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Computational-Reumathological CAD Clinical Diagnosis with Lumbar Vertebral Cadaveric Specimens and Spine Sub-Units Mathematical-Biomechanical Modelling Part II

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Abstract

Based on previous studies, a reumathologically-directed clinical study with 3D-CAD imaging- processing techniques for new/different lumbar cadaveric specimens were obtained. The objective of the research is mainly focused on clinical detection of lumbar spine arthrosis findings and disk herniations. Along with a successive series of 3D-CAD lumbar vertebral images, the methodology is explained step by step as sharply as possible. Results show the proof that, from scanned cloud data of cadaveric specimens, a significant amount of clinical and diagnosis data can emerge and be extracted. Applications on computational-necropsia, computational-forensics, medical physics, and biomedical engineering are got from these cadaveric specimens imaging-processing systematic comparison. Therefore, reumathological-clinical applications for patient diagnosis and treatment are guessed. A brief of epidemiological/statistical is detailed. Moreover, a mathematical spine sub-unit model is briefed and explained.

Keywords: Computational anatomical dissection; Image processing; Software engineering; Surfactal programming; Computer aided design (CAD); Computer aided manufacturing (CAM); Anatomical cadaveric imaging simulations; Biomechanics; Bioengineering; Spinal computational surgery; Spinal ligaments; Spinal anterior longitudinal ligament (ALL); Low back pain (LBP)

Introduction and Objectives

This article part is divided into several sections. It is considered necessary to introduce/update recent concepts in LBP, and Lumbar Biomechanics and Surgical Pathology. Firstly, recent advances in spinal and lumbar spine biomechanics with statistics; Table 1; are introduced. Author's comments, concepts, and criteria are also presented. Secondly, a Biomechanical-mathematical model based on sub-units for lumbar spine is briefed; Figure 2. Finally, the objectives of the research are precisely pointed out. Spinal Biomechanics and Spinal-Pathology Recent Advances Lumbar spine bears a head-thorax-abdomen load of about 500 N during most lifetime: [1-3 mainly]. However, when any patient lifts a weight, the reaction forces of the disk could reach around 6.000 N [3]. The reason is that there is a rather high force produced by erector spinae [3]; and the bending moment also has an important biomechanical role. For this and other causes, such as biomechanical continuous movements dealing with high loads; trunk rotations; disk nutrition defaults; and recent increased times of postural and sedentarism at workplace; the spinal column degenerates far earlier than other musculoskeletal tissues [4-19]. In other words; the spine and lumbar and cervical spine biowear along life and caused by recent changes in life lifestyles; is higher than other biomechanical systems. The biomechanical load; despite the hard and resistant structure of vertebral bodies given by their natural optimal design; is so significant/constant that yearly prevalence of back pain (LBP) is estimated to range from 15% to 20% in the US and from 25% to 45% in Europe [4-20]. This implies that osteo-pathological lesions get a high probability to occur. However, the links among symptoms and objective lumbar osteo-lesions is rather random/individual [3,18]. For example, osteophites; spine deviations; scoliosis; and teenager spine deviations are radiologically diagnosed in routinary health checks, but the patient has not talked any subjective symptoms [18]. Namely the opposite; patients with painful indicators and for example sciatica ones; do not show in radiological or CT/MRI explorations objective lesion confirmations.

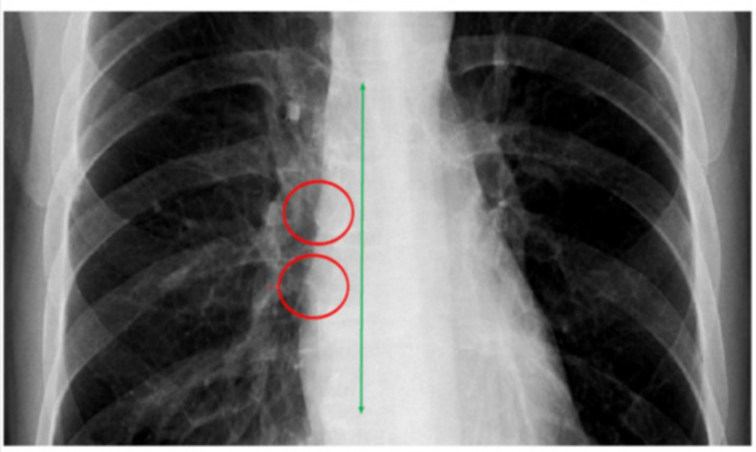

Figure 1: [2, Casesnoves-Bioengineering-Laboratory-Specimen-3.11]. Illustrative routinary RX thorax PA example that shows how early ostheophites of age-degeneration osteoarthritis can be detected during simple radiological explorations. At thoracic spine, two osteophites are clear (red circles) and thoracic spine alignment is slighty deviated (green arrow). Patient: male of 65 years old without any pathology. The image of ostepophites corresponds to a diffusive peak or elongation along the borders of vertebral plates. This ageing-normal alteration does not implies a significant pathology unless its size and surrounding structures/nerves are not pressed or damaged. This our laboratory specimen signs are also detailed by other authors, for example [15].

Table 1: Incidence and Prevalence of Lumbar Osteoarthritis and specially arthrosis lesions [24-36] with complementary explanations. Remark: all database from other authors is set as references numbers.

Brief of Lumbar Osteoarthritis-Arthrosis Related to this Study		
LUMBAR SPINAL DISORDER Patients with a spinal disorder whose etiology is unclear [3]	**DATABASE** ≈85%	**ADDITIONAL** [3]
Lifetime prevalence of LBP	≈ 75-85%	The lifetime prevalence for Irradiated leg pain seems to be about half that of back pain in general, and the lifetime prevalence of sciatic pain Is estimated to be much lower, approximately 3-5% [3].
Economical Social Cost	Most of studies coincide it Is in general high	Two main reasons: causes of work leave and hea1th Insurance diagnosis and treatment high cost. From (3): Work-<related disability from non-specific spinal disorders has become epidemic in industrialized countries.
From [10) Prevalence of Lumbar Spine Arthrosis	From [10): Facet arthrosis was present in 53% (L1-L2), CC% (L2-l3), 72% (L3-l.4), 79% (L4-l5). and 59% (l5-S1).	Remark: arthrosis is an exclusively degenerative disease with No etiological causes from immunology factors (Arthritis Rheumatoid), Infections, or metabolic (Uric Acid). Those are other types of Osteoarthritis.
From (10] Prevalence of Lumbar Spine Arthrosis by Age	From [10): coincidence with this cadaveric study results: facet arthrosis was present in 57% of 20- to 29-year-olds, 82% of 30- to 39-year-olds, 93% of 40- to 49-year-olds, 97% In 50- to 59-year-olds, and 100% in those older than 60 vears old.	Coincidence with this cadaveric study results in age segment older than 60 years old. Table 2.

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From (10): Overal Prevalence of Facet Arthrosis	Overall prevalence of facet arthrosis, age-Independent. For Age-dependent the results are the same.	This data matches in general other author's studies [3-15).
Prevalence of Face joint Arthrosis from (8)	Male 20% Female 80%	Lumbar spinal stenosis (LSS) and facet joint arthrosis (FJA) are important causes for low back pain.
Anatomical Lumbar Region Prevalence of facet joint arthrosis	From (8): The prevalence of FJA increases cranial-caudally from L1 to L5, and the highest incidence being at the L4-L5 Spinal level.	It is most important than FJA the arthrosis localized al vertebral bodies, facets and plates.

Table 2: Rheumathological-Diagnosis. The findings coincide with previous publications [3,8,10,11].

Results of 3d Computational CAD Lumbar Spine Necropsia Osteoarthritis Diagnosis Related to this Study		
Lumbar Spinal Disorder	**Database**	**Additional**
Arthrosis Signs	≈100% of vertebra specimen	Confirmation of extensive clinical database as [8,9,1OJ. Specially [10].
Vertebral Facets osteo- degeneration/deformation signs	≈75% of vertebra specimen	Confirmation of extensive clinical database as [8,9,1OJ. Specially r101.
Vertebral Facets endplates osteo-degeneration/deformation signs	≈80% of vertebra specimen	Matches (3] criteria.
Disk deformations and volume- degeneration	≈90% of vertebra specimen	There are disk herniation unprecise locations, were discarded for study results. Exclusively lateral and frontal deformation were included.
Vertebral bodies concavity alterations/lesions	≈90-100%	Very clear in all lumbar vertebras studied.
General Age-Related Changes	≈100%	Matches [10] author diagnosis.
Clear evidence of higher degeneration at L4-L5	Not clear compared to rest of segments.	Important to remark that the study is with one sample, statistics with large number of cadaveric samples affirm that fact.

The basic spine functional unit is formed by two subsequent vertebras united by the intervertebral disk; not vertebras and disks independently. This biomechanical model [16; Casesnoves-Bioengineering-Laboratory-Specimen-Model-4] is formed by two masses (vertebras) united by springs and a damper; better a hydraulic damper; at center; a very simple model with several degrees of freedom; Figure 2. The functional spine can biomechanically be resembled to the miosine and actine overlapping in the muscle fibers. Therefore, spine biodynamics is considered as a whole functional unit constituted by these subunits. The spine system; was developed and optimized by nature along millions of years; and it has a rather complicated biokinematics; biostatic; and biodynamics. Despite this extraordinary biomechanical system made by nature for humans and a large number of species; even fish; the functional task for its long-time survival in animals and humans copes a rather large pathological problems during the lifetime. All the thorax load and head-neck systems have to be stabilized and supported by spine and hip. Down to the hip; there is second also complicated biomechanical system whose more susceptible parts to suffer traumatological problems are the hip and knees; and have to support and balance that first biomechanical system load during the walk and run mainly.

For this number and other reason series; the spine prevalence and incidence of stability diseases; such as deviations; scoliosis; kyphosis; spondylolisthesis; and disk pathology among others which are not the least ones. All these biomechanical and traumatological reasons led/obliged both the surgical specialization and surgery prosthesis; instrumentation and orthopaedics industry to develop a large number of mechanical systems; super-specialized instrumentation and surgical-theatre techniques and surgical-robots during centuries. One important spinal geometrical 3D location is the Instantaneous Rotation Center of the disk and vertebras; that has a significant consequence for bending moment calculations and other important biomechanical parameters; or design of artificial disks and prostheses [19-21]. The more frequent statistical-epidemiological causes of LBP correspond to segment L4-L5. This is confirmed by series of publications in literature; for example [3,10,11]. Authors's criterion about biomedical/biomechanical reasons for this clinical and experimental evidence is;

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1 L4-L5 supports all trunk biomechanical load; therefore, the probability of disk herniation and vertebral disorders is higher. Loads at lumbar segments are around 500 N; and could create substantial deflection of the endplate (up to 0.5 mm) [this numerical data from 3; page 47].

2 L4-L5 form an important part for the spine-hip union; therefore, additional biomechanical forces during all any movement dynamics are added. Not only flexion-extension; but also, trunk rotations; lateral flexion-extension movements; etc;

3 Being the union between trunk and inferior walk biodynamics system; the Newton reactions forces during walk and running; standing up; or legs enforced movements; create an additional pressure over L4-L5 segment and its intervertebral disk.

4 Spine musculoskeletal system is not an isolated part of the body biomechanics. Its interaction with trunk muscles; such as erector spinae and spinal ligaments creates a rather complicated biodynamics system that implies difficulty to obtain both precise biomechanical models, calculations and simulations. Bending moments when lifting weights or normal flexion-extension movements also are significant factors.

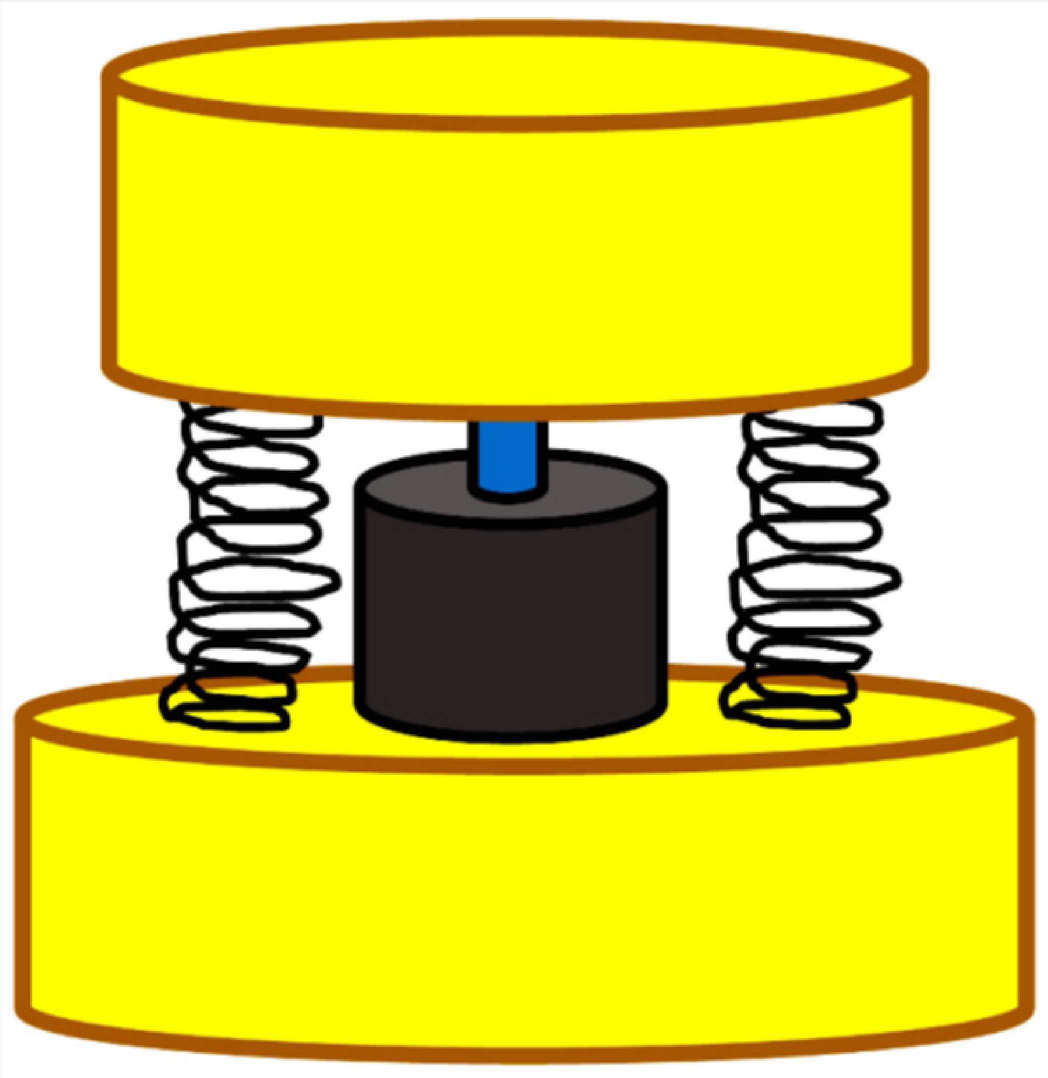

Figure 2: [16, Casesnoves-Bioengineering-Laboratory-Specimen-Model-4]. Simplification of Biomechanical-Concept of the lumbar vertebral-functional unit Casesnoves Model. It is formed by two

masses (vertebras) united by springs and a damper at center, better an hydraulic damper, which is a very simplified model sketch with several degrees of freedom. The extremes of damper have a semispherical mechanical articulation that can rotate around xyz axes. Damper corresponds to nucleus pulposus modelling, and the springs simulate the elastic fiber tissue of fibrous annulus. Springs could also simulate the most important ligaments, namely Anterior Longitudinal ligament, Posterior Longitudinal and Ligament Flavum. Equations system and Lagrangian has been developed by Author at Bioengineering Laboratory.

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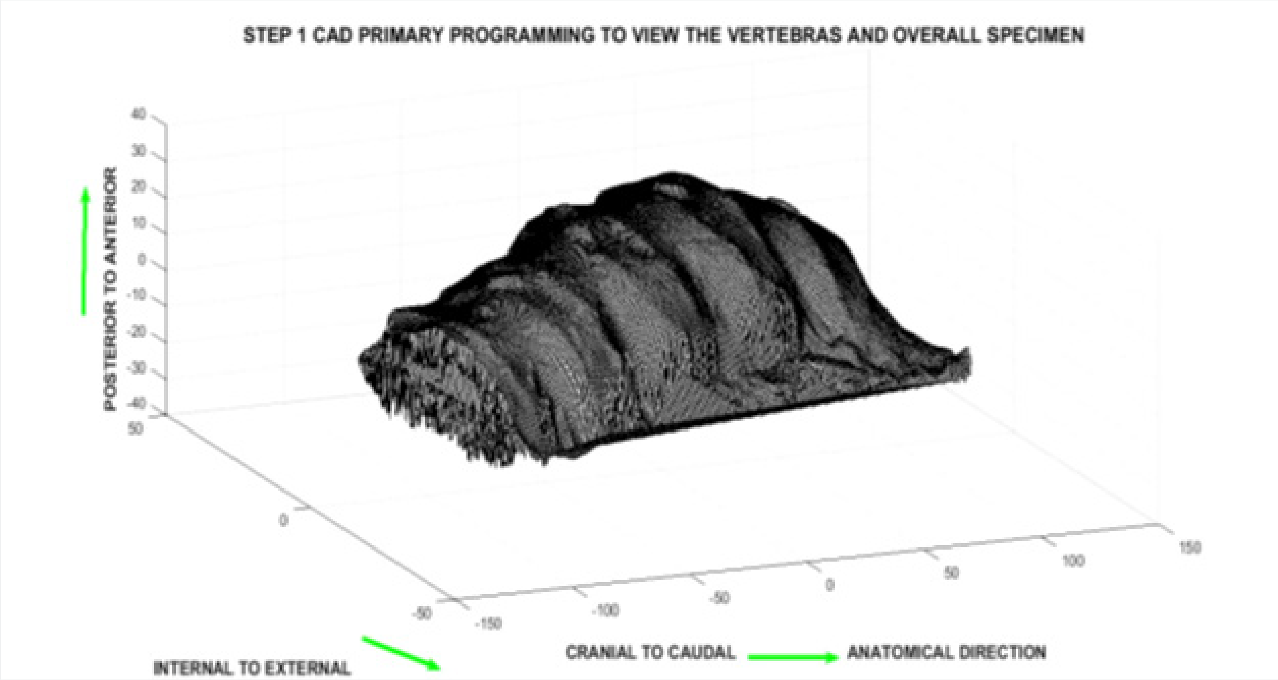
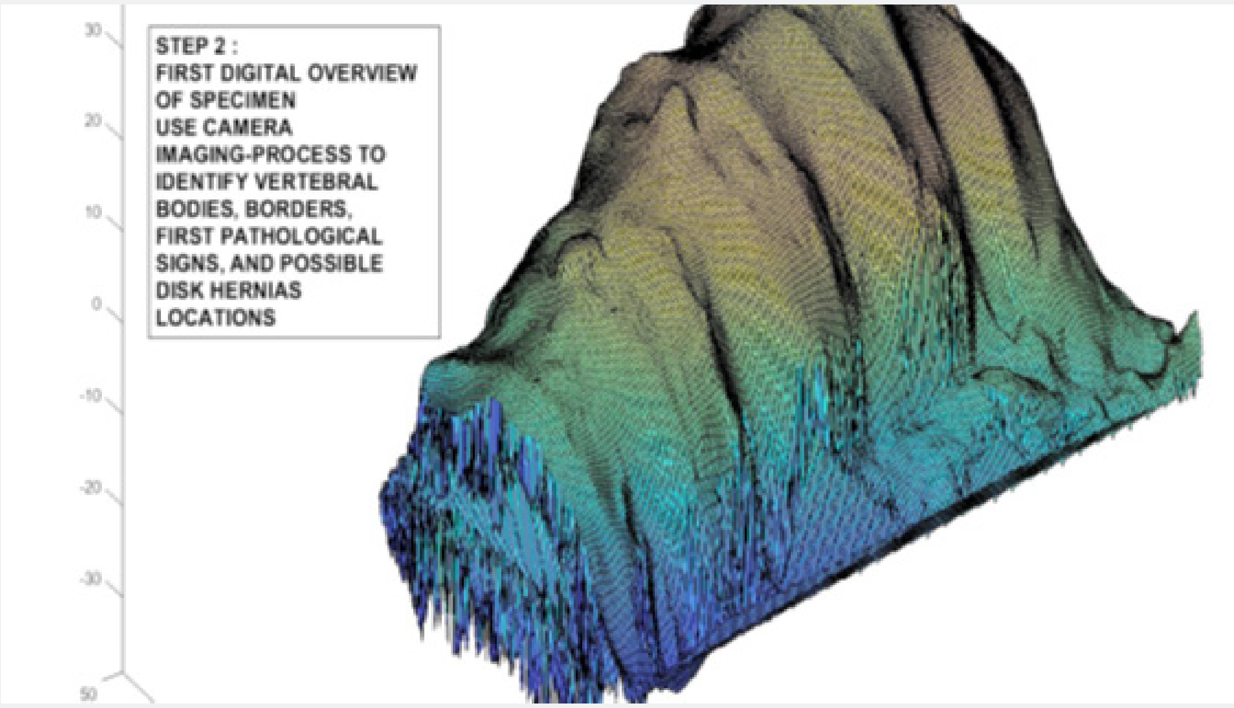


CAD Step 1: The cadaveric specimen general first view. Medial to lateral direction, cranial to caudal, and posterior to anterior are set. The image processing color is set simple in first overview. Vertebral bodies, disks, plates, and osteoarthritis signs. After that, it will be necessary to rotate the specimen searching the best vision angles and projections. The size of the image can be changed proportionally.



CAD Step 2: Pursuing a sharper/detailed image, the camera image-processing was applied. L2-4 anterior vertebral surfaces are relatively clear. It is necessary to adjust the image color and Delaunay tiles magnitude. The first diagnosis, for instance, for L2 can begin be guessed, there is an anterior clear osteoarthritis deformation at anterior-central vertebral facet.

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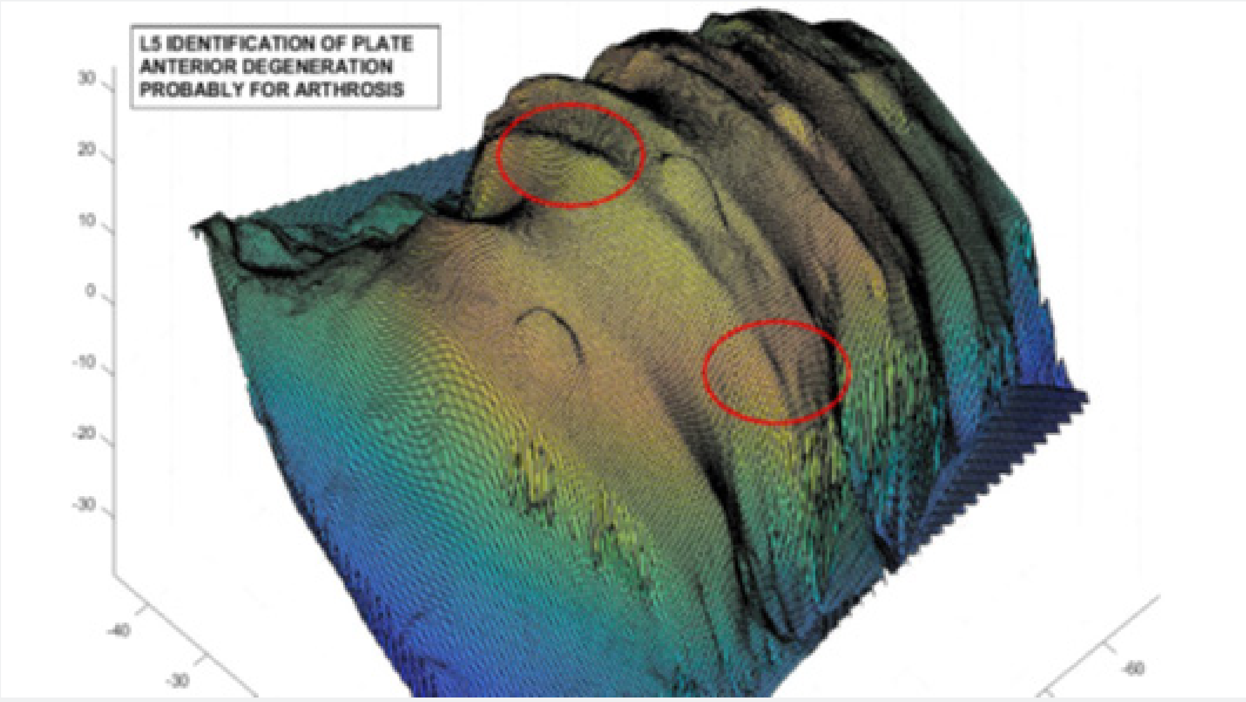
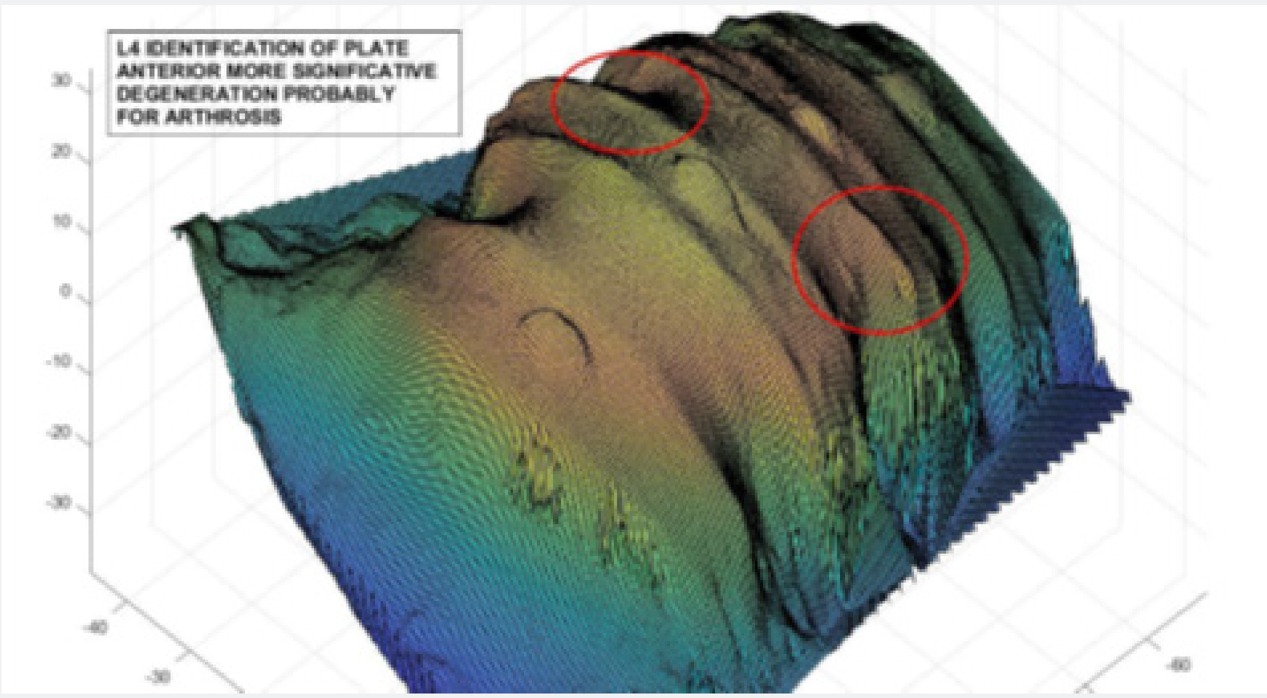


CAD Step 3: Camera findings at L5 anterior plate degeneration deformities. The same process has to be followed for all specimen vertebras and disks. Note that between both main findings the anterior border shows also degeneration signs. There are significant deformities at L4-L5 disk. It is necessary to rotate; select contrast through color choice and carefully examinate the different perspectives to reveal sharply the pathological findings.



CAD Step 4: Caudal and cranial border plates main deformities in L4 are marked and detected. The anterior herniations of the L5-S1 and L4-L5 disks could be anterior herniations; which are not frequents since usually the disk herniation ids posterior and creates pressure of nerve roots with acute pain and parethesias. The herniations could also correspond to effects of cadaveric specimen experimental work. In this specimen it is not possible to view the facet joints. Enhanced in Appendix.

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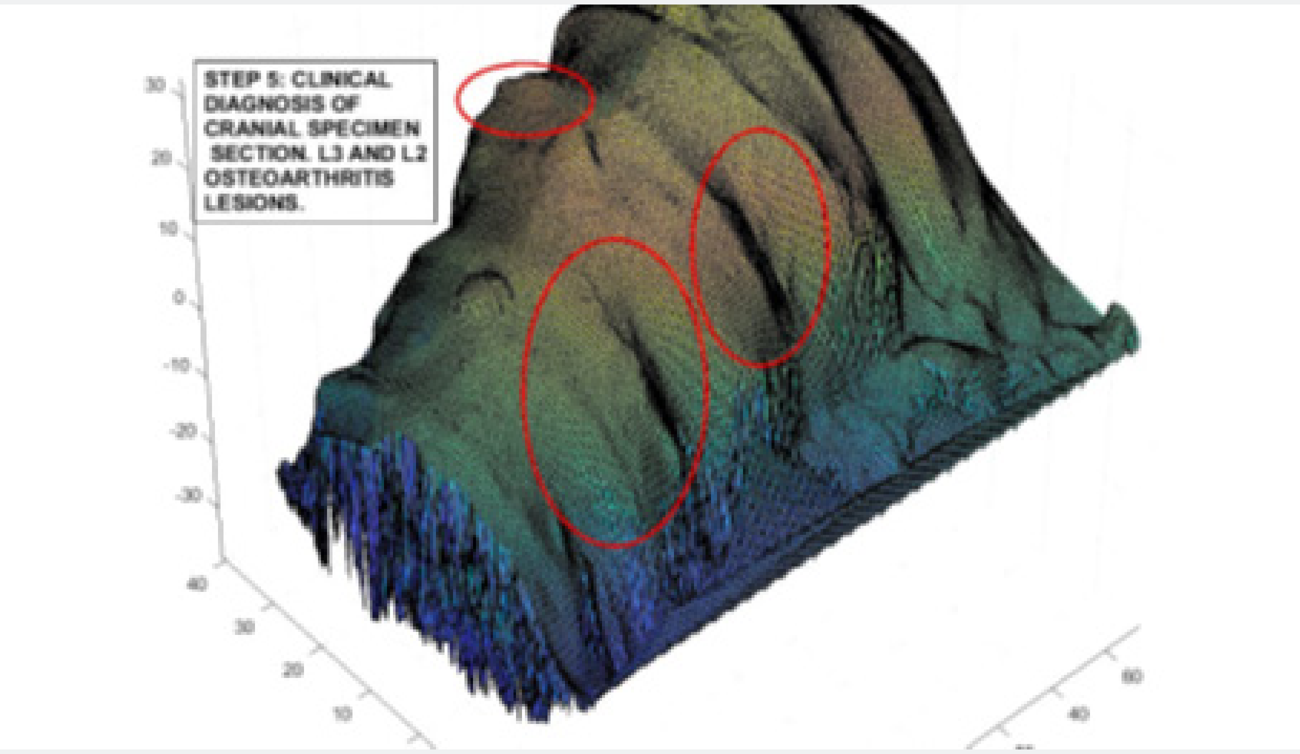
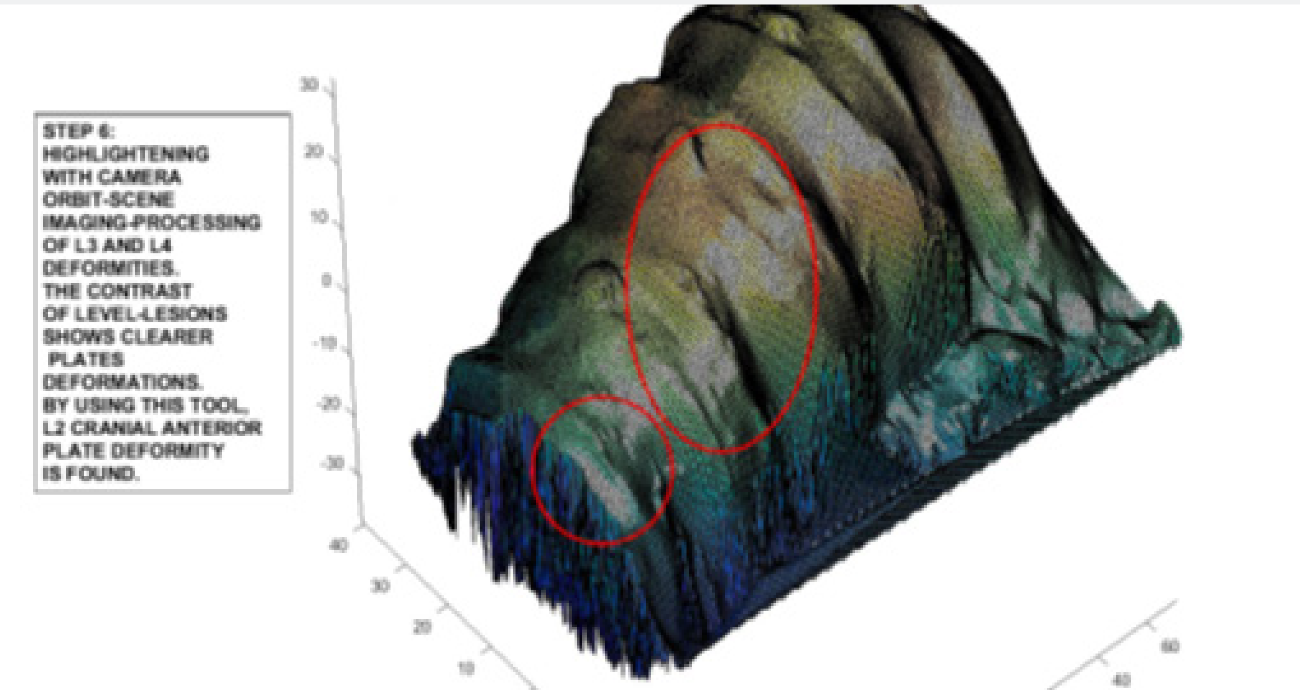


CAD Step 5: Camera tilt and rotation to get imaging-process of cranial specimen zone. Severe lesions at L3 vertebral body and plate borders. Deformities at right lateral part. A probable osteophyte detected for at the left lateral part of L4 vertebra. L2 vertebral body is well conserved. The general conservation of this specimen is acceptable.



CAD Step 6: Camera orbit-scene imaging highlighting process and tilt with rotation to get imaging- process of cranial specimen zone. Severe lesions at L3 vertebral body and plate borders. Deformities at right lateral part. L2 vertebral body is well conserved; but with orbit-scene a L2 cranial anterior deformity is diagnosed.

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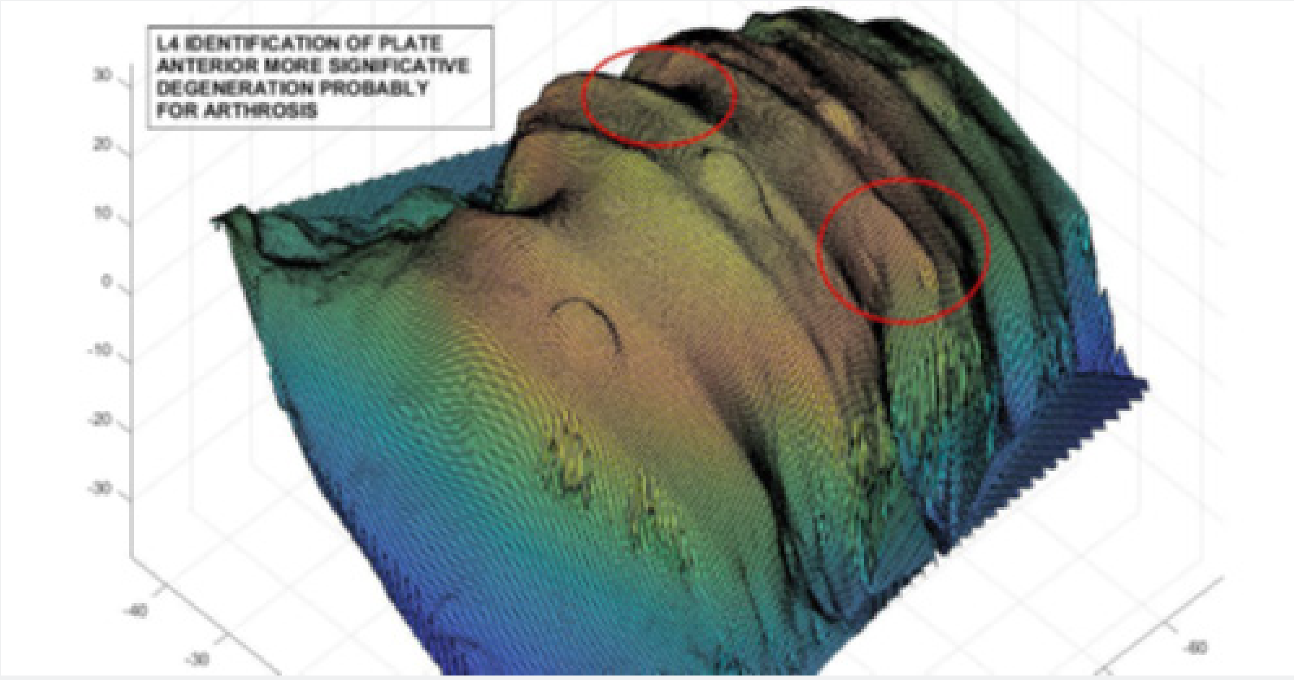

CAD Step 4 (enhanced): Caudal and cranial border plates main deformities in L4 are marked and detected. The anterior herniations of the L5-S1 and L4-L5 disks could be anterior herniations, which are not frequents since usually the disk herniation ids posterior and creates pressure of nerve roots with acute pain and parethesias. The herniations could also correspond to effects of cadaveric specimen experimental work. In this specimen it is not possible to view the facet joints.

Lumbar spine traumatological and neurological pathology is extensive; frequent; and varied [refs 1.8 mainly]. Figure 1 shows how osteoarthritis can be detected also in routinary checking explorations; [2; Casesnoves-Bioengineering-Laboratory-Specimen-311]. The objectives of this study are to explain and detail how CAD digital necropsy methods with new/different lumbar cadaveric specimens can extract reumathological signs, pathological evidence and epidemiological statistics. Mainly focused on epidemiological incidence/prevalence of osteoarthritis; disk degeneration; vertebral plates deformations; and lumbar spine curvature distortions. The emphasis is set on cloud-data scanning CAD and imaging-processing methods with clear explanations and sharp details; illustrated along a series of CAD images and camera graphics software-engineered with Matlab®. Images are designed to provide with a fast and precise understanding of digital specimens; and supply with emerging ideas for applications at other medical/surgical branches/specializations. Surfactal Computer Aided Design (CAD) and Computer Aided Manufacturing (CAM) methods have been integrated to modern biomedical research methods. The statistical study of vertebral shape; facets; ligaments; curvature; geometry at necropsia and during different stages of any disease or normal lifetime can supply imaging database for surgical pre-post-operative planning or instrumentation manufacturing. Besides, it is useful; as an objective of this study; for evaluation of incidence/prevalence of spinal disorders. CAD and CAM are widely used for design of orthopedics prostheses/apparatus [25,26]. For instance; new prostheses; spinal screws; stabilization kits; artificial intervertebral disks; grips; etc.

Concise Introduction of the Mathematical-Biomechanical Model of Spine Sub-Units [16; Casesnoves-Bioengineering-Laboratory- Specimen-Model-4].

This subsection shows biomechanical and mathematical details of the Sub-Units Spine Model and a basic sketch; Figure 2.

Objectives of the Research

The main objectives of this paper are two: firstly, present sharply the 3D CAD method to get clearer and more uncovering imaging-processing from lumbar vertebra cadaveric specimens. Secondly, obtain and make epidemiological statistical records for clinical, diagnosis; research; and biomedical industrial manufacturing applications. Additional part is constituting the presentation of the sub-unit spine biomechanical model from [16; Casesnoves-Bioengineering-Laboratory-Specimen-Model-4]; Figure 1. In brief; 3D imaging processing for a new cadaveric lumbar spine is shown; anatomically; statistically and epidemiologically

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diagnosed. The spine mathematical sub-units' model is presented and biomechanically explained [16; Casesnoves-Bioengineering-Laboratory-Specimen-Model-4].

Computational Methods and Cad Reumathological Diagnosis

This section is based on 3D image processing improvements from previous publications and diagnosis/exploration with clinical evaluation of pathological signs found in the specimen. It is developed in a 3D image-series steps with explanations and details about the imaging-processing tools that were implemented and their respective importance. Any individual and particular reumathological sign is marked properly [8-10,15].

Clinical Reumathological Results

The results of CAD analysis of specimen are detailed in Table 2. All vertebras and disks show reumathological alteration signs. The most frequent ones found is arthrosis and deformation of vertebral plates. Since specimen is cadaveric; the age-related changes are sharply evident. However; in previous publications; the vertebral anterior surface regions of interest (ROIs) were mathematically modeled with a hyperboloid equation and optimized with Inverse Least Squares methods [25,26].

Table 3: Brief of applications of the study.

BRIEF OF LUMBAR CLINICAL REUMATHOLOGICAL APPLICATIONS	
SPINAL SURGICAL PATHOLOGY FIELD	**APPLICATIONS DATABASE AND ADDITIONAL**
Lumbar Spinal CAD	All tools and prostheses optimal design
Lumbar Spinal CAM	All tools and prostheses optimal manufacturing design
Spine tools and surgical apparatus and prostheses	Spinal instrumentation, implants and deformity correction prostheses, implant-bone optimal interfaces instrumentation, all kind of screws, rods, grips, distractors, screw-insertion-angle optimization for a wide range of implants
Design of Precise Prostheses	All types of implants, artificial disks, clamps, stabilizers, etc
Orthopedics Applications	Spondylolisthesis, scoliosis, and another types of deformations orthopedics apparatus
Pre-operation Failure Probability Prediction and control	Pre-operation computational simulations/optimization, pre- operation design of implants or necessary new tools at theatre
Post-operation Failure Probability Prediction and Control	Complications prevention, post-operation tracking, imaging post- operation computational checking, design of necessary additional post-operation implants
Functional and Post Surgery Rehabilitation	Post-surgery orthopaedics rehabilitation for motion

Statistical Biomechanical and Epidemiology Applications

Biomedical and Bioengineering applications of three types of computational dissection can be divided into theoretical and practical. Theoretical comprise all computational software and database for Computer Aided Manufacturing (CAM) and/or CAD of any prostheses; implant; apparatus; orthopedic stabilizer; etc. Also, statistical data and CAD software for analysis of spinal pathologies-for example; incidence/prevalence of age-related spinal diseases evolution; statistics of elderly spinal diseases incidence; professional-risk of spinal damage; etc. Other types of practical applications are extensive and varied. Table 3 presents them; from surgical theatre tools manufacturing till implants; artificial disks; stabilizers; pediatric orthopedics; etc. Table 3 shows a complete synopsis of these biomedical applications. One important application is the CAM design of interfaces. Interfaces of surgical tools, implants; prostheses and orthopedic apparatus have to fit as much optimal as possible. This property avoids complications; malfunctionality; breaks; corrosion of interfaces; friction problems; wear of materials; histocompatibility immunological reactions; post-operative pain; and a wide of unpredictable complication possibilities.

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Discussion and Conclusion

The objectives of the study were the confirmation of necropsia-diagnosis of reumathological signs in lumbar cadaveric specimens with CAD computational methods. The second aim was to obtain verification of RX; MRI and CAT database pathological data published in literature [8,9]. Additional research was to show; for example, a biomechanical vertebral unit model developed recently; [16; Casesnoves-Bioengineering-Laboratory-Specimen-Model-4]; Figure 1. Further research-review included statistical; epidemiological; and incidence-prevalence data given by some recent publications [3-18]. It was included at introduction modern computational applications on current lumbar spine diagnosis; applications; and future investigation. Imaging processing methods for resolution in improved vertebral contrast/facets/positioning; vertebral- anatomical parts separation; visualization of lumbar spines; and different 3D imaging options available; are explained and proven. In clinical medical physics and computational anatomical pathology, these advances associated to improve previous imaging contributions and statistical data are demonstrated.

The 3D CAD Imaging-processing results show sharpness and acceptable clarity of anterior lumbar vertebras images. The improvements of this study have been the better use of camera vision and optimization of rotations; tilt; perspectives; and contrasts to get sharp verified diagnosis. Statistical results section; Table 2; show the reumathological diagnosis particularly oriented for lumbar arthrosis. A significant objective inconvenient of this method is that to get clear and precise images takes time. There are many 3D Imaging-processing tools to be selected to obtain the optimal picture. The software programmer's experience plays an important role in this task. Further conclusion is that the lumbar cadaveric specimens should be scanned at their complete anatomy for better studies. The cloud point data could be increased to improve the CAD 3D Imaging quality. In summary; selecting a new lumbar cadaveric specimen; and based on previous software advances; a study for reumathological arthrosis mainly was made. Computational 3D imaging-processing methods were explained/detailed step by step. Results comprise statistical data for L2-L5 in cadaveric necropsia and a brief of clinical utility applications in reumathology. The functional sub-unit biomechanical spine model was concisely described.

Scientific Ethics Standards

Additional Statistical Data are from authors at [2-18]. Model [16; Casesnoves-Bioengineering- Laboratory-Specimen-Model-4]; Figure 2; belongs to Casesnoves Intellectual property and Casesnoves Bioengineering Laboratory. Figure 1 RX image belongs to Casesnoves Bioengineering Laboratory; [2; Casesnoves-Bioengineering-Laboratory-Specimen-3.11]. This contribution is based on Graphical Visualization-Optimization methods for different clinical laboratory cadaveric specimens of lumbar spine; namely Specimen 10. 3D Imaging Computational Methods were created by Francisco Casesnoves from 2007-2019. Forensic Robotics Integrated Systems engineering-concepts were developed by Casesnoves in July 2020. 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 [38,39]. This research was completely done by the author; the software; calculations; images; mathematical propositions and statements; reference citations; and text is original for the authors. When anything is taken from a source; it is adequately recognized. Ideas from previous publications were emphasized due to a clarification aim; [38,39]. When a citation such as [Casesnoves; 'year'] is set; it is exclusively to clarify intellectual property at current times; without intention to brag. The article is exclusively scientific; without any commercial; institutional; academic; any religious; religious-similar; non-scientific theories; personal opinions; political ideas; or economical influences. When anything is taken from a source; it is adequately recognized. Ideas and some text expressions/sentences from previous publications were emphasized due to a clarification aim. Number of references is large to provide literature in open access for public health care institutions.

Appendix

CAD Step 4 (enhanced)

Caudal and cranial border plates main deformities in L4 are marked and detected. The anterior herniations of the L5-S1 and L4-L5 disks could be anterior herniations, which are not frequents since usually the disk herniation ids posterior and creates pressure of nerve roots with acute pain and parethesias. The herniations could also correspond to effects of cadaveric specimen experimental work. In this specimen it is not possible to view the facet joints.

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). He works as independent research scientist in computational-engineering/physics. Dr Casesnoves earned MSc-BSc, Physics/Applied-Mathematics (Public Eastern-Finland-University, MSc Thesis in Radiotherapy Treatment Planning Optimization, which was developed after graduation in a series of Radiation Therapy Optimization-Modelling publications [2007-present]). Dr Casesnoves earned Graduate-with-MPhil, in Medicine and Surgery [1983] (Madrid University Medicine School, MPhil in Radioprotection Low Energies Dosimetry [1985]). Casesnoves resigned definitely to his original nationality in 2020 for ideological reasons, anti-monarchy-corruption, democratic-republican ideology, and ethical-professional reasons,

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and does not belong to Spain Kingdom anymore. His constant service to the International Scientific Community and Estonia Republic technological progress involves about 80 articles, more than 100 total publications, and about 4 books. Recent advances published are in Superconductors Mathematical Modelling and Radiotherapy Brain Neurobiological Models, 3D-AI Isodosezones and Isodoselines. Among Dr Casesnoves inventions and scientific creations are:

Numerical Reuleaux Method

Radiotherapy Omega Factor correction for AAA model wedge filters dose delivery

Integral-Differential materials erosion model

Graphical Optimization

Interior Optimization

Superconductors Molecular Effect Model

Superconductors Multifunctional Transmission Line

BED radiotherapy model GA optimization

RT Isodoselines and Isodosezones

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