

Designing a prototype with elements of Virtual Behaviour, for interactive Biomechanics application

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Abstract

This project has the working title of Ortho Studio 3^d. It is an exploration into 3D computer graphics (CG) application and the design process to enhance the practice of biomechanics visually and interactively. In current biomedical practice, various high-end technologies, such as MRI, x-Ray, CT and 3D ultra sound are the means of image data capture. These technologies have been essential in imaging the internal human body. Although each individual has a unique skeletal structure, comparative relationships with static anthropometrics also exist. The study of biomechanics is extremely complex in terms of actual kinematics and is therefore difficult to communicate in its absolute diagnosis. 3D CG offers opportunity for presenting visuals and simulations of otherwise hidden objects, with a clear yet clinical approach. Such that both patients and practitioners can comprehend, demonstrate and interact with these human skeletal behaviours. This paper reports on the associated areas of data collation methods, 3D computer modelling, animation hierarchies with virtual behaviour and the design process towards a software package concept. A pre-prototype demonstration has been developed illustrating that a desktop data imaging method concept is viable, by controlling a customisable virtual skeleton (3D), from external body imagery (2D). It concludes that customisation of individual samples can be achieved effectively, and representation of associated biomechanics appear probable, within a virtual environment. Future research areas are identified as necessary for effective development of the concept.

Key indexing terms: Image mapping, 3D Computer Graphics, biomechanics, virtual behaviour, Controlled Animation.

1. Introduction

Health is one of the most important aspects in life. Well-being has been closely associated with healthy skeletal structure and associated dependants, by several practices within human science. Prior to 1969 only 2D radiographic analysis of the spine were performed [11] and until 1975 only one study of 3D analysis existed. Some comparisons with biomechanics and mechanical engineering exist, in particular the findings of Harrison D. D. [6,7]. Ortho Studio 3^d is the development of pre-prototype software, using 3d computer graphics, to assist in the diagnostics of rehabilitation science (In particular, but not exclusively Chiropractic science) and as a design process tool further exploring ergonomic relationship on product development. The current technologies used in internal body imaging are costly and require expertise in their operation and maintenance. These methods have been viewed by many, as unnatural within the diagnosis of rehabilitation science and have been subject to debate [17,18]. This paper will explore the use of less expensive methods, and more readily available equipment to create data at a reduced level of complexity, being more appropriate for a certain range or

stage of applications. It is not the intention to replace them entirely, but to reduce the reliance on them. The goal is to offer a desktop approach to skeletal imaging and patient communication.

Within Industrial design, the Bauhaus philosophy of “*form follows function*” is a well-practiced theory, based on engineering logic. However, the associated view that “*form explains function*” is an increasingly popular practice, which has helped inform this project. Currently in computer graphics, modification of a virtual 3D character is directly controlled by the animation bone structure within the 3D object. These modifications will update the external visual of the form respectively. Ortho Studio 3^d proposes to reverse this process. By recording an external form, using digital imagery, then mapping this to the 3D virtual character using key points, the internal CG skeletal structure will update accurately. With respect to the proposed Biomechanics application, essentially a 3D interactive x-ray transpires. This is a *significant new approach* offering opportunities to established low cost methods of computer art modeling and human body reprographic methods.

Accurate 3D modelling of a skeletal structure is required as the main 3D object, before applying animation. There are many available virtual skeletons to purchase online offering various qualities ranging from low resolution for games (Turbo-squid), medium to high polygon counts for animation and multimedia broadcast quality (Viewpoint and 3DModelworks) and even digitised laser scanning (VRML format) as described by Kappelman [15]. Within a commercial context, the BBC commissioned *Soho Red*, London, to present a one-minute long skeletal toddler sequence for a BBC iMAX film *The Human Body*, reviewed as "one of the most successful large-format productions ever made" [16]. This piece is particularly relevant as attention to detail in motion is highly evident. The skeletal kinematics were analysed and applied by using motion capture techniques, then applied as a visual layer over a movie sequence of the baby crawling. However there is no evidence that these are anything more than visually believable as opposed to offering realistic biomechanics. Many computer generated models available, do not have any record of quantifiable data in terms of ethnic origin or percentile range and could be from multiple sources. Some may be only use visual reference.

Micro Photonics can construct 3d geometry from numerous x-rays and cross-sectional data. [Skysan Micro-CT]. Similarly, University College London [3D Medical imaging Workstation] and Able Software corp. [3D-Doctor] developments rely on specialist imaging technology such as MRI, CT, and 3d ultra sound and Microscopy information for data extraction. Ventura Design, [*Posture pro V*] have developed a database and information CD-ROM using 3D CG as an illustrative feature, for chiropractics. Some elements of 2D interactivity exist in their products. Primal pictures publish an award winning product range of interactive CD ROM's such as interactive spine [interactive spine]. These are also accessible as an online resource [Anatomy TV]. The interaction offered in terms of 3D is limited to layered imagery with rotation and zoom control, which is suitable as textbook imagery replacement. Although these product developments have been successful, they do not address the Interactive 3D world of virtual biomechanics.

The hypothesis for this pre-prototype stage of research is to ascertain to what extent accuracy is achievable by controlling a customisable virtual skeleton (3D), from external body imagery (2D). The supplementary aim is to produce a pre-prototype to demonstrate biomechanics virtual

behaviour. To begin, data collation methods relating to biomechanics and anthropometrics for modelling and animation hierarchies were required.

2. Data collation

The initial stage of research involved data collation (personal details, x-Rays, orthographic digital images and body measurement) from three test samples allowing for error or vague data. Ultimately a single sample (a volunteer, 14%ile Male age 31) with an existing record of spinal maintenance, including radiography records created the template for the virtual skeleton, using the skeletal manikin for geometrical reference not apparent on the x-ray. Biomechanics key points were established (Fig. 1). These were analysed and compared against comparative anthropometrics data [12, 25] defining relative measurements (Fig. 2), profiling external body measurements. The second stage of Data collation uses a wider group of volunteers. The group includes 35 participants in total, Male and Female, aged between 5 to 65 years, from two general lifestyle sectors. Thoracic Kyphosis remains similar across age, gender and race [9]. The first an established patient group(23), the second an impact sports group (Rugby, 12). Group one, a random selection, have a history of treatment with varied spinal degradation, with full history of treatments recorded, they have a varied level of health and fitness. Group two have a good level of physical fitness. They experience body impacts that have effect on spinal alignment and growth. This group is important as results may show evidence of vertebral misalignment, which could affect normal biomechanics behaviour. All samples were asked to complete a lifestyle and medical history questionnaire. All volunteers received payment for their participation. The main key points were defined creating a final map for data collation and control points for the animation hierarchy, prioritised as primary, secondary and minor importance. The primary elements aligned along the main spinal column. Certain static anthropometrics data are identifiable as constant, and are directly transferable to the Key points. Dimensions from standing position were used, the ground level being the datum point. In relation to body space these can be visualised as orthographic views (Fig. 3). For the key points to be visible on x-ray and digital image, the sample had metal indicators attached. Provisionally, the x-ray samples are for comparative evaluation. They focus on the spinal structure only as this is the most complex and important structure in terms of motion. To reduce perspective distortion when

imaging, the sample was positioned as far away as possible and captured with a zoom lens (Flatter perspective). This is closer to the type of image created by radiography. A scale indicator placed on the background behind the subject supported quality control, required later when integrating the image into the modelling software

Key points	Priority	X-ray	Image
AC	Secondary	X	X
ASIS	Primary	X	X
Mastoid	Primary	X	X
Superior sternum	Secondary	X	X
Xiphoid	Secondary	X	X
Pubic sacrum	Primary	X	X
C07	Primary	X	X
T12	Primary	X	X
S01	Primary	X	X
Tibia	Minor		X
Wrist	Minor		X

Fig. 1 Key point locations

Ref no.	Description	Ref no.	Description
2	Stature	51	H to C07, sitting
6	Sitting Height (H)	54	AC-AC
23	Mastoid H, standing	58	AC H, standing
25	Mastoid to back of head	72	Trunk H-Sternum
26	Mastoid to top of head	83	H of S1, sitting
44	Mouth to top of head	84	ASIS-ASIS
50	H to C07, standing	227	Tibia H, standing

Fig. 2 Classification of relevant anthropometrics data

Motion capture was extracted from a single sample, (14%ile Male) at Musgrave Park Hospital GAIT laboratory. Appropriate clinical and everyday behavioural motions were performed. The data extraction includes digital video and c3d format, which is interpretable in KAYDARA FilmBox into 3DSMAX formats. Any obstruction of the markers can render the data unusable, therefore some minimal physical rigs and props were designed for specific behaviours, involving external objects, for example driving a car or carrying a rucksack (Fig 4.) Additional data such as centre of mass can be extracted through a force sensor system in the

floor. This information will be retained for future reference. These results are currently being processed.

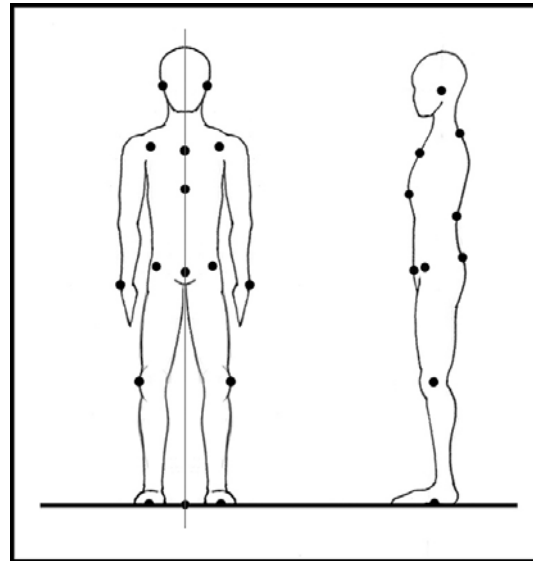


Fig. 3 key point positions



Fig 4. Motion capture examples

3. Virtual Behaviour

To create a 3D skeleton with Virtual behaviour attributes requires the skeletal structure itself. There are software programs available that can sculpt virtual forms extracted from numerous x-Ray and cross sectional data, described in the introduction of this paper. Therefore as a first response NURBS surfaces appeared to be an appropriate choice, however difficulties did occur. Visually complex wire frame structures and file size caused by intersecting forms and inclusion of voids were difficult to modify. The

surface quality had a rippled texture due to U loft orientation of sectional data. Patch modelling shared many of the problems associated with NURBS. Both methods were suitable for some of the limb structures but surfaces remained complex. Within the games industry, smoothed low polygon modelling has been successful addressing some of these issues. The newer Poly tools available in 3DSMAX 5.1 allow for greater control and less complex mathematical structures than in the past. Sub-level objects offer vast flexibility in terms of construction and editing forms both at local and object modification. NURMS is the smoothing effect on Low polygon structures within 3DSMAX, referred to as a method of NURBS modelling by some software producers. This reference is due to the visual quality of the mesh created. In the final solution, all objects in the virtual skeleton were NURMS generated. A series of Free Form Deformation (FFD) modifiers, with different lattice structure were used to fine tune proportion. The application of UVW texture mapping created visual realism. The model structure has symmetry about the origin, to represent an ideal skeletal structure. The end result produces a high resolution model of 221,322 polygons. The multi resolution modifier allows various combinations of lower polygon count for different applications.

The Animation hierarchy is based on specific biomechanics data and behaviour. To define these, discussion on the clinical biomechanics of the spine must be presented. The spine has three sectors, the Cervical (C/S), Thoracic (T/S) and Lumber (L,S) spines it also includes the sacrum, each with their own geometrical construction [8]. The general curvature of the spine makes an extended S form. Good alignment of body parts is determined by this structure and reduces muscle activity [19]. To achieve alignment the individual objects in the spine need to follow a certain profile, described in the work of Harrison et al. towards an “ideal spine” [8,9,10,11]. These objects are the vertebrae and associated discs. They each have unique behavior in terms of motion, independently these are illustrated in Fig. 5, modified from [4,5,13,20]. The ideal spine has alignment through the centres of C7, T12 and S1. In turn this S shape has apex curve points at C4/C5, T6/T7 and L3 referred to as the “Stress Vertebrae”[7]. This S shape is described in biomechanics as Lordosis (normally C/S and L/S) and Kyphosis (normally T/S and Sacrum). The spine as a whole can flex forward, extend backwards, rotate and flex laterally (Fig. 6). The first 50-60 degrees of spinal flexion occurs in the L/S, mainly in the lower motion segments. The T/S contributes little to Z movement of the total

spine because of construction, orientation and interaction with the Ribcage [1]. Each vertebrae can move mathematically speaking with six degrees of freedom (Fig. 7). Additional flexion of the spine is predominantly accomplished by forward tilting of the pelvis. In static equilibrium, where the feet are in fixed positions, the pelvis has only four degrees of freedom, ie. Pelvis cannot translate in Y or X. When walking or running the other two degrees of freedom are present. The Cartesian method of coordinates (X,Y,Z) is applied, this is an accepted method for Biomechanics data [11], even though the behavior is rotational in nature (U,V,W). It is also different to practice within the industrial design industry, in particular the experiences of the author as an automotive designer. (Z=vertical axis, typical engineering practice). The Cartesian method also shares logic in terms of screen-based interaction, which is appropriate in terms of the GUI. To represent the geometrical layout of the “ideal spine”, a modified visual integrating Harrison’s established [8] and modified findings [9,10,11] is presented in Fig 8. This integrates the Circular construction of the C/S with the Elliptical construction of the T/S and L/S. Additional static anthropometrics have been applied using the 50%ile Male statistics (Fig. 2)

Element	+/-Z	+/-X	Rot Y	T
C1				
C2-C3	8	10	9	
C3-C4	13	11	11	
C4-C5	12	11	12	C4-5
C5-C6	17	8	10	
C6-C7	16	7	9	
C7-T1	9	4	8	
T1-T2	4	6	9	
T2-T3	4	6	8	
T3-T4	4	6	8	
T4-T5	4	6	8	
T5-T6	4	6	8	
T6-T7	5	6	8	T6-7
T7-T8	6	6	8	
T8-T9	6	6	7	
T9-T10	6	6	4	
T10-T11	9	7	2	
T11-T12	12	9	2	
T12-L1	12	8	2	
L1-L2	12	6	2	
L2-L3	14	6	2	
L3-L4	15	8	2	L3
L4-L5	17	6	2	
L5-S1	20	3	5	S1

Fig 5. Limits of vertebral motion degrees (Modified by author)

Key	Direction
Flexion/extension	+/- Z
Lateral Flexion	+/- X
Rotation	Y Rot.
Terminators/ Stress Vertebrae	T

Fig. 6 limitations of motion -Cartesian system.

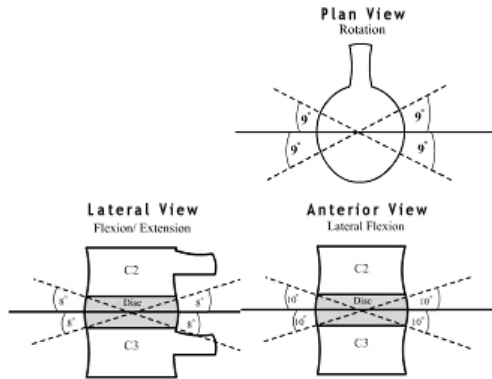


Fig. 7 Six degrees of directional motion

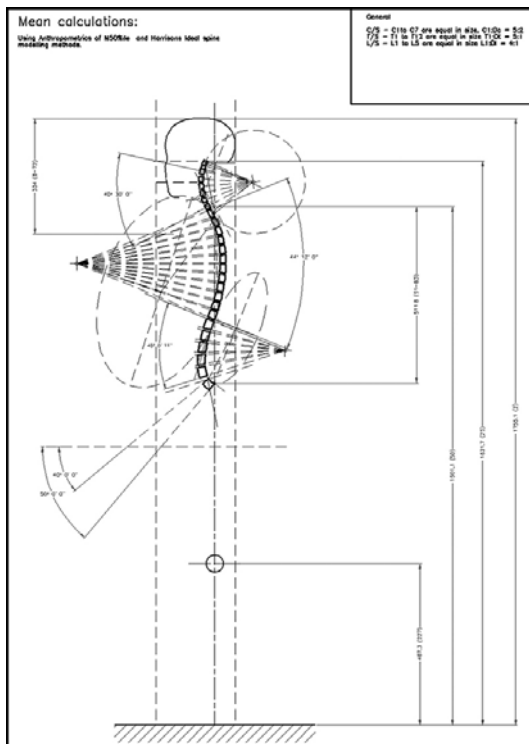


Fig. 8 Ideal spine, 50%ile anthropometrics data (Modified by Author)

The hierarchy of motion in the human skeleton was defined based on the previous biomechanics findings. The specific mathematical data was applied to the rig, forcing it to limit motion based on purely structural/ mechanical behaviour of the spine and for now excluding the other dependants and restraints (e.g. muscle tissue and

ligaments). There were different methods of kinematics tested including IK Splines, direct linking IK, soft and hard body modifiers within reactor and IK bone structures. Various combinations of dummy objects were used throughout. Applying this information into the animation rig, proposes that each object's pivot point is centred to itself, and aligned to the virtual world. The limbs have IK bone structures applied while all the other bones are directly linked, adjacently. The pelvis acts as the main terminator for the skeletal rig. All bones are linked to the Pelvis. The entire skeleton is linked together using IK within which, there are three main chains.

1. Foot>Lower leg>Upper leg> Pelvis
2. Hand>Lower arm>Upper arm>Clavicle>Scapula>Ribcage>Spine (C/S & T/S)>Pelvis
3. Mandible>Skull>C01(C/S) leading down spine to Pelvis

Limitations are set for each object in terms of rotation, translation and lateral flexion. For the limbs a restriction of Y=0 outlines the direction of bending. Z restriction limits rotation about the joint. The spine is much more complex. All vertebrae including discs from C1 - L5+ S1 are direct linked, adjacent objects terminating at the Pelvis. The spinal column has additional minor terminators (Fig. 5), which represent the stress vertebrae (apex of the spinal curve) [8].

4. Testing image mapping Concept

The hypothesis asked the question; What extent accuracy is achievable by controlling a customisable virtual skeleton (3D), from external body imagery (2D). To explore the proof of concept, simulation within 3DSMAX 5.1 was chosen as an appropriate test bed to compare modifications to the virtual spine for a series of individual cases. The virtual skeleton was scaled based on the key point data sheet measurements. Then Images of the relative samples were applied as UVW Planar maps to a simple plane (Plane 1) with the same aspect ratio as the images, to prevent distortion. Then the image plane was scaled using helpers, to accurately match the virtual skeleton (Scaling feasibility). In the front viewport the key points on the virtual skeleton were aligned to match the X,Y positions on the image plane using the ASIS and AC key points along with S1, C7 and mastoid to define the Pelvic, Thoracic and Cervical translations (Lateral flexion). This was repeated for the other orthographic views in terms of Z positioning. The lateral view controlled the Flexion extensions and rotations of the upper body

permutations for each sample. S1 acted as the main datum point. In order to validate the accuracy of the 2D to 3D imaging process, x-Rays were used for comparison against the updated Virtual Spine as methodology. The x-Rays were hand traced as a series of spinal line drawings, a method used by Chiropractic Bio Physics [21] for extracting data from radiographic samples. Scanned images of these drawings were then mapped to Plane 2, using the same process of scaling as before. Linear dimensions (millimetres) of the offsets were recorded on the orthographic views (Accuracy observation) and a percentage of error calculated. Spine drawings from printouts of the virtual spine, were also created. Harrison's Posterior Tangent (HPT) method [22] was applied to both the virtual and real spinal line drawings, to measure comparative coupling inconsistencies. Seven samples have been tested to date identifying some issues. A number of x-Rays are unclear which make analysis difficult, in particular the T/S, which is obstructed by the ribcage and internal organs. The HPT method showed some results with unexpected variant comparing the x-Ray to the Virtual Spine. These results were large, although the previous linear dimensional results were generally quite small and the comparative profiles closely approximated. At closer analysis it was discovered that the optimal spine HPT angles were inaccurate on the Virtual spine. This error occurred when first generating the Virtual spine profile. The virtual profile is correct along the pivot points of all vertebrae, as are the independent kinematics controllers for each, although the angular position of the vertebrae are not representative of the optimal spine. They adopt the values of the initial 14%ile M sample, used for modelling. Testing is therefore not conclusive at this stage, but has been very positive as an evaluation. New tests have begun.

5. The visual pre-prototype

The hypothesis stated that the supplementary aim is to produce a pre-prototype to demonstrate biomechanics virtual behaviour. Ortho Studio offers completely new functionality towards diagnosis within biomechanics. The interface has a unique aesthetic designed around its unique functionality. Consistency was a key issue. The end user would be a medical practitioner or educator, with an audience of patients or students. It needed to be logical, informative, formal, yet friendly in function and appearance - based on user-centred design. The structure of the interface follows standard format illustrated in the block diagram Fig. 9. The system

developed uses a simple 3-stage approach, for navigation between tasks. Each stage deals with distinct information, all of which can be controlled by the control panel. A task analysis of these activities is included in Appendix 1. The Menu bar has the functions of File, Edit, View, Tools and Help. All the functions of the software can be controlled from the menu bar as well as the control panel, if desired. The Stages include

Set up- This involves creating a new file, opening existing files, adding general patent details including measurements and importing relevant orthographic imagery.

Data input- This stage allows the user to align all the key points to match the images. These can be edited and removed if required. This process is continued for all 4 views. Front, Back, Left and Right. A pop up window is also available for additional lifestyle information at this stage. This is a file customising stage for each patent.

Diagnosis- This stage allows the user to generate a 3D virtual model representative of the patent on screen (Fig. 10). There are new controls available at this stage including animation control, motion capture upload, comparative ideal spine demonstration, interactive control of Key points and predictive diagnosis charts.

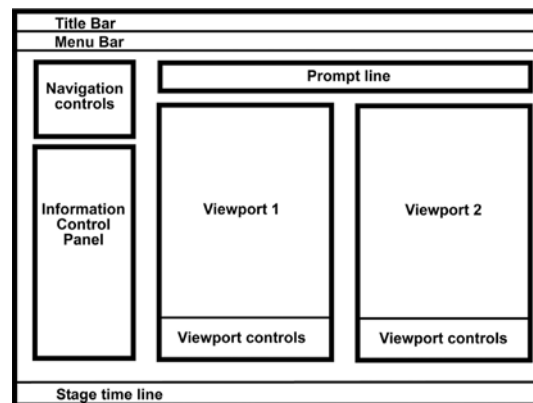


Fig. 9 GUI layout

The title bar describes the product type and release version. The menu includes the functions of File, Edit, View, Tools and Help. The Navigation control panel is the stage selector of the programme, while the information control panel changes to match the functions of the stages. The Stage time line offers feedback on completion progress and the prompt line assists the user through the tasks. The viewports are for viewing imported images or interactive Virtual data. The viewport controls offer interaction with, or control of the viewport content.

McDonagh-Philip and Lebbon state that “*user centred design is more than just function*” and go on to say that the emotional domain exists. This is “*the emotional relationship with the product and the user*”[23] further defined as the “*soft functions*” of the product. As Ortho Studio is customisable for each new sample, it should reflect this- the user should feel that it is personal to them. As absurd as it may seem, it was also important in terms of function that the interface looked good. Norman discusses the emotional domain further with a title “*Attractive things work better*”[24]. He refers to emotion as being “*affect*” and explains that it “*regulates how we solve problems and perform tasks*”. He also explains that there are neurochemical reasons for this fact, which changes the way we perceive, decide and react. These discussions yet again promote how “*form explains function*”, and have been applied throughout the interface development.



Fig. 10 GUI design at Stage 3

6. Relation to other work

This paper discusses a body of work that is unique to other systems and research in the field discussed in section 1, specifically in its approach to Virtual Behaviour and customisation concepts. It includes interactive 3D geometry that is intelligent with respect to biomechanics motion, an extremely well researched area that is still in the process of rationalisation. Posture Pro V, has some level of 2D customisation to demonstrate the alignment of general anatomical structure of a sample, although Ortho Studio goes further. It is customisable to demonstrate 3D alignments creating a 3D virtual x-Ray that is interactive in a very detailed way. Some of the practical results of the research will be useful in the form of supplying an interactive manikin as support for existing or new biomechanics literature.

7. Conclusions for future work

The current Demo exists as a simulation, with testing performed within 3DSMAX utilising its animation engines. External advice on Programming elements required to produce Ortho Studio software as a stand alone package as well as some evaluative recommendations are currently being formally reported. Mindmakers.org [mindmakers] have discussed possibilities based on their Psyclone, blackboard server product for multi module and multi-agent systems. Both sets of feedback suggest development possibilities exist within 3DSMAX using its SDK (C++ based) to create a module plug-in.

Ortho Studio also proposes a future development of predictive analysis. This is a diagnostic tool concept based on the research findings of leading Biomechanics experts (Section 3. Virtual behaviour). It will predict the effect over time of specific lifestyle routines on the individual structure and suggest possible avenues for treatment. The questionnaire information extracted as part of data collation would have additional value at this stage as part of a database facility.

During data collation certain quality control issues were subject to debate. These were mainly in relation to lens distortion in the imaging process, dimensional distortion in radiography and human error or inaccuracy in the measuring process. Calculating the Mean of multiple samples is standard mathematical practice for attaining acceptable averages, this is also the practice for Biomechanics. All of these methods have an accepted level of tolerance build up, or distortion. Therefore, dimensional accuracy is not completely achievable. Additionally the skeleton is a living and growing structure. Vertebrae change form in their attempt to correct load bearing caused by deformation, disease or body mass fluctuation. The effects of everyday behaviour and gravity also cause a change in the curvature from morning to night. [Schukra]. Applying static anthropometrics measurements to the virtual skeleton introduced a consistent control measure for each unique sample. Therefore, it can be concluded that, in relation to existing data collection methods for anthropometrics and biomechanics, it is possible to create a suitably accurate 3d computer representation of the human structure, by construction. Tests on the accuracy of the 2D to 3D imaging method have begun. This process has been evaluated and refined and is ongoing.

The animation rig has been a success in terms of its motion behaviour. However, the animation

outcomes are partially interpretable at present. This is because the actual behavioural motion of the spine is more complex than pure kinematics limitations. Frankel et Al. suggests “*The range of motion differs at various levels of the spine, depending on the orientation of the facets of the inter-vertebral joints at each level. The motion between 2 vertebrae is small and does not occur independently. Spinal movements are always a combined action of several segments.*” [1], furthermore “*Segmental motion cannot be measured clinically. Any motion of the spine is a combined action of several motion segments.*” Although very satisfactory the application of cluster vertebrae motion behaviour, including muscle and ligament influences are recommended for future research. The more detailed information on complex spinal coupling described by Harrison [11] needs to be tested.

This paper has only assessed the male structure in any depth. Although similar to the female structure and with comparative spinal information, some differential values in terms of static anthropometrics exist, which also vary culturally. A key example is the pelvis. The kinematics motion is also subtly different. These elements are proposed as logical and essential next stages of investigation. A secondary stage of data collation, already begun will be ongoing to assist with further testing and database information generation, associated with the predictive analysis.

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6. 3D doctor - <http://www.ablesw.com/3d-doctor/3ddoctor.html>
7. Posture pro - <http://www.posturepro.com>
8. Interactive spine – <http://www.primalpictures.com>
9. Anatomy TV – <http://www.anatomy.tv>
10. Schukra – http://www.schukra.com/rd_lumber1_pr.html
11. Mindmakers- <http://www.mindmakers.org>

Appendix 1.

Diagram illustrating the functions of Stages 1,2 and 3 of the interface.

Flowchart : OrthoStudio : Interface

