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Multiobjective Optimization for Ceramic Hip Arthroplasty with Medical Physics Applications

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ABSTRACT

In a previous contribution a total hip arthroplasty optimization for metal materials was presented [5]. THA constitutes an important group among the most frequent used implants in Biomedical Engineering and Medical Devices research field. In this further multiobjective study, modelling and nonlinear optimization is performed with four commonly used ceramic materials for CoC hip arthroplasty—among the most surgically utilized currently. These are ZTA Biolox, ZTA Biolox-Delta, Alumina (Al_3O_2), and Zirconium (ZrO_2). Numerical results for dual optimization show acceptable figures with low residuals. Results with algorithm of 2D Graphical Optimization and 3D Interior Multiobjective Optimization are proven, explained, shown acceptable. According to these optimal findings and calculations, the model parameters are mathematically demonstrated, and verified. Results of 2D graphics and 3D Interior Multiobjective Optimization to obtain the local minima are sharp. Optimization rising numbers match the model design because the hardness and experimentally-published erosion intervals of Alumina, Zirconia, ZTA Biolox and ZTA Biolox-Delta intervals overlap one another approximately. Medical-Mathematical Physics consequences emerge for new nonlinear multiobjective optimization algorithms. Based on these numerical multifunctional data results, applications in Biomedical Engineering devices and future Bioengineering/Biomaterials designs are guessed.

Keywords : Software Engineering Methods, Multiobjective Nonlinear Optimization, Artificial Implants (AI), Hip Implants, Total Hip Arthroplasty (THA), CoC (Ceramic on Ceramic implant), Objective Function (OF), ZTA (Zirconium Taughtened Alumina), Prosthesis Materials, Wear, Biomechanical Forces.

I. INTRODUCTION AND HIP ARTHROPLASTY BIOMECHANICS

There are two main mechanical elements in THA implants, namely, the cup and the head. In bioengineering, the nomenclature is usually CoC (ceramic-on-ceramic, both cup and head), CoM or MoC (ceramic with metal, either). Because of the erosion magnitude and other mechanical/material parameters such as stress, friction, or elasticity modulus, hard bearings are usually CoC, MoC, CoM, or MoM [30]. When at least one component of polyethylene used in THA are withind the group of soft bearings, such as PoC, MoP or PoP. However, there are other factors, apart from the materials themselves, that could determine whether the bearing is hard or soft. Just remark that these groups of materials are the common ones in the recent decade.

All of them show traumatological-clinical advantages and inconvenients. The elective diagnosis and treatment depends of a number of functional factors. These are classified [Casesnoves, 2021] into two groups, clinical factors of the patient (PF), and technical-clinical ones (TCF), let's say external to patient factors. PF are varied and individualized, for instance, age, sex, walk and run activity, associated pathologies, immunological conditions, body frame, weight, etc. TCF are also diverse, technical surgical equipment, surgical staff available, economic conditions of the in-set implants, instrumentation, etc. Table 1 shows this classification.

Table 1.- PF-TCF classification for hip arthroplasty surgical treatment [Casesnoves, 2021].

As a consequence for the elongation of lifetime and traumatological reasons, hip implants constitute the surgical routine at traumatology and/or orthopedic services at any general/specialized hospital. In elderly population, ostheoporosis, movement habits, associated diseases, degenerative pathologies, tumor invasion of zone or methastasis, and loss of biomechanical capability became some of the crucial THA factors [1,5,17,18,21,23,25,27].

PF-TCF Hip Arthroplasty Functional Treatment Classification [Casesnoves, 2021]		
Type / Factor	**PF (Patient Factors)**	**TCF (Technical-Clinical Factors)**
FACTOR TYPE	Optimal THA individualized Inmunology Histocompatibilty Associated Pathologies Infection (resistance to radiation for eliminating infection)	Surgical staff available Technical equipment Instrumentation Hospital functionality Type of THA Economical factors Country technology in Industrial Medical Technology Precision in pre-operative diagnosis, imaging diagnosis and evaluation

Hip constitutes the fundamental-mechanical meshing-union between trunk and legs— essential for standing up posture and usual/normal movements. The forces exerted over hip frame are biomechanically transmitted to knee and feet articulations. If hip articulation fails, the biomechanical consequence is rather difficult/very similar to be sorted compared, e. g., to knee articulation failure or other biomechanical limitation. This change in incidence/prevalence of hip diseases during recent decades creates a high demand of these type of THA implants. The appropriate mechanical/material improvements at production is highly demanded. One type is CoC, which is the objective of this study.

Therefore, this contribution presents a multiobjective mathematical optimization of common CoC implant materials. These are Alumina (Al_3O_2), ZTA Biolox, ZTA Biolox-Delta, and Zirconium (ZrO_2) [5,21,30]. Their tribological properties/functionality are computationally modelled in 2D and 3D, by using classical model equations. Reasons for this kind of choice are their extent use in medical physics, biomedical engineering and histocompatibility of these materials. Numerical Nonlinear Optimization in 2D Graphical Optimization methods and 3D Interior Optimization ones are applied with specific software. Results validate a series of numerical data and imaging 3D graphical surfaces to select/compare ceramic materials and get objective parameters database for ***in vitro*** simulations, manufacturing and/or tribotesting of THA implants.

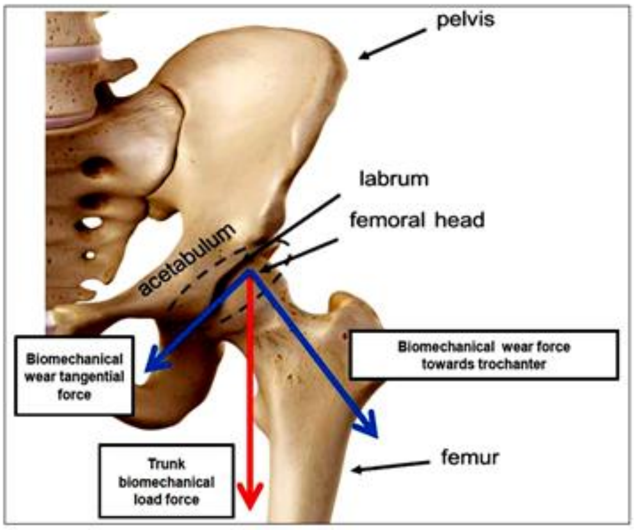


Figure 1.- (Google free images with author's draws) pictured inset, 2D basic forces distribution in normal hip. On the image background, the elementary structure of the hip anatomy, acetabulus, femoral head and trochanter. There are a wide number of implant apparatus-kit variants in biomedical engineering. Before setting the implant, the bone has to be prepared according to implant geometry. In general, it is a complicated surgical intervention. Strong forces have to be exerted, and those have to be done precisely—the mechanical reason for modern robots usage. CoC implants have a high hardness magnitude, in all their material variants. The trunk and abdomen loads are approximately perpendicular to the standing surface of the legs. Gravity center of body is located usually at S2 level. This force, for biotribological purposes, is decomposed into a tangential component in-between interface of implant cup and implant head surface, and other perpendicular to the semi-spherical implant head towards the femur trochanter. Both force-components of biomechanical load cause wear and debris at the THA implant surface while the the artificial articulation rotates.

Usually the load forces distribution is rather complicated and divided in X,Y,Z components [1,25]. When doing approximations, average values and/or forces resultant values are taken. For nonlinear optimization, the average values are be implemented in the program [1,25]. In software data, a load of around 200% of body weight (200%BW) is implemented for optimization constraints, according to the most usual values of literature [5,21,25,27,30].

II. NUMERICAL METHODS AND ALGORITHMS

The necessary numerical data for optimization are hardness of CoC (hard bearings) materials, implant head standard diameter, experimental interval of erosion widely published in literature, units, and other complementary data which are mentioned but not implemented on this study model [5,7,17,18,21,22,25,27]. Table 2 details numerical parameters and units database. Ceramic histocompatibility is usually good. Histocompatibility can be mechanical, surfactal, and chemical mainly. Further histocompativility involves pharmacological biocompatibility and thrombus formation probability. Infection probability constitutes an important factor/inconvenient. The osteomyelitis-type infections are frequently resistant to antibiotics and very difficult for total cure, even if radiation is used.

Table 2.-Materials CoC data implemented in multiobjective optimization models with complementary details.

NUMERICAL DATA		
Material	**Hardness (GPa) and Histo-compatibility**	**Density (g/cm^3) and Head Diameter (mm)**
Alumina (Al_3O_2)	22.0	3.98 28 [22-28]
Zirconium (ZrO_2)	12.2	5.56 28 [22-28]
ZTA Biolox	[15.2 , 16.3]	4.37 (approx) 28 [22-28]
ZTA Biolox-Delta	[15.2 , 16.3]	4.37 (approx) 28 [22-28]
Complementary Data	ElasticityModulus and Fracture Thougness are useful for other type of calculations. Density varies slightly in literature. The standard femoral head used diameter is 28mm. Hardness also varies in literature. For Biolox and Biolox-Delta (ZTA) hardness magnitude varies in the literature.	

The determination of hip implant wear in all the study is referred to cup and prosthesis head together [5]. The volume parameter is set in mm^3 always, the mass in kg, the force in N, time in seconds, and the constants of the models applied are function of these units along all study. The erosion of arthroplasty hip implants is specified in different ways along the literature [5, 21,25,27]. Namely, for ***in vitro*** research, mm^3 of eroded material per million cycles (Mc) of the femoral head and/or THA cup, mass of eroded material per year per Mc, very frequently mm^3 of eroded material extrapolated to year, mass of eroded material per Mc extrapolated to year, and others. For ***in vivo*** studies it is frequent to consider mass or volume of erosion per time interval—usually one or several years.

Here the mm^3 per Mc is selected for the entire study. It is considered a rough approximation mm^3 or mass of eroded material per year, because the number of cycles of the patient during a year is a non precise measurement—unless large statistical data for age, kinetics, physical activity, etc, intervals is applied.

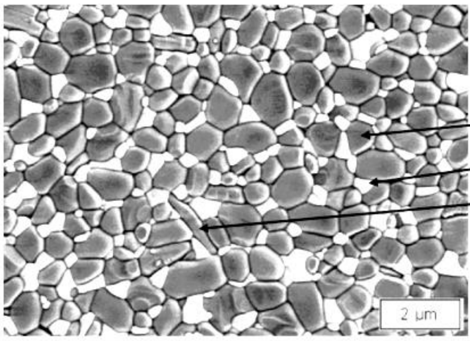
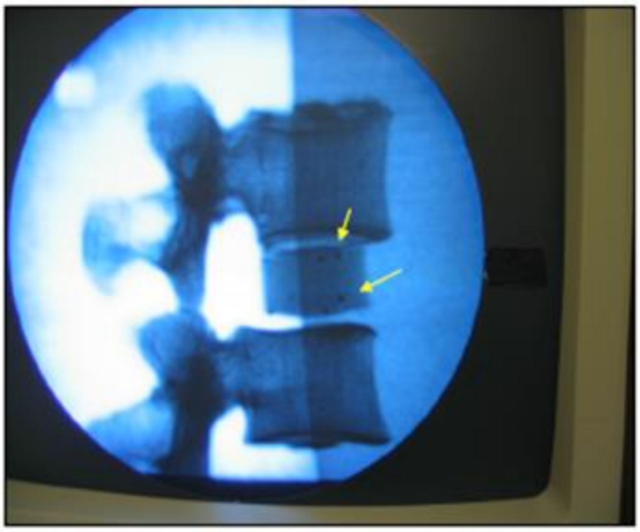


Figure 2.-ZTA Biolox microstructure [Image from Google Images]. In metal recycled materials, not related to THA, it was experimentally and numerically proven that at the binding zone, the hardness decreases [Casesnoves, 2017-8, 23]

Other important parameter in kinesiology is to determine exactly/approximately what length has a cycle. Natural movement intervals also change during lifetime. According to kinesiology/anatomy of the natural hip, the average rotation of femur head cannot reach 180°. This is valid for flexion, extension, flexion-rotation, extension-rotation, abduction, adduction, external/internal rotation. One cycle in this study is taken as the length corresponding to the maximum kinesiologic rotation angle. From literature it varies, and postoperative movement range is different than normal movement and preoperative dynamics [24]. The maximum value implemented here is 145° for flexion. Therefore, the erosion data resulted from the optimization always has to be considered as the maximum. In other words, as the worst case possible. This point is clarified at every optimization step. By using wear unit in mm^3 , the model constant K results adimensional, as it is proven. Classicaly, [31], the K constant had been expressed with proper units. However, in this study erosion is set in mm^3 , and as a practical result, K becomes adimensional. Erosion simulations, experimental and/or theoretical, namely, ***in vitro***, show clearer results by using this nomenclature.

When erosion is measured ***in vivo***, other type of units are frequently selected. In this case, for instance, the volume variation of head and/or cup in mm—that is, the wear-imaging, comparison at boundaries of a time interval. This ***in vivo*** experimental is more difficult and for example radiological markers are used to determine the wear of the THA. Figures 2 and 3 [Casesnoves, 2005-9],



show how much useful radiomarkers are for position-determination of lumbar artificial disks.

Figure 3.-This is an illustrative example of radiomarkers applications, as it also happens for ***in vivo*** techniques to measure the THA erosion magnitude—there are several methods and usually the erosion in mm in a year period is determined. In this example, [Casesnoves, 2006-2015,22], the radiomarkers are used in a ***in vitro*** simulation to determine the changes in the movement of artificial lumbar disks. Imaging was optimized with a Siemens Siremovil-4k C-Arm RX machine. It was determined the optimal radio-opaque material proportion in the radiomarker manufacturing process, in this case Tantalum. Radiomarkers, [Casesnoves, 2007-2015,22], are also very useful in THA and other bioengineering implants to measure ***in vitro*** and/or ***in vivo*** a number of parameters. Namely, erosion rate, imaging optimal visualization implant Instantaneous Rotation Center (IRC), post-operation correct position checking, post-operation evolution, etc.

Figure 4.-The clinical biomechanical ***in vivo*** application and outcome of the radiomarkers optimization process made in previous figure. [Casesnoves, 2008]. In this left-lateral RX image positioning of radiomarkers at lumbar spine L4 level are visualized—anterior ones yellow, posterior and posterior-lateral in orange. They show the artificial disk implant positioning after surgery. In the same way, with THA the volume erosion changes in head and/or cup can be determined after a time interval. Today, radiomarkers biomedical applications constitutes an open investigation field for future practical applications.

The load magnitude applied for optimization constraints is 200%BW [1,5,21,25,27,30]. This value was selected as usual in literature. Constraints for load are set for a 50kg patient till a 80kg patient. 50 kg corresponds, for example, to the body weight of elderly women, who present a high incidence/prevalence of femur head fractures and osteoporosis.

The kinetics and dynamics of the patient is another factor [2]. It depends on a number of varied parameters. They could be genetical, race, age, sport activity, physical work, walking habits, country, climate, culture, individual habits/circumstances, etc. Therefore, Mc within maximum rotation angle of 145° is considered a feasible mathematical-software approximation.

The algorithms that were implemented are based on classical Archard's model [5]. A variant from this model with evoluted algorithms was developed in previous contributions

[Casesnoves, 2018-20,5]. The classical equation for wear optimization of hip implants reads,

$$W = K \frac{L \times X}{H} \; ; \tag{1}$$

where K is wear constant specific for each material, L biomechanical load (N, passed here to kg and mm), X sliding distance of the acetabular semi-sphere of the implant (mm), and H is the hardness of the implant material (MPa, here it is used always kg and mm). X is measured as the number of rotations of the implant multiplied by approximately half distance of its circular-spherical length. Number of rotations depend of the daily physical activity of the patient, one/several million cycles (Mc), is the standard.

Model (1) is used in integral form for finite elements techniques in hip implants. K is a parameter, although in previous contributions, [5], this algorithm was implemented for more parameters, such as optimal hardness or number of rotations. Number of rotations is calculated with the circumference implant-head radius R by π for a factor of angle of 145°. The OF with L2 Norm that is used, [Casesnoves Algorithm, 2020-1], without fixed constraints reads, minimize,

$$\left\| W - K \frac{L \times X}{H} \right\|_2^2 = 0 \; ;$$

subject to (generically),

$$\begin{bmatrix} a \\ b \\ c \\ d \end{bmatrix} \le \begin{bmatrix} K \\ L \\ X \\ H \end{bmatrix} \le \begin{bmatrix} a_1 \\ b_1 \\ c_1 \\ d_1 \end{bmatrix} ; \tag{2}$$

where a, b, c and d are constraint parameters to be selected. That is, any parameter(s) can be constrained for optimization. W values are experimental figures from the literature, in mm^3 . The most important one is H, since what is intended is to get practical optimal results for a multiple-group of arthroplasty materials. Load parameter is selected within a wide range [50,80] kg of patient weight. The reason is that this weight comprises from an older patient until a sporting young person, for instance.

The power 2 of the least squares algorithm converts the objective function into a nonlinear function, and the power (-1) of the hardness model makes it nonlinear. Therefore, OF is a nonlinear least squares one, that has provided acceptable results in materials engineering, [1-5]. The data setting was hardness of ceramic hard-bearings THA types, and loads. The parameter with constraints that is mainly to be determined, is the K coefficient of (1). 2D Graphical Optimization several-curves images were done with more complicated software that depends on subroutines in few parts [2-5,23,26]. This original software, [2-5,26], was improved from previous contributions, and 3D Interior Optimization programs for Figs 7,8 is a new design. Residuals and optimal values for K and the rest of parameters are also obtained in the programs. W is set in mm^3 . The proof that for model (1), by using the selected unit kit, makes K adimensional follows straightforward when the chosen units are implemented.

III. SOFTWARE PROGRAMMING TECHNIQUES

The software and mathematical methods of this contribution constitute both an improved evolution and completely different programs from previous publications [5] with Matlab. Fortran 90 was used to check/validate the numerical precision of the results. The variations/improvements are usage of 2D Graphical Optimization and 3D Interior Optimization methods [2-11]. The software is different in each case. The least-squares inverse algorithm [Casesnoves, 2021] implemented reads,

$$
\begin{aligned}
&\text{minimize},\\
&\| F(W,K,H,L,X)\|_2^2 = \ldots\\
&\ldots = \sum_{i=1}^{i=N} \sum_{j=1}^{j=N}\\
&\sum_{k=1}^{k=N} \left(F_{ijk}\left(W_{ijk},K_{ijk},H_{ijk},L_{ijk},X_{ijk}\right)\right)^2 + \ldots\\
&\ldots + F_N\left(W_{N,N,N},K_{N,N,N},H_{N,N,N},L_{N,N,N},X_{N,N,N}\right)^2;\\
&\text{subject generically to,}\\
&\begin{bmatrix} a \\ b \\ c \\ d \end{bmatrix} \le \begin{bmatrix} K \\ L \\ X \\ H \end{bmatrix} \le \begin{bmatrix} a_1 \\ b_1 \\ c_1 \\ d_1 \end{bmatrix};
\end{aligned}
\tag{3}
$$

K is the principal variable for optimization. The reason is that with a multiobjective K parameter it is possible to carry out ***in vitro*** simulations in the materials selection process. The 2D Graphical Optimization is the implementation of this Objective Function (OF) (2) related to erosion interval and every selected parameter of the model with constraints. N in (1,2,3) was chosen for an easy running time as 2 million functions. The usage of several subroutines combined/complemented with new patterns was essential to obtain results. Software was also designed to obtain clear visualization of imaging-results. In all calculations for every optimal parameter, always a local minima is determined. The 3D volume-matrix of the algorithm was converted to a 2D matrix with series of arrays for implementation in patterns.

The imaging 2D charts have surfaces, and simple and/or combined parameter curves. The plotting of these curves and regions, when combined, constitutes rather a difficult task. The reason is that to obtain a sharp visualization of several or all model parameters together, it is necessary to set them within the pattern with scale factors. Those calculations involve a series of computational trials with approximations to get the best charts with clear local minima. Total running time for programs results be between 2 and 7 minutes because 2 million functions were chosen. A range of parameters were selected in (2),(3), for 2D Graphical Optimization [5,21,25]. These are hardness, load, and model wear.

The 3D Interior Optimization of Fig 7 is subject to the same constraints of 2D Graphical optimization but different. That program in based on volume-matrix arrays to set a suitable matrix data configuration for a validating image of the previous 2D Graphical Optimization figures. Constraints for both programs were selected as follows,

$$\begin{aligned}
&\min imize\ OF,\ subject\ to,\\
&N = 2 \times 10^6\ ,\\
&0.02 \le W \le 0.1 \quad mm^3\ ,\\
&12 \times 10^6 \le H \le 23 \times 10^6\ kg, mm\ ;\\
&7.5 \times 10^4 \times 9.8066 \le L \le 2.0 \times 10^5 \times 9.8066\ ;\\
&X = \pi \times 28 \times (145 \times 10^6)/180\ (1\ Million\ cycles)\ ;
\end{aligned} \tag{4}$$

IV. RESULTS

Results constitute an advance from previous contributions in metal THA [5]. Are presented both numerically and in graphics. Numerical figures, truncated, are detailed in Table 3. Graphic software was designed to show local minimum in function of several parameters. In Table 3, the multiobjective nonlinear optimization for Alumina, ZTA Biolox, ZTA Biolox-Delta and Zirconium is shown. Figs 5-6 show the model 2D Graphical Optimization. Figs 7-8 the 3D Interior Optimization for validation of 2D optimal parameters. The curves and areas correspond to model objective function (Y axis) related to parameter values (X axis). Nonlinear optimization matrix was set with 2 million functions. Running time was about 2-7 minutes to obtain local minima and graphics. The 2D surfaces obtained are filled with all the OF values for these 2 million functions. Each one has a different combination of parameters. Residuals are low considering the number of OFs of the optimization matrix.

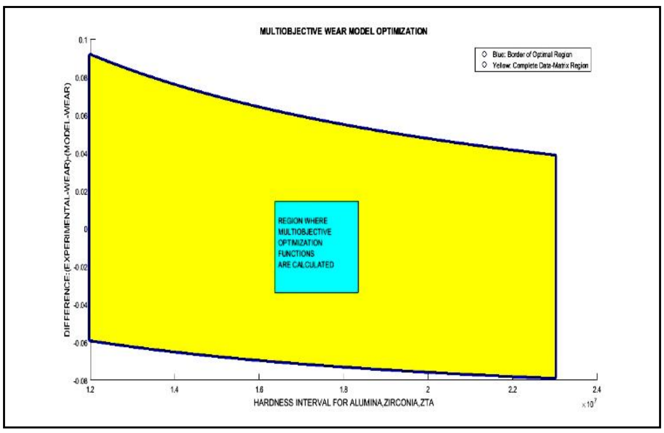


Fig 5.- 2D multiobjective graphical optimization of model for K. All parameters are in Kg and mm (one million cycles). The matrix for all evaluated parameters in optimization program covers a 2D region. The numerical result of the difference between model and experimental wear axis Y. Matrix has all possible combinations of parameters, namely, load, hardness, and experimental wear. The initial 3D volume-matrix, that is, a 3D matrix with 3 variables, hardness, load, and experimental magnitudes was converted with programming arrays to a 2D matrix of 2 million functions. Optimal K is 9.587464×10^{-9} . Residual is 1.76697×10^{3} .

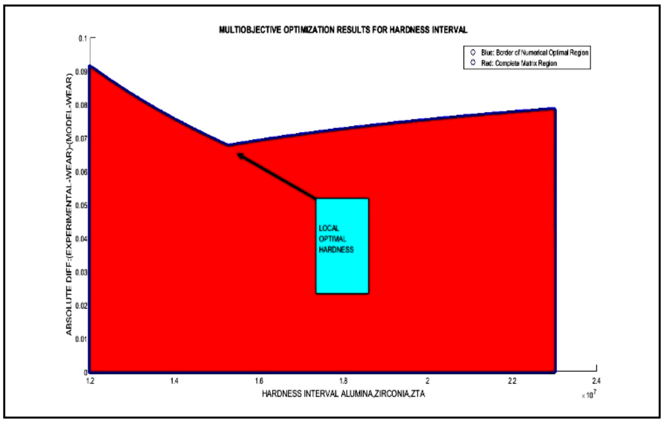


Fig 6.- 2D Graphical Optimization of model for hardness. Absolute value of OF. All parameters are in kg and mm (one million cycles). The matrix for all evaluated parameters in optimization program covers a 2D region. The numerical result of the difference between model and experimental wear axis Y. Matrix has all possible combinations of parameters, namely, load, hardness, and experimental wear. Optimal hardness can be observed at peak-concavity approximately at 1.5×10^7 (units at Table 2, kg and mm^3). With 2D Graphical Optimization is exactly 1.526×10^7 . OF absolute value is within interval [0,0.08], which is an acceptable result for the experimental data implemented, [0.02, 0.1].

In Figure 7, the 3D Interior Optimization results are shown. K and Hardness magnitudes are set along axes within the constraints intervals. It is confirmed that erosion increases inversely proportional to hardness. The optimal K value from 2D graphical Optimization is validated.

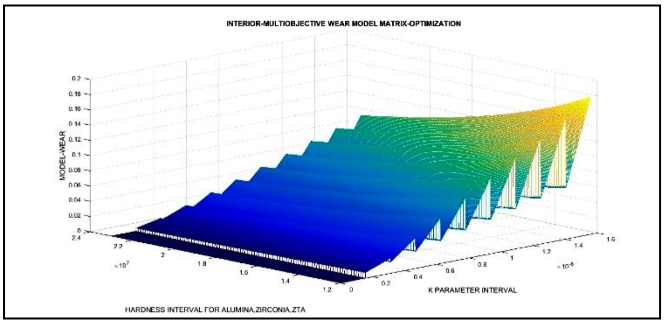


Fig 7.-3D Interior Multiobjective Optimization to prove that erosion is higher when hardness is lower and load is higher. Matrix has 10^5 elements and was set with K optimal interval that was obtained with 2D optimization algorithm. The program was rather difficult with several long nested patterns.

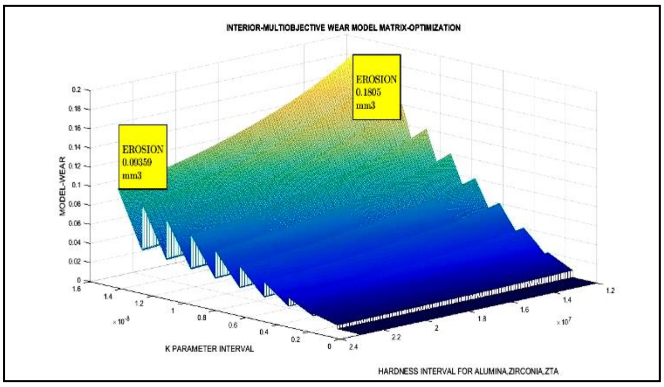


Fig 8.-3D Interior Multiobjective Optimization to prove with numbers in mm^3 that erosion is higher ($0.1805\ mm^3$) when hardness is lower ($0.09359\ mm^3$) and load is higher.

This is the confirmation of the hypothesis, validity of algorithm, and general tribology theory—the lower hardness and higher load, the higher erosion. K intervals that comprise the local minimum of 2D optimization were inset in matrix in 10 group-intervals. Enhanced figures in Appendix I are shown as it is an important mathematical validation of all previous algorithms-calculations. For numerical verification of local minima values within model, the equation is as follows,

$$\left| K\,(\text{optimal}) \text{ x } \frac{\text{Load}\,(\text{optimal}) \text{ x } Mc}{\text{Hardness}\,(\text{optimal})} \right| = \\ = 9.59\text{x}10^{-9} \text{ x } \frac{1.10\text{x}10^{6} \text{ x } Mc}{1.53\text{x}10^{7}} = \\ = 0.0489 \in [0.02, 0.1]; \tag{5}$$

Therefore, the optimal numerical values obtained with the software are within experimental interval. The figure 0.04 corresponds to about the center of the interval. That is a good numerical result, as it is not set around the boundaries of experimental interval, but about its center.

This implies that for Alumina, ZTA Biolox, ZTA Biolox-Delta, and Zirconia materials, the optimal K value obtained is acceptable for the experimental wear magnitudes published in literature [21]. Just remark that units are always kg and mm for an erosion measured in mm^3 . Table 3 shows all nonlinear multiobjective optimization results.

MULTIOBJECTIVE OPTIMIZATION RESULTS		
Material	**Optimal K adimensional**	**Optimal hardness (kg, mm)**
ALUMINA **ZIRCONUM** **ZTA BIOLOX** **ZTA BIOLOX-DELTA**	9.6×10^{-9} [truncated]	1.5×10^{7} [truncated]
Material	**Optimal Erosion (mm^3)**	**Optimal Load (kg, mm)**
ALUMINA **ZIRCONUM** **ATZ BIOLOX** **ATZ BIOLOX-DELTA**	0.05 [truncated]	1.01×10^{3} [truncated]
RESIDUAL FOR OPTIMAL HARDNESS **AND ADDITIONAL DATA**	**1.8×10^{3} [truncated]** All units used in optimization are passed in Kg and mm. Number of nonlinear function for program is 2 million. The initial Volume-Matrix, that is, a 3D matrix with 3 variables, hardness, load, and experimental magnitudes was converted with programming arrays to a 2D matrix of 2 million functions. Absolute difference between (experimental wear interval)-(model wear interval) $\in [0, 0.08]$.	
3D INTERIOR OPTIMIZATION RESULTS		
3D matrix Program	Validation of K optimal parameter In chart Validation of erosion rises when Hardness decreases	

Table 3.- Multiobjective optimization numerical results. Acceptable figures.

V. COMPUTATIONAL-SURGERY AND BIOMECHANICAL APPLICATIONS

This K coefficient for similar/equal materials with hardness values within the interval corresponds to Alumina, ZTA Biolox, ZTA Biolox-Delta and Zirconia gives useful applications. Table 4 shows a number of Medical Physics and Bioengineering applications. That is, simulate/predict approximately the wear that will be caused in the implant for that load with higher number of Mc.

BIOMEDICAL-BIOENGINEERING APPLICATIONS	
TYPE	**USAGE**
MANUFACTURING THA	Simulations in design of materials
EROSION PREDICTION FOR INDIVIDUAL PATIENT	Clinical Individual THA selection
RESEARCH FOR FUTURE THA	Simulations of new similar ceramic materials
RESEARCH FOR FUTURE THA	The composed materials wear whose hardness fall within the computed interval can also be simulated with these optimal results.
THA DURABILITY PREDICTION	For optimal functionality clinical orthopedics
MODEL PARAMETER OPTIMIZATION	optimal parameters for hardness, load, and wear efficacy
PRE-OPERATION SIMULATIONS	Computational simulations for pre-operation THA selection

Table 4.-Brief of Medical Physics and Bioengineering applications of study results.

VI. DISCUSSION AND CONCLUSIONS

Principal results are shown in Tables 5. The THA erosion model has been improved related to previous contributions. New definition for a K adimensional practical constant was demonstrated. For load interval implemented at the model, average values of the patient body-weigh (BW) were implemented with basic approximations. The inverse algorithm set was nonlinear least squares with about 2 million functions.

Both with 2D Graphical Optimization and 3D Interior Optimization the proof of the exclusive existence of local minima was demonstrated. Average software running time resulted about 4-7 minutes, and residuals are low for this number of functions. 3D Interior Optimization confirmed the 2D Graphical Optimization optimal parameters. 3D Interior Multiobjective Optimization chart was obtained sharp and demonstrative with special volume-matrix program.

Applications in Medical Physics are theoretical and practical. Theoretical are useful for model improvements. And practical ones for THA design simulations ***in vitro*** and prediction of erosion of THA ***in vivo***. Clinical Medical Physics applications are extent and presented in Tables 5. Biomedical and Bioengineering extrapolated usages emerge from the study results.

RESULTS (I)	
FINDING TYPE	RESULT
Computational Software Medical Physics applications	New software design and improvements for theoretical and applied Medical Physics
2D Multiobjective optimization	K model parameter with low residual (local minimum)
2D Multiobjective optimization	Optimal hardness
2D Multiobjective optimization	Optimal Load
2D Multiobjective optimization	Optimal modelling parameters for erosion
3D Multiobjective Interior optimization	Validation of K parameter and optimal Hardness and Load for 4 materials
Medical Physics applications	For simulations ***in vitro*** in Bioengineering THA design

RESULTS (II)	
FINDING TYPE	RESULT
Medical Physics applications	For simulations ***in vitro*** in Bioengineering THA design
Medical Physics applications	For THA erosion model improvements
Clinical Medical Physics applications	In durability of clinical results in THA
Computational	New software

Software Medical Physics applications	design and improvements for theoretical and applied Medical Physics
THA Model Parameters	Simplification of model units and K parameter adimensional for ***in vitro*** simulations

Tables 5. Summary of Medical physics and Modelling results of the study.

VII. SCIENTIFIC ETHICS STANDARDS

2D/3D Graphical-Optimization Methods were created by Dr Francisco Casesnoves on December 2016. This software was originally developed by author. This article has a few previous paper information, whose inclusion is essential to make the contribution understandable. Specifically, the 2D graphics in optimization resulted very similar to previous publications because the ZTA Biolox and ZTA Biolox-Delta hardness/erosion rates set precisely within the optimization hardness-interval of a previous paper. The 3D Interior Multiobjective Optimization plot validates all these results. The nonlinear optimization software was improved from previous contributions in subroutines modifications, patters, loops, graphics and optimal visualization. This study was carried out, and their contents are done according to the European Union Technology and Science Ethics. Reference, 'European Textbook on Ethics in Research'. European Commission, Directorate-General for Research. Unit L3. Governance and Ethics. European Research Area. Science and Society. EUR 24452 EN [16,29]. This research was completely done by the author, the software, calculations, images, mathematical propositions and statements, reference citations, and text is original for the author. When anything is taken from a source [Figures 1, 2, Google Images], it is adequately recognized. Ideas from previous publications were emphasized due to a clarification aim, [16,29].

VIII. REFERENCES

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IX. AUTHOR'S BIOGRAPHY

Dr Francisco Casesnoves earned the Engineering and Natural Sciences PhD by Talllinn University of Technology (started thesis in 2016, thesis defence/PhD earned in December 2018, official graduate Diploma 2019), and computational-engineering/physics independent researcher. MSc-BSc, Physics/Applied-Mathematics (Public Eastern-Finland-University), Graduate-with-MPhil, in Medicine and Surgery (Public Madrid University Medicine School). Casesnoves studied always in public-educational institutions. Casesnoves resigned definitely to his original nationality in 2020 for ideological, and ethical-professional reasons. His constant service to International Scientific

Community and Estonian technological progress (2016-present) commenced in 1985 with publications in Medical Physics, with further specialization in optimization methods in 1997 at Finland—at the moment approximately 100 recognized publications with 50 DOI papers. His main branch is Computational-mathematical Nonlinear/Inverse Methods Optimization. Casesnoves best-achievements are the Numerical Reuleaux Method in dynamics and nonlinear-optimization [books 2019-2020], the Graphical and Interior Optimization Methods [2016-8], the new Computational Dissection-Anatomical Method, [2020] and invention of Forensic Robotics [2020-2021]. Dr Casesnoves scientific service since 2016 to the Free and Independent Republic of Estonia for technological development (and also at Riga technical University, Power Electrical and Electronics Department) is about 29 physics-engineering articles, two books series, and 1 industrial radiotherapy project associated to Europe Union EIT Health Program (Tartu University, 2017).

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X. APPENDICES

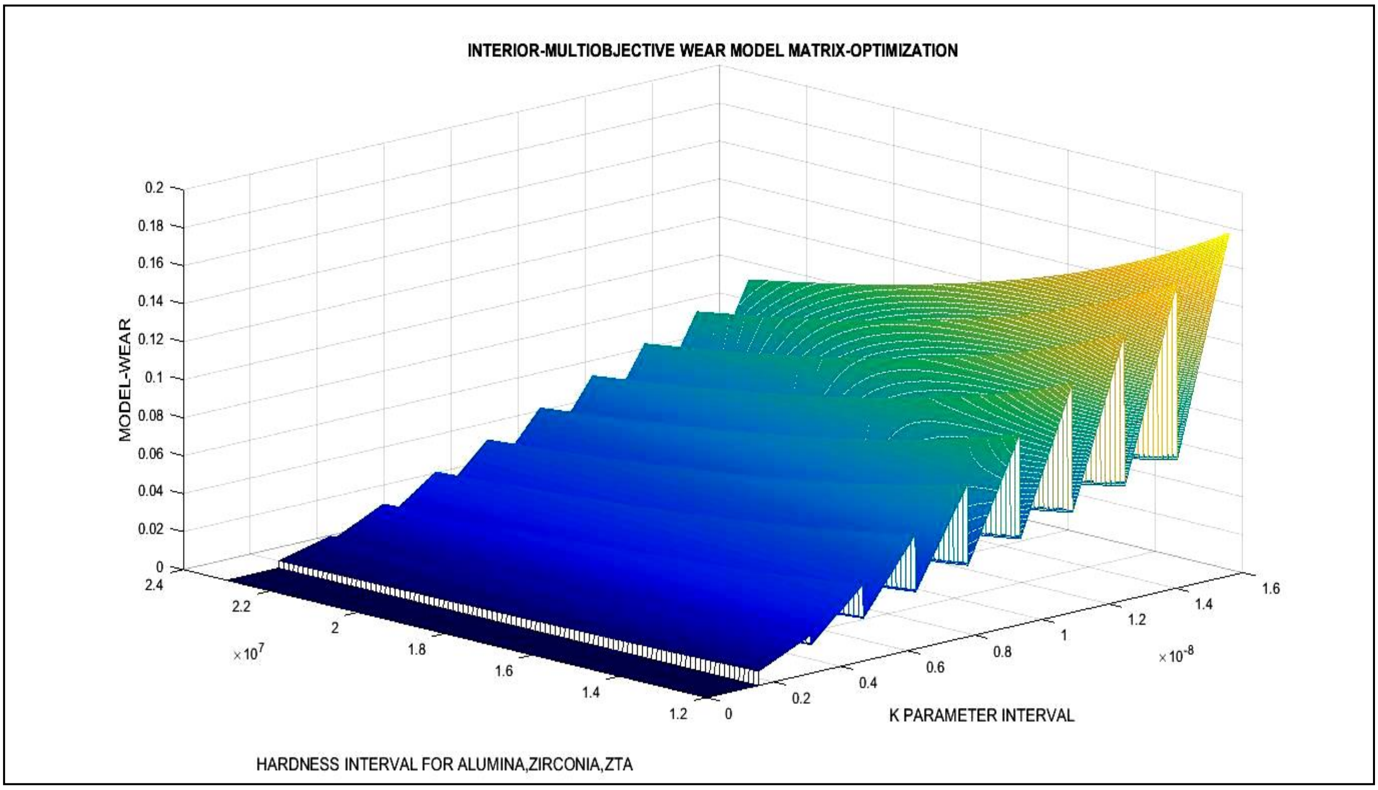

Figure 1. 3D Interior Optimization to validate the K parameter obtained in 2D Graphical Optimization. It is shown how the optimal K value is located around the middle of the surface. This place is visualized as the best for all the hardness interval.

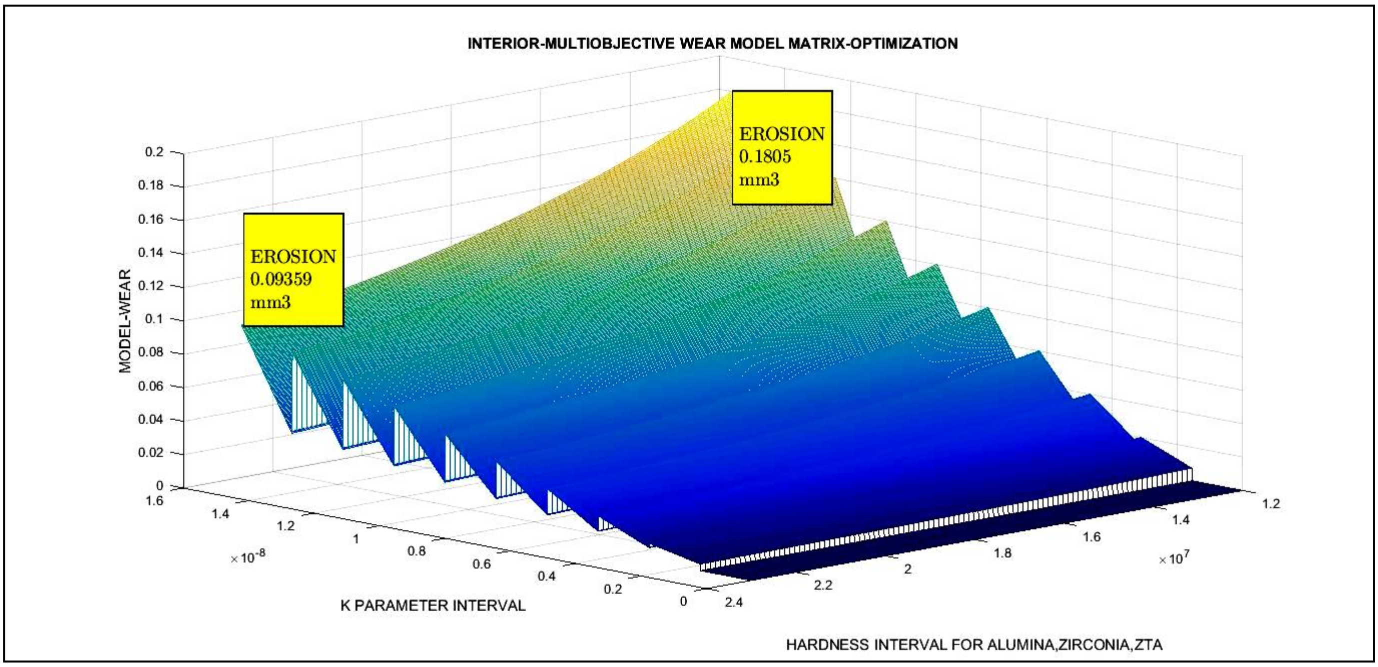

Figure 2. 3D Interior Multiobjective Optimization to prove with numbers in mm^3 that erosion is higher (0.1805 mm^3) when hardness is lower (0.09359 mm^3) and load is higher

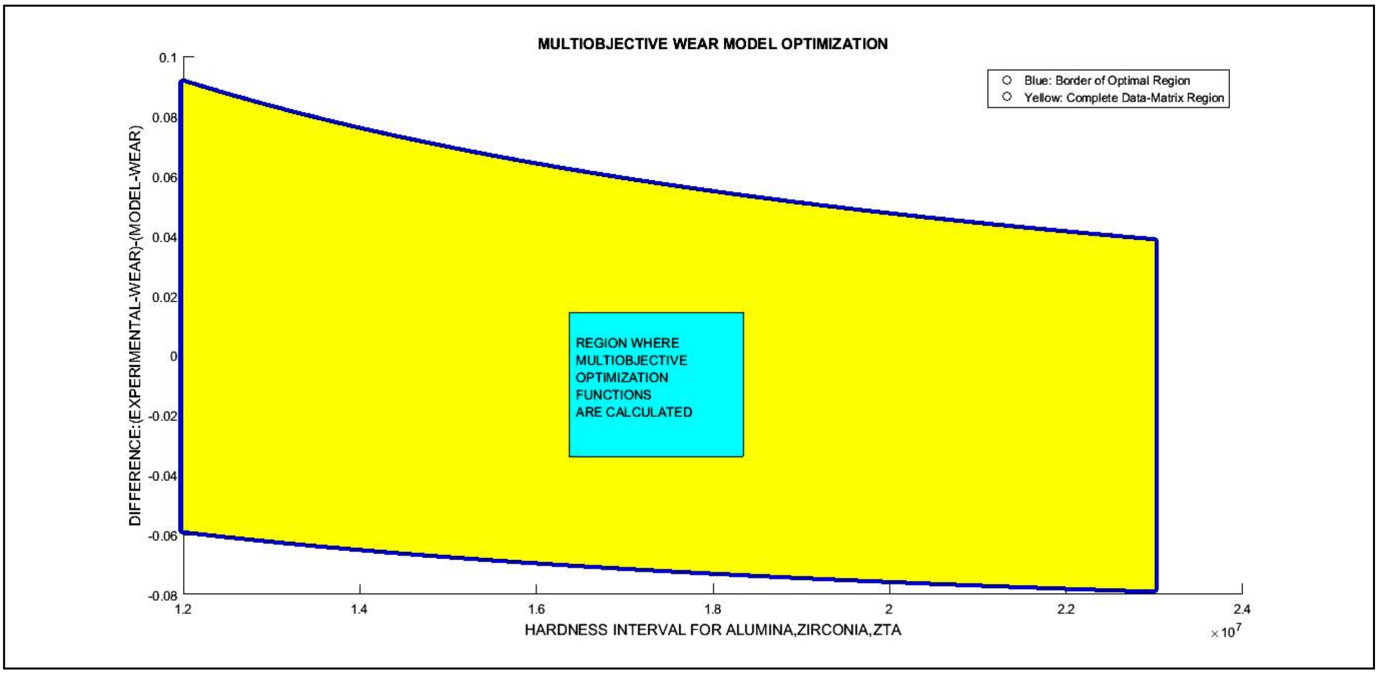

Figure 3. Enhanced chart of Figure 5 for better visualization of numerical regions

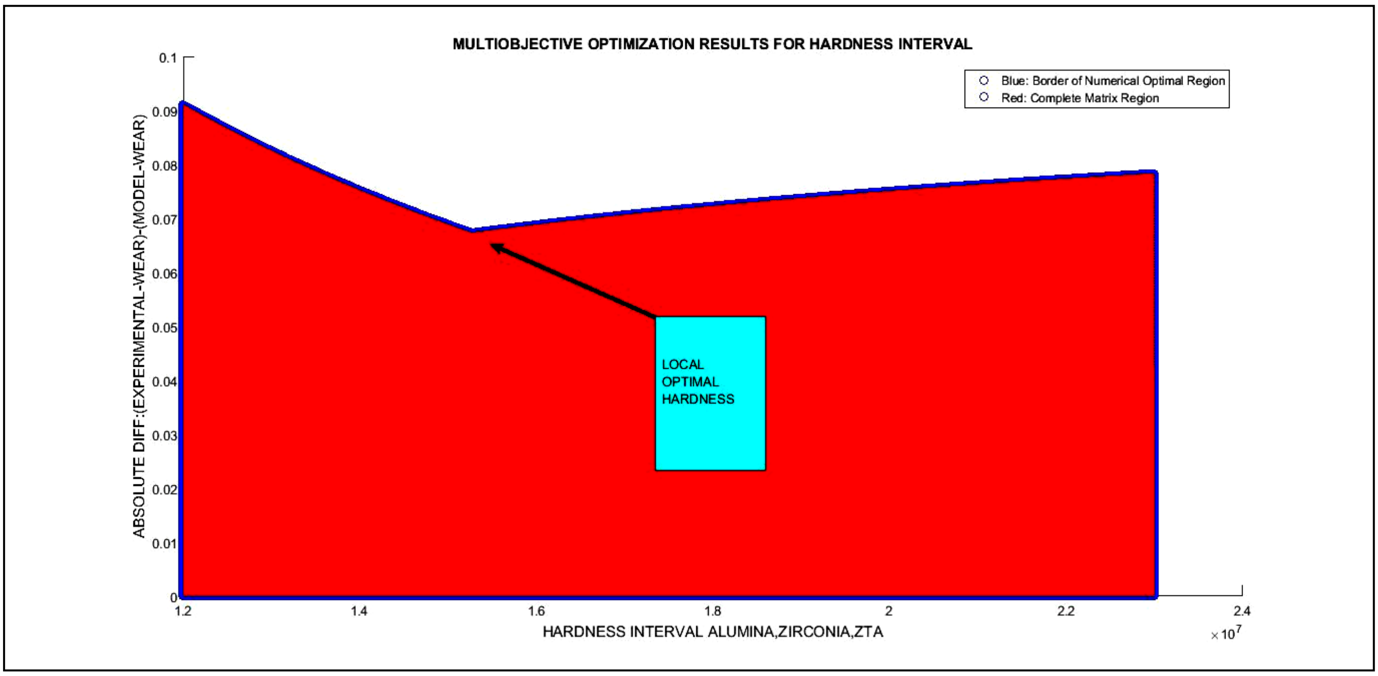

Figure 4. Enhanced chart of Figure 6 for better visualization of numerical regions