is related to the ability and how to interact with the surrounding tissues(23). This feature could be regarded as biotoleratbility. Properties such as Osteoinduction, osteoconduction, osseointegration, .etc is under this section. The interaction of biomaterials with the tissue environment is a bulk property. The vast majority of the interaction is depending upon the surface properties, and materials could be classified into:

a) Passive(24)

According to the properties of the proteins that interact with the implant surface, the body response will be determined (Osteoinduction, osteoconduction, giant cell response …etc.). It also depends on the material size and the texturing of the surface. This is also determined to which degree the implant could be colonized by bacteria. The passive effect could be

- A positive passive effect like in Osseo inductive material
- A neutral passive effect like in peek surface and UHMWPE

b) Active(25)

- The implant had a positive effect on the environment such in case ions or other chemical releases like antibiotics
- Positive and negative in the same time as in case of GIC (glass ionomer cement), it will give beneficial ions such as F & Ca and at the same time give Al as a negative effect
- Neutral like in PEEK or Ti. They are different in passive effect, as Ti is better and better
- Positive like calcium carbonate as a void filler and MTA in case of dentine replacement
- PMMA cement give some negative effect on the surface interaction but after setting or in the case of set material, it is one of the best materials on the passive surface effect
- In case of bone cement, which have antibiotic, it is positive and negative at the same time

In case of negative effect on the surrounding tissues this material already is not included in the discussion as it has no biotoleratbility. Nevertheless, biotolerabitity and biocompatibility is relative

2) Stress shielding is the core issue that is related to this aspect of implant performance(26). The resultant stiffness after implementation of this hardware which is highly anatomically dependent. Stiffness could be related to the used material or to the design itself. The occurrence of the stress shielding has occurred with another accompanying phenomenon which is the counterpart of the stress shielding and could be named as stress concentration that leads to overcorticalization while in stress shielding we have osteolysis will develop (27). General stiffness. It depends upon the stress transfer rate and the amount which resulted in:
    - Stress shield and osteolysis
    - Stress concentration and overcorticalization, which is a less settled concept due to improper claim of stiffer bone structure are better.

Arrangement of material is very important the part with the least stiffness should be as close as possible to the bone while the stiffest part is as far as possible from bone

Stiffness will affect growth which is continued beyond the physical maturation, as when we see in the implants dental implants in comparison to another to the adjacent with aging

Growth and the change in the shape of bone will not depend on physical maturation

Bone physiology is mainly the only matter of discussion about stiffness nowadays, with little attention to its effect on growth. This could be due to poor ability to correlate change over a protracted time.

The ratio of bone marrow volume to the trabeculae volume should be kept as much as possible to the natural. This golden ratio will be disrupted after hard tissue replacement implantation.

Also, we should not that stiffness will affect bone either

a) Passively
   Any placement of material implanted and fixed to the bone will affect the stress transmission through the bone. In case of the unilateral edentulous mandible and the patient is eating on the contralateral side, the bridge side will be affected passively by the presence of implants and the bridge, by which the bridge material will have aconsiderable effect on the net stiffness
b) Actively (27)
   Like when the patient eating on the same side of the implant-supported bridge in case of a unilateral edentulous mandible

The osseointegration which is in ankylosis in nature (28)mandates the least stiff part at this area to increase bone stimulation. The bone material is designed to transmit stresses in an even fashion with a gradient of elasticity in its milieu and not to receive direct stresses.

So osseointegration should be studied and dealt with as a deviation fromthe normal biomechanical behavior ofthe bone(29)

Important to remember that the most insulted region of the board at the entrance of the osteotomy site. As a result of the osteolysis at this region should be reviewed as multifactorial

The Effect of material selection in the case of tooth born prosthesis had a less pronounced effect upon the bone than in the case of implant born prosthesis, as we think, due to the difference between teeth and implants in the mechanism of attachment within their bony sockets(30)

Implant ankylosis had just mechanical stimulation, while in the case of tooth loadingwe have mechanochemical stimulation

3) The tribological properties of the replacement are very important to be considered to judge the biocompatibility of the replacement, which resultant from modularity presence(31).Tribology feature not only occurring between the prosthesis parts but also the bone-prosthesis interface.

As many advances in the engineering material occur, combinations of different material provide a solution that is not available by a single material

All modularities when used will include some sort of friction and inter parts movements. Different corrosions products will affect the tissues as there is no single type of corrosion would occur.

Silicones had lead to many failures when implemented in the arthroplasties, while it is one of the best biocompatible materials in the small joints replacements(32, 33). In that situation, the silicone was used as a bearing surface, but in the case of the small joints, the arthroplasty is made from one piece of silicone.

The risk of small joint arthroplasty is the wear of silicone(34).This problem had been repeated with TMJ and when we had to do an interpositional disc from silicone(35).

Many materials are appealing as replacements but continuous reviewing of their performances and judicious appraisal is a mandatory ethical and scientific obligation.(36)Almost all materials had certain biotoleratbility, but even the autograft is not biocompatible many times.

The surgeon when respect bone physiology, should worry only about the design of the implant he placed. No need to worry about bone, but we should seek the best design that provides the optimum condition to permit the bone to still grow and remodel in a favorable direction. In the case of a well-osseointegrated implant, we assume that almost always the bone will adapt itself to the implant whatever the shape or dimension of this implant is.

Biocompatibility should not be reduced in just the material are not cause inflammation in the implantation site
Design is an integral part of biocompatibility.(37) Platform switching is an example of how the macro design criteria could reduce the negative effect of the device on the living tissues.(38)
Many materials and designs have poor biocompatibility but still in the market due to:

1) Lack of proper knowledge and improper explanation of the failures. A clear example is the explanation of crestal bone loss in dental implant without considering titanium corrosion(39), while in many Prestigious textbooks the corrosion of the dental implants is considered in the speaking of the titanium resistance to it (Contemporary Implant Dentistry 3rd Edition / 2007) although the next edition of that book had denoted to the titanium corrosion
2) Due to proprietary issues in the design or material companies could have a financial benefit (40)
3) The personal attitude to make a glory or an achievement through surgical career (41)

The biocompatibility of a device is related to the function of that device in a manner that relatively safe during its performance, and many materials have proven to be biocompatible in a field and cause significant morbidity and mortalities in another field.

Silicones had been caused devastating morbidities when applied to TMJ as interpositional discs or as part of the arthroplasties but it is one of the best materials when it is used in the small joints total arthroplasties.

Due to the diversity of the biomaterials' origins and classes with no consensus about the definitions and classifications, it is better to classify the hard tissue replacements according to the function they will restore(42). This classification is partly derived by proven used material and designs that guide us better to know the biological systems how they are working

1) Replacement of the non-articulating non-load carrying portion (augmentation, voids fillers, and compartments separators)
   A clear example is the facial augmentations and cranial implants that replace part of the calvaria, where both will replace intramembranous originated bone or where the little effect of load could be encountered to maintain bone healthily. The most important issue the good tissue interaction to keep the implant in its place and stable material that will not be deteriorated with time. Additional fixation component could be used to secure the implant to the bone
2) Replacement of the non-articulating load carrying portion
   In such cases, stiffness is a feature that must be included. Osseointegration is the feature we are looking forward but as this category mostly temporary, this feature is not emphasized. One-piece dental implants could be fit in this category
3) Replacement of the articulating non-load carrying portion of the skeleton
   A clear example is the small joints arthroplasties
   Silicones are one of unique material that had a wide range of applications
   In arthroplasties, the applications of silicones had been ended with severe morbidities and mortalities. This was due to the configuration used, as they had been implemented as bearing surfaces
   In small joints arthroplasties with special design, silicone could be used safely with excellent performance
4) Replacement of the articulating load-carrying portion of the skeleton
   This category requires ultimate design and material selection criteria
   This category requiresin addition to the best interaction and stiffness, it needs the tribological performance to be ultimate, simply as arthroplasty is not a car bearing that replaced at the mechanic's shop
   Any wear product could lead to bone loss locally or distant tissues damage
5) Bone cements and thermosetting materials that are set after implantation.
   This category emphasizes the interaction of the material withthe body tissues. Mechanical properties requirements will follow
6) Middle ear ossicles replacements.
   Due to the histology, anatomy, and physiology of these structures, the application of GIC (Glass ionomer cement) had gained popular acceptance in the otolaryngologists' community
   Unique bone physiology had met the unique properties of this material which stand behind the success of GIC in middle ear surgery
7) Dental hard tissues replacement
   This category had been enormously expanded in recent years.
   One should emphasize that the aesthetic demand had led the market as the teeth had a direct impact on people's life. The mechanical properties of the dental structures are not well established till now but we had general guidelines that insight our material selections.
   The nature of the enamel and dentine is permissible in case of interaction but the stiffness and tribological requirement remain important to be considered
8) Dental implants
   As we think the most item of all hard tissue replacement that had been exposed to different conflicts is the dental implants. Marketing pressure had led to turn a blind eye.
   The market is full of poor design that is based upon faulty biomechanical concepts
   Modularities in dental implants make this type of hard tissue replacements mimics modular arthroplasties.
   Dental implant review should be based upon the current concepts that had been established well in other replacements

Dental prosthesis whether removable or fixed have important effects on the bone and had an intimate connection to the hard tissues so it had been included in this classification

When selecting the surface bearings for arthroplasties we require the strictest criteria of selection, while volumizer could be regarded as soft tissues replacers as well.

Dental implant share may feature with the arthroplasties and both had many equivalent requirements. Both osseointegration and corrosion in the main are two very important features that are required when arthroplasties when designed.
The hard tissue replacement must be evaluated in a parametric approach

References

[1] Maas SA EA, Halloran JP, Weiss JA. A general framework for application of prestrain to computational models of biological materials. . 2016 Aug.
[2] Currey J. Measurement of the mechanical properties of bone: a recent history. Clin Orthop Relat Res. 2009;467(8):1948-54.
[3] Guimarães CF, Gasperini L, Marques AP, Reis RL. The stiffness of living tissues and its implications for tissue engineering. Nature Reviews Materials. 2020;5(5):351-70.
[4] Rudrappa SS, Wilkinson DJ, Greenhaff PL, Smith K, Idris I, Atherton PJ. Human Skeletal Muscle Disuse Atrophy: Effects on Muscle Protein Synthesis, Breakdown, and Insulin Resistance-A Qualitative Review. Front Physiol. 2016;7:361-.
[5] Wenger MPE, Bozec L, Horton MA, Mesquida P. Mechanical properties of collagen fibrils. Biophys J. 2007;93(4):1255-63.
[6] Fong H, White Sn Fau - Paine ML, Paine Ml Fau - Luo W, Luo W Fau - Snead ML, Snead Ml Fau - Sarikaya M, Sarikaya M. Enamel structure properties controlled

by engineered proteins in transgenic mice. (0884-0431 (Print)).
[7] Shoulders MD, Raines RT. Collagen structure and stability. Annu Rev Biochem. 2009;78:929-58.
[8] Győri DS, Mócsai A. Osteoclast Signal Transduction During Bone Metastasis Formation. Frontiers in Cell and Developmental Biology. 2020;8:507.
[9] Krafts K. Tissue Repair. In: Wexler P, editor. Encyclopedia of Toxicology (Third Edition). Oxford: Academic Press; 2014. p. 577-83.
[10] Geraldes DM, Phillips ATM. A comparative study of orthotropic and isotropic bone adaptation in the femur. Int J Numer Method Biomed Eng. 2014;30(9):873-89.
[11] Wu Z, Ovaert TC, Niebur GL. Viscoelastic properties of human cortical bone tissue depend on gender and elastic modulus. J Orthop Res. 2012;30(5):693-9.
[12] Fondrk M, Bahniuk E, Davy DT, Michaels C. Some viscoplastic characteristics of bovine and human cortical bone. Journal of Biomechanics. 1988;21(8):623-30.
[13] Rolvien T, Schmidt FN, Milovanovic P, Jähn K, Riedel C, Butscheidt S, et al. Early bone tissue aging in human auditory ossicles is accompanied by excessive hypermineralization, osteocyte death and micropetrosis. Sci Rep. 2018;8(1):1920-.
[14] Moradian-Oldak J. The REGENERATION of TOOTH ENAMEL. Dimens Dent Hyg. 2009;7(8):12-5.
[15] Goldberg M, Kulkarni AB, Young M, Boskey A. Dentin: structure, composition and mineralization. Front Biosci (Elite Ed). 2011;3:711-35.
[16] Li Y, Xu L. Advances in understanding cartilage remodeling. F1000Res. 2015;4(F1000 Faculty Rev):642-.
[17] Hard Tissues: Structure, Properties, Healing, Remodeling, and Biocompatibility. In: Bioceramics. . New York, NY: Springer,; (2008)
[18] Zysset P. RL. Mechanics of Biological Tissue Berlin, Heidelberg. : Springer,; 2006)
[19] Sarmiento A. Orthopedic guidelines: Relevance. Indian J Orthop. 2011;45(3):191-3.
[20] Varnum C, Pedersen AB, Rolfson O, Rogmark C, Furnes O, Hallan G, et al. Impact of hip arthroplasty registers on orthopaedic practice and perspectives for the future. EFORT Open Rev. 2019;4(6):368-76.
[21] Chang W-C, Chang Y-C, Lin C-k, Chen Y-W. Using the silastic as interpositional material in the management of left temporomandibular joint ankylosis. Journal of Medical Sciences. 2015;35(5):226-9.
[22] Fricton JR, Look Jo Fau - Schiffman E, Schiffman E Fau - Swift J, Swift J. Long-term study of temporomandibular joint surgery with alloplastic implants compared with nonimplant surgery and nonsurgical rehabilitation for painful temporomandibular joint disc displacement. (0278-2391 (Print)).
[23] Lane JM, Mait JE, Unnanuntana A, Hirsch BP, Shaffer AD, Shonuga OA. 6.616 - Materials in Fracture Fixation. In: Ducheyne P, editor. Comprehensive Biomaterials. Oxford: Elsevier; 2011. p. 219-35.
[24] Toth JM. Chapter 7 - Biocompatibility of Polyaryletheretherketone Polymers. In: Kurtz SM, editor. PEEK Biomaterials Handbook. Oxford: William Andrew Publishing; 2012. p. 81-92.
[25] Osada N, Terada A, Maeda H, Obata A, Nishikawa Y, Kasuga T. Tuning of ion-release capability from bio-ceramic-polymer composites for enhancing cellular activity. Royal Society Open Science.6(9):190612.
[26] Ait Moussa A, Fischer J, Yadav R, Khandaker M. Minimizing Stress Shielding and Cement Damage in Cemented Femoral Component of a Hip Prosthesis through Computational Design Optimization. Adv Orthop. 2017;2017:8437956-.
[27] Chen H-H, Lai W-Y, Chee T-J, Chan Y-H, Feng S-W. Monitoring the Changes of Material Properties at Bone-Implant Interface during the Healing Process In Vivo: A Viscoelastic Investigation. BioMed Research International. 2017;2017:1945607.
[28] Pasqualini U PM. Chapter X, OSSEOINTEGRATION OR “INTEGRATING BONY ANKYLOSIS”. Available from: 2009 Oct. [Available from: https://www.ncbi.nlm.nih.gov/books/NBK409630/.
[29] Roberts WE. Bone dynamics of osseointegration, ankylosis, and tooth movement. (0019-6568 (Print)).
[30] Lin J, Lin Z, Zheng Z. Effect of different restorative crown design and materials on stress distribution in endodontically treated molars: a finite element analysis study. BMC Oral Health. 2020;20(1):226.
[31] Rieker CB. Tribology of total hip arthroplasty prostheses: What an orthopaedic surgeon should know. (2058-5241 (Print)).
[32] Brase DW, Millender LH. Failure of silicone rubber wrist arthroplasty in rheumatoid arthritis. The Journal of Hand Surgery. 1986;11(2):175-83.
[33] DeChamplain RW, Gallagher CS, Jr., Marshall ET, Jr. Autopolymerizing silastic for interpositional arthroplasty. Journal of Oral and Maxillofacial Surgery. 1988;46(6):522-5.
[34] Verhaar J, Bulstra S Fau - Walenkamp G, Walenkamp G. Silicone arthroplasty for hallux rigidus. Implant wear and osteolysis. (0001-6470 (Print)).
[35] Hartman LC, Bessette RW, Baier RE, Meyer AE, Wirth J. Silicone rubber temporomandibular joint (TMJ) meniscal replacements: Postimplant histopathologic and material evaluation. Journal of Biomedical Materials Research. 1988;22(6):475-84.
[36] Shafaghi R, Rodriguez O, Schemitsch EH, Zalzal P, Waldman SD, Papini M, et al. A review of materials for managing bone loss in revision total knee arthroplasty. (1873-0191 (Electronic)).
[37] Aravamudhan S. 3 - MEMS for in vivo sensing. In: Bhansali S, Vasudev A, editors. MEMS for Biomedical Applications: Woodhead Publishing; 2012. p. 81-96.
[38] Gehrke SA, Dedavid BA, Prados-Frutos JC. Effects of different switched or not-switched implant and abutment platform designs and marginal bone loss on fracture strength: An in vitro study. LID - S0022-3913(20)30767-8 [pii] LID - 10.1016/j.prosdent.2020.11.038 [doi]. (1097-6841 (Electronic)).
[39] Chaturvedi T. An overview of the corrosion aspect of dental implants (titanium and its alloys). Indian Journal of Dental Research. 2009;20(1):91-8.

[40] Wagner WR, Sakiyama-Elbert SE, Zhang G, Yaszemski MJ. Biomaterials Science: An Introduction to Materials in Medicine: Elsevier Science; 2020.
[41] Muth CC. Conflict of Interest in Medicine. JAMA. 2017;317(17):1812-.
[42] Parida P, Behera A, Mishra S. Classification of Biomaterials used in Medicine. International Journal of Advances in Applied Sciences. 2012;1.