Relationships Between Rigs and Humanoid and Coveroid Landmarks

William GLASCOE *[1], Katy SCHILDMEYER [2], Emma SCOTT [3],
Simeon GILL [4], Alfredo BALLESTER [5], Carol MCDONALD [6]
[1] Web3D Consortium, Burtonsville MD, USA;
[2] KS Apparel Design & Consulting, Salt Lake City UT, USA;
[3] Fashion Should Empower Research Group, Victoria BC, Canada;
[4] The University of Manchester, Manchester, England, UK;
[5] Instituto de Biomecánica de Valencia, Universitat Politècnica de València, Spain;
[6] Gneiss Concept, Washougal WA, USA

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Abstract

3D body scanning, 3D body photography, and motion capture systems, along with Coveroid creation and ideation tools still have significant interoperability gaps and user interface shortfalls. As much as consumers want to trust virtual try-on platforms, and brands want a return on investment of 3d tools via industry key performance indicators like fit-related returns, the trade-offs brands made in repurposing creation tools from the gaming industry remain insufficient for designing Coveroids (virtual apparel or garments) to fit Humanoids (avatars) of consumers. Currently, mesh construction is a painstaking process, involving joint hierarchy definition, binding of mesh vertices to joint centers, and application of weights to each joint. Apparel landmarks are equally as challenging, with many landmarks located on soft tissues that slide over the underlying skeleton and bony references moved by the Coveroid and/or body movement. The most appropriate positions to associate with vertebrae and spinal sections (Cervicale, Thoracic, Lumbar, Sacral) for the rigged model are of discussion.

Keywords: Humanoid, Coveroid, rig, landmarking, rigging, digital skeleton, 3D mesh, avatar, body scan

1. Introduction

Rigged Humanoids 1) enable interactive animation and near real-time simulation, 2) drive 3D digital product creation and 3) support consumers' purchase decisions by virtual try-on experiences.

The apparel industry wants to scale its virtual product collections. The 3D photography, scanning, and motion capture systems are capable of acquiring the data necessary for authoring Humanoids in digital product creation for people. However, those interrelated 3D tools, the creation process, and support services are not well-integrated to effectuate scaling a virtual collection to the size of many physical collections as noted by Harrop [1]. Research to automate weighting and binding of the Humanoid mesh vertices to their joint centers, the proper mesh or skin deformation during animation, the appropriate Coveroid soft physics modeling and deep learning modeling continues.

This paper examines modeling Humanoids only from an animation perspective, then mapping Humanoids to Coveroids and linking of the two perspectives. It also studies the relationships between landmarks used for designing apparel and those used for rigging Humanoids. From there, the authors consider that the modeling of Coveroids is possible with the Coveroid interacting with the Humanoid model appropriately. From a product development perspective, cross- platform interoperability will be essential.

2. Modeling Humanoids, animation

We will explain how current mesh construction, a painstaking process involving joint hierarchy definition, connection of mesh to joints, and application of weights to each joint, and highly dependent on very specific user knowledge. This illustrates the challenges, of scaling, automation, and constructing of Humanoids for the expected market growth in Coveroids so that billions of users can perceive a realistic Humanoid and Coveroid animation on personal computing devices. This is key to enabling technology to be employed effectively in addressing realistic virtual apparel fitting.

*William Glascoe – eosocxo@comcast.net

Modeling a Humanoid for animation results in a rig which is composed of joints and segments (bones or segments). The Humanoid skin is usually represented as a watertight mesh of vertices. The mesh can be annotated with landmarks, measurements, and displacement of the landmarks. The deformation of the skin is very important to be modeled properly. Since every segment of the body is connected to the spine (where the root or parent bone is usually located), the modeling of the spinal column using vertebrae joints will be the focus of the examples shown in this paper. To have the appropriate spinal column modeling is useful for product design of wearables, from garments to shoes with the classifications of *Covers* with their representations are classed as *Coveroids*. Also**,** the adequate modelling of the spine curvatures and hip rotations, if modeled correctly can address the asymmetry we see in an aging population that also needs clothing and suitable Humanoid / Coveroid relationships. The separation into the different spinal sections (Cervical, Thoracic, Lumbar and Sacral) is important as each section has a unique spine shape facilitating different forms of movement [2] which is explained accessibly in [3]. A more complete spine allows for better action modeling with regards to animations and structure. Bones that are typically referred to as joints in 3d animation are referred to as both in the paper. This is due to the association with the actual human skeleton.

There are animation methods with HAnim v2 tied to ISO 19774-1:2019 [4]. Various software tools have rigging or auto-rigging capabilities, but interoperability can be an issue as the rig is irreversibility transformed. Popular software include: Blender, Maya, CLO, Browzwear, Mixamo, digidoppel, Maxon, DAZ, CC4, Unity, and Unreal Engine. These software do neither utilize common architecture for Humanoid rigs nor animation methods. Table 1 lists some differences and similarities between the Humanoid rigging and animation methods with examples shown in Figures 1 through 6. Methods that are animating the Humanoid mesh focused on mesh surface tracking of the Humanoid and camera, and connecting with bone locations, are not explored in this paper.

Table 1: Humanoid Animation Method

Software System or Standard	Humanoid Animation factors	Coveroid Compatibles
ISO/IEC 19774-1 HAnim v2 [4]	Joints, joint centers, segments (bones), keyframe animation	Yes
Stitched Puppet (SP) [5]	Body segments stitched together	Not mentioned
Methods based on ISB conventions [6,7,8]	Anatomical references on body surface, joint center location, hierarchy of joints (kinematic chains), conventions of axes and orientation, physiological degrees of freedom and motion ranges based on International Society of Biomechanics (ISB) conventions	Not mentioned
OSSO system [9]	Dual energy X-ray Absorptiometry (DXA) images and regressors	Not mentioned
Graphical Body Model [5]	Geometric primitives	No
Blend Shape on CMU skeleton [10]	Joints, bones with identity shapes and customization of body shape from silhouette	Yes
Tracked Body in Unity [11]	Body segments with default body rig	Yes
Mixamo [12]	Humanoid form in set position required for auto-rig	Yes
MDD (Point Oven plugin) [13]	Animation file for Humanoid	Yes
SMPL [14]	Skinned Multi-Person Linear model (SMPL)	Not mentioned

HAnim Joint Hierarchy: An HAnim character is composed of joints centers, sites, displacers, end effectors and segments (bones) in four different joint hierarchies – Level of Articulation (LOA) 0 through 4. LOA2 and LOA3 are shown in Figure 1. All the spine sections are animated. The LOA3 and LOA4 delivers a more accurate modeling than just the standard inverse kinematics (IK) bone map. LOA2 has l5, l3, l1 for Lumber, t10, t6, t1 for the Thoracic and c4, c2 for the Cervicale. LOA3 has l5 -l1 for Lumber, t12- t1 for the Thoracic and c7-c1 for the Cervicale.

Stitched Puppet (SP): Combines a 3D body shape and pose that contains shape and pose parameters with graphical body model and "stitches" the parts together. Each body part has a mean shape and subspaces of shape learned shape deformations using principal component analysis. The Graphical body model is used to establish relationships between the body segments. Figure 2 shows examples from the paper.

Methods based on ISB literature: These methods use existing literature globally accepted by the biomechanics scientific community such as [6, 7, 8] to estimate joint centers based on anatomical references located over the body surface and analyze human motion. Typically for health workplace ergonomics and sports applications. They also propose conventions for the axes and orientations of joints and body segments that are consistent with human biomechanics and motion analysis terminology (e.g., flexion-extension, abduction-adduction, and rotation along the bone/segment axis). They also provide typical physiological degrees of freedom and motion ranges of humans for such joints and conventions. For certain, complex joints such as the shoulder, there are different accepted methods for computing joint location depending on the number of anatomical references used. This literature can be used to create biomechanical models of different depth and complexity. Figure 3 provides an example of application to rig 3D scans or synthetic avatars. This literature does not include methods for obtaining skin attachments so rigging methods using this literature have to complement it with a method/software for computing such skin attachments

OSSO Method: Using 3D statistical shape models based on STAR (trained articulated human body regressor) to estimate the person's skeleton from the body shape. From input DXA images, obtain the skeleton and skin masks. The skeleton masks are used to predict the 2D landmarks. Figure 4 shows example from the paper.

Blend Shape: The goal is quick mapping of a person to existing identity body shapes for putting Humanoids that look like a person into a VR environment. A simplified skeleton is used for height adjustment. Adding a skeleton with body shapes that used as models for the identity body shapes. Figure 5 shows example from the paper.

SMPL Model: Joints centers coordinates uniquely correspond to human bodies and are invisible. Ionizing radiation is how absolute and relative joint center 3D coordinates are verified with estimative methods. The SMPL method encourages symmetric joint center locations. Joint center coordinates are influenced by the surface as shown by the colored lines and need to be optimized. Figure 6 shows the mesh demarcations relationship to the joint center coordinates.

Mixamo and MDD: Mixamo and MDD plugin are explained in Section 4.

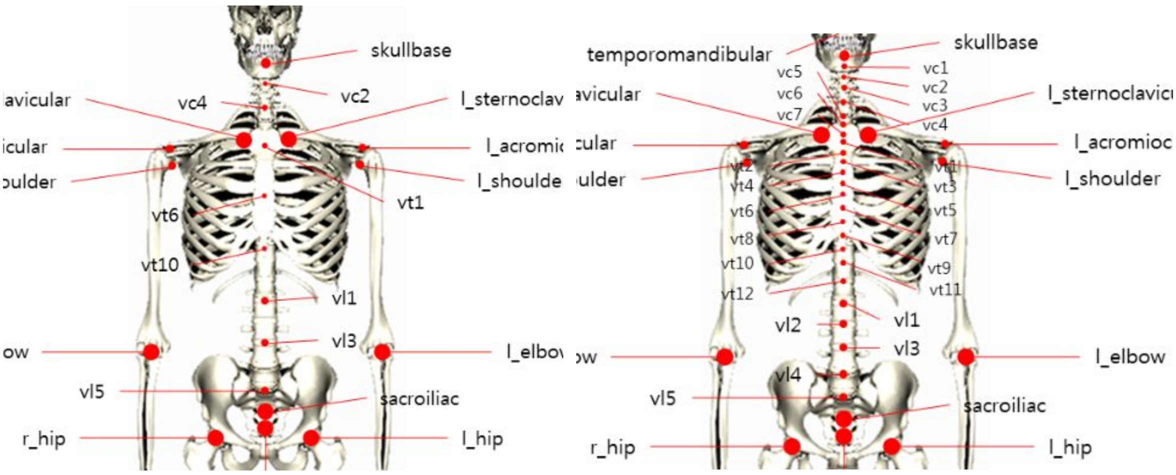

Fig 1. ISO/IEC 19774-1:2019 LOA2 [4] and ISO/IEC 19774-1:2019 LOA3 [4]

Fig 2. Example of graphical body model and Stitched Puppet bodies, Figure 1 and 2 from [5]

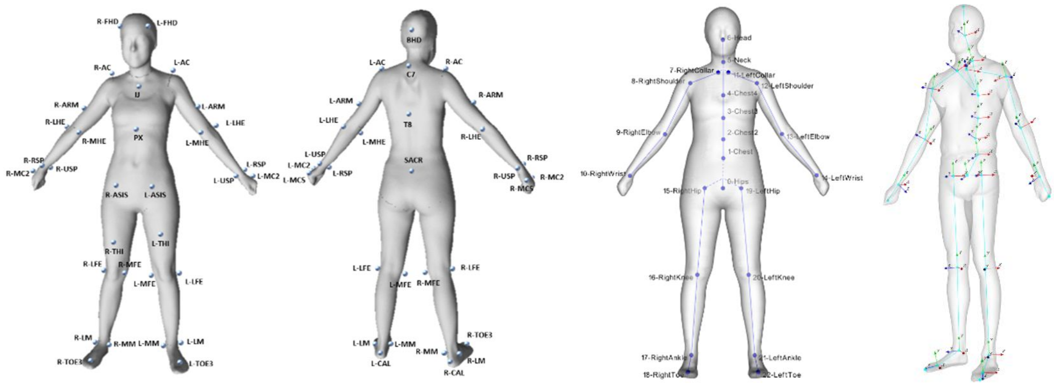

Fig 3. Examples of the adaptation of ISB literature made by IBV to rig registered 3D meshes (e.g., body scans or synthetic avatars) using a simple biomechanical model of the full body (23 joints). From left to right: anatomical references on body surface, joint centers and hierarchy, and convention of axes based on [6,7,8].

Fig 4. Examples of OSSO skeletons, qualitative results, Figure 5 from [9]

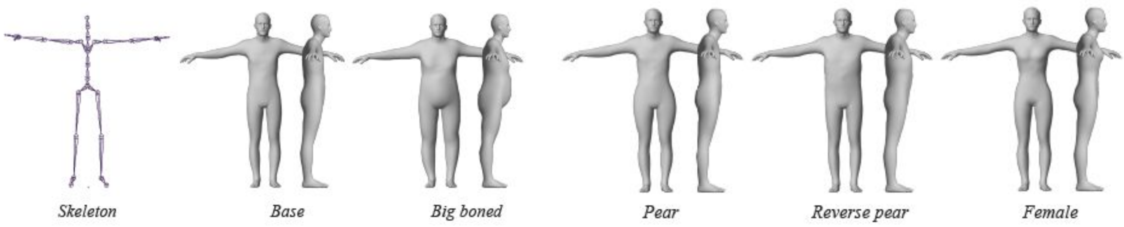

Fig 5. Example of Body skeleton and identity blendshapes, Figure 7 from [10]

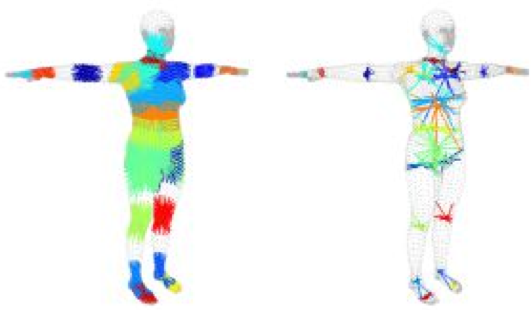

Fig 6. Example of joint regression for SMPL, Figure 6 and 7 from [14]

3. Mapping Humanoids to Coveroid- Apparel

For apparel product development landmarks serve as the base points of reference between which measurements are extracted to drive Coveroid shaping and geometry. For human animation, joints form the basis of the virtual skeleton (rig), connecting virtual bones for the simulation of human motion. Inconsistencies in apparel landmarking can cause difficulties with human animation. For example, apparel identifies numerous waist positions, some suited to morphology and others to product design. Varied waist landmarking used for animation can lead to inconsistencies in rig models' spines with compounding effects on neck, shoulders, armscye points, bust, and hip. Such inconsistencies are further compounded during complex spine articulation associated with gaits and poses. Cross-platform use of Humanoids is made difficult if landmarking protocols between apparel and animation are not aligned. Whether feature points on the rig (indicating joints) are projected to the surface as landmarks, or surface landmarks are projected inward to derive rig feature points, a direct correlation between joint feature points and apparel landmarks would improve the realism and accuracy of virtual fittings.

In this paper, stable landmarks are identified as those which are common across the human population, can easily be identified through a range of dynamic human motion, inclusive of gender, age, and dysmorphia (e.g., shoulders, elbows, crotch, knees, ankles). Morphological landmarks are understood to denote areas of variability across the human population. (e.g., breasts, biceps, hips, thighs, calves) and are known to change position with shifts in posture, movement and even by forces exerted by the Coveroid. In both rigging and apparel, stable landmarks are used as base points of reference for understanding morphological variation as geometric relationships between static and morphological landmarks. From this common ground, we considered the possibility for defining stable landmarks suitable for apparel product development and animation.

Figure 7 illustrates torso landmarks derived as geometric relationships [15,16,17]. The stable landmarks are as identified in ISO 18825-1:2016 [18] which are based on first version of the Humanoid Animation (HAnim) standard which has been superseded by ISO/IEC 19774-1:2019, [4]. The attributes of the definitions are in ISO 18825-2:2016 [19] A comparison of landmarks is shown in Table 5 in Annex A. Notes in the table highlight the areas of required future improvements. Also included for reference are the ISO standards related to manual measurements of the human, ISO 7250-2:2017 [20] and ISO 8599-2: 2017 [21]. This includes the "stable" landmarks – those directly tied to the spine and the "morphological" landmarks – those landmarks that surface of skin landmarks that are linked to the stable rig joint landmarks. In this example, the torso is segmented into eight sections between the underarm and crotch landmarks to derive a close approximation of the twelfth thoracic (t12) vertebrae for a rigging waist joint.

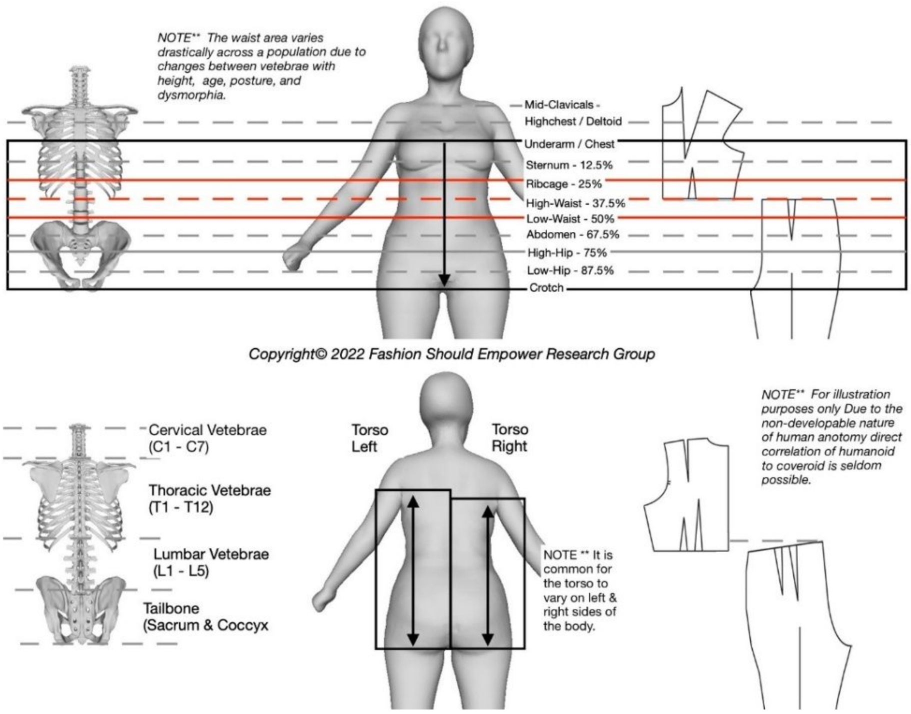

Fig 7. Humanoid to Coveroid cross application landmarking.

The neck vertebrae joints, c1 (top) and c7 (bottom), are easily located and considered stable landmarks. The other vertebrae joints are reasonably estimated but lack standardization due to conflicting apparel practice. For example, apparel product development relies heavily on waist landmarks as both a location for pant waistbands and a reference point for coordinating the location of upper body covers. Depending on seasonal trend, pant waistbands are styled to sit at t12, slightly below t12, or drastically below t12. Body weight distribution, however, can counter this 'rule'. For example, heavy front body weight distribution (as with a protruding abdomen or a maternity belly) can cause pant waistbands to slide below the distended abdomen. Product developed for this type of morphology often favors a shaped waistband lower in the front than back. While essential for customer centric design, such product creates challenges for both apparel and human animation. From an apparel perspective, landmarking for styling fluctuation inhibits geometrically constrained pattern relationships. From a human animation perspective, **product landmarking may not be relevant to human motion.** Locating product specific landmarks with reference to stable landmarks (geometric relationships) stands to improve 3D product development for both animators and pattern-engineers. Styling landmarks are best identified with regard for a geometric relationship to stable landmarks.

Geometric relationships could be particularly useful in cases of spinal deformity where an overall length of vertebrae is more important than an exact vertebrae location. These relationships are approximate but have the benefit of holding true for height categories from infant to aged adult. The broad range of demographics requires an evolution of fit testing. It is common knowledge that posture changes with age. To adequately model back curvature in a population, across ranges of postures (including scoliosis) adjust the spine and pelvis for the various postures is essential. This is very important for apparel product development. Figure 8 illustrates an example of the spine spinal change due to age, posture, and compression. The first image illustrates how the spine gets flattened with current vertebrae/ joint placements. The second image illustrates how current workflows causes a hump where it may not exist to gain hunched positions and improper deformation of the Humanoid. Adding joints and segments at red circles would result in an accurate Humanoid. The authors recommend four to six spine joints for current biped animation rigging, depending on the program utilized.

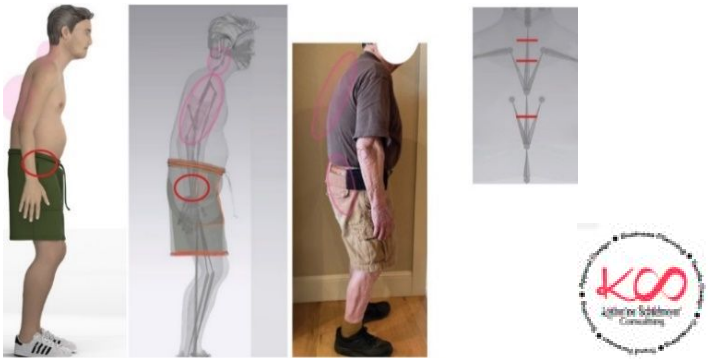

Fig 8. Apparel spinal column aging posture impact

Often these predictive models are driven by systems that simplify the modeling the body's skeleton, for instance, some approaches fail to separate the seat (greatest posterior buttock protrusion) from the hip (trochanteric projections) [22]. However, if one has the seat as l5 and the low hip as the low hip joint, these can be modeled properly as separate joints.

Modeling with the neck joints with more joints than extant 3D system but fewer than all cervical joints is shown in Figure 8. Humanoids with accurate relationships to aging consumers, athletics, shoe design, and more realistic modeling and animation for fitting Coveroids are the results. Table 2 relates the spinal column zone to the joints shown in Figure 9. The spinal shapes are associated with facilitating movements, longer posterior spine in Cervicale and Thoracic facilitating forward bending and shorter spines in lumber facilitating greater rotation.

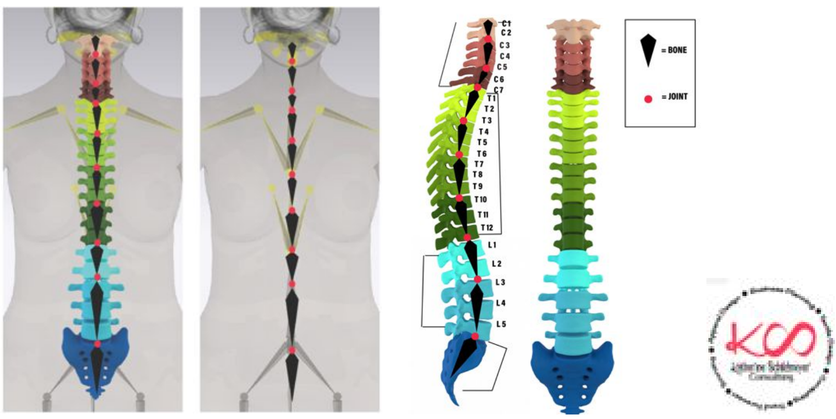

Fig 9. Apparel spinal column divisions including the neck joints

Table 2. Spinal column zone to joints

Zone	Description
Cervical	c1 back of lower skull
	c4 and c7 – posture of neck
Thoracic	t3- t6, Breast attachment point
	t4-t5 – Underarm; Breast apex – varies by person, posture, supports, and Cover worn
	t6 and t8 - Underbust
	t12 lower spine curvature –high waist point of posture,
Lumbar	l1 – relates to t12;
	l1, l2, l3 – lower waist or buttocks transition,
	l4 – pelvic tilt
Coccyx and Sacrum	Tailbone – gluteal fold depth

Figure 10 illustrates how a rig with too few joints can lead to an unrealistic rigid spine. Here the shoulder are locked to the upper thoracic and clavicle column causing problems with the center back and shoulder postures along with other compounding effects throughout the Coveroid. To improve this bone structure, we recommend the lower neck cervical to upper thoracic area of the rig be provided a minimum of three neck joints.

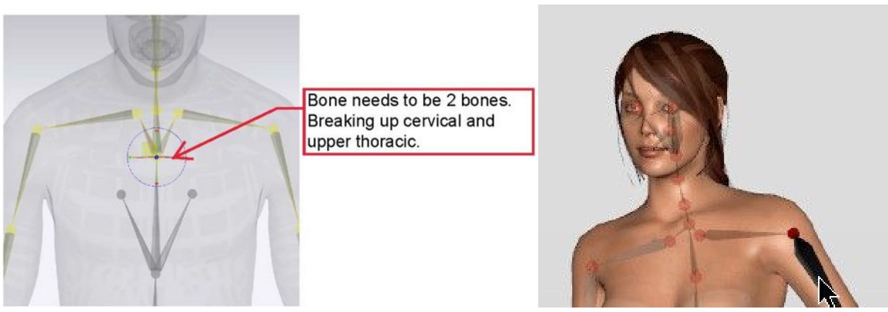

Fig 10. Lower neck cervical and upper thoracic (example of program specific rig)/ Browzwear neck structure.

The Virtual Try-On (VTO) experience should include the Coveroids are stretching while the Humanoid puts on / takes off Coveroids, male/ female walk, sitting, shoulder shrugs, and stand to bend. Likewise, requisite poses required from any user defined perspective germane to the purpose of the Coveroid (e.g., bicycling, or military uniforms) should be able to be provided. Poses are also driven by the purpose of product design. Poses described in ISO 18225-2 are very limited.

There are also postural issues related to using configurable avatar generation engines which base pose does not correspond to a “natural” standing pose. Figure 11 provides an example of a female avatar generated with a widely used clothing CAD software in A-pose pose compared to three actual body scans in A-pose, namely, a male, a female of similar complexion to the avatar and a child. In the three real scans we observe that the antero-posterior location of the hip center is at the level of the midfoot (close to metatarsophalangeal joint) while in the generated avatar it is located at the level of the ankle joint, leading to an unnatural leaning backwards standing posture. Such discrepancies may lead to suboptimal Coveroid patterns and fit.

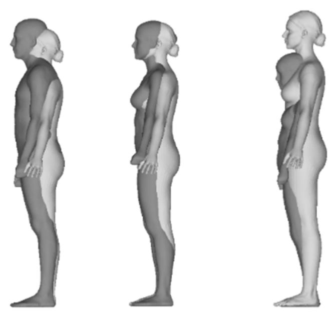

Fig 11. Example of postural discrepancies in A-Pose between three different actual body scans (dark gray) and a synthetic avatar generated using clothing CAD software (light gray).

4. Comparing two Humanoids

The most appropriate positions to associate with vertebrae and spinal sections (Cervicale, Thoracic, Lumbar, Sacral) for the Humanoid are of important to the success of the model. Humanoids also require hip, seat, and upper thigh identifiers (site or feature points) for lower spine and hip bones. The amount and distribution of soft tissue due to weight and gravity may cause discrepancies, increasing uncertainty in either the estimation of the hip iliac crest or in bust movement. Anatomically aware segmentation of circumferences will facilitate locating nearby bones features and improve body weight and anisotropic distribution. Some skeletal estimation techniques are used in conjunction with databases of Humanoids in motion using Mocap or 4D scans as an estimation. If these databases are amassed from a range of narrow body shapes, then estimation for obese people or other outlier bodies may be erroneous.

This is where a problem arises, and it becomes a visual simulation and not the true replication at least as much as possible. Next, the comparison between MDD, Mixamo, and other software and have the proof to create the suggestions to allow the design user to define what end use the animation simulation is for. Gaming is fine with Mixamo while if we want the fidelity and integrity, we need human driven motion capture (mocap). It is recommended that a host of demographically different bodies should be utilized to have variety of application for purpose of products.

A common pose used in apparel is the A-pose and not all animation uses this as a base pose. This implies that a repose is required. Bone count is also an important issue between rigging software. Table 3 relates the bone or shape segment count between the animation methods.

Table 3: Table on Bone or Shape segment count

Software	Arms (each)	Legs (each)	Spine	Neck/ Head*	Feet (each)	Hands (each)
HAnim LOA 2	7	2	6	1	7	19
HAnim LOA3	7	2	17	7	7	19
Stitched Puppet	3	2	1	1	1	1
Methods with ISB references	Flexible method with no fixed number of bones/joints on images					
OSSO system	Bone count not specified on images					
Graphical Body Model	2	2	1	1	1	1
Blend Shape with CMU skeleton	3	3	3	1	1	1
Tracked Body in Unity	2	2	4	2	1	1
Mixamo	2	3	4	1	3	3
MDD	4	2	4	3	8-18	10-20
SMPL	2	2	5	1	Unknown	24

*Not counting joints for eye and jaw movement

4.1. Interoperability and Loss

When programs apply animation to forms differently, there is an issue for interoperability of Humanoids between programs. For example, Mixamo is a quick tool to animate and helps users without access to customized animations or the knowledge of rigging. It is also good when users want to move an item into the meta /game/ and animation spaces. Browzwear only accepts Mixamo on 3rd party avatars. Then validating the form integrity if a person was using this for fit creation and was not correct with the initial form. Findings are shown in following figures. Mixamo does have its place in the end-to-end process.

An Mixamo example: The default pose in Mixamo is not an A pose Humanoid, therefore, a re-posing is required. The pink areas show the areas of losses in the crotch, buttocks, armscye, and parts associated with trunk, Figure 12. Designers have to manually repose. Mixamo automatically changes the mesh and the relationship to the segments (bones) and segments (bones) themselves.

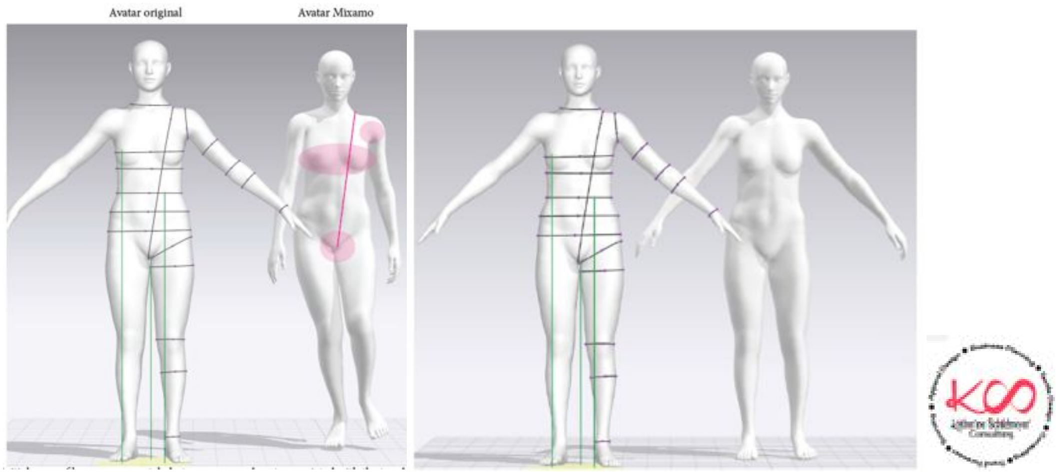

Fig 12. Mixamo changes required: A-pose and points of loss and re-pose

The bone count changes the mesh and the impact as shown in Figure 13. The other issue is the lack of stabilized landmark measurement that will be able to be embedded in the form data to ensure any program can have the landmark measures in the same place to ensure every designer gets the right measurement and placement. In Mixamo, there are no bones for the chest and the pelvic ball creates universal rotation, but this becomes problematic for bone adjustments. Generally editing the animation form will delete the animation. Programs like Optitex, Browzwear, and etc. have noted problems with fit accuracy in Mixamo animation. The animation is used purely for creative presentation, and not fit validations.

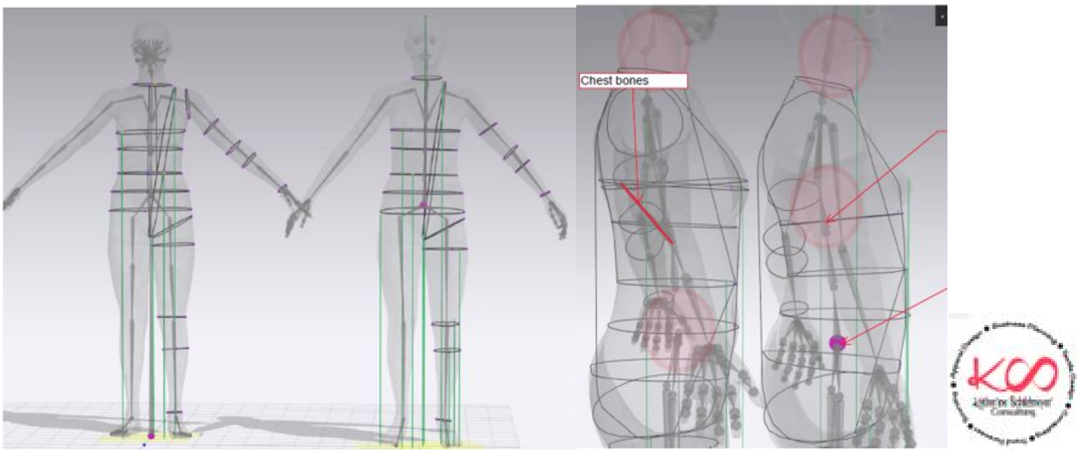

Fig 13. Bone changes detail including bone count and changes

The image in Figure 14 is the result after matching the bone and joint placement on the original form. The conclusion is the bone reduction and smoothing to armscye, bust, etc. caused lossiness or increased in the exterior and will impact the fit of the Coveroid. This may be acceptable for animation for marketing, gaming and AR/ VR but be un-acceptable for digital product creation.

Mesh Intersections have changed under Mixamo when bones become aligned to the length and position of the original. The proposed method is to allow for a more defined IK bone structure that doesn’t have bone rig restructuring with animation being applied. Instead, we need animation to understand the key joints and bone structures that maybe used to achieve human-centric realism of movement that will impact virtual try-on tests and consumer trust during virtual try-ons.

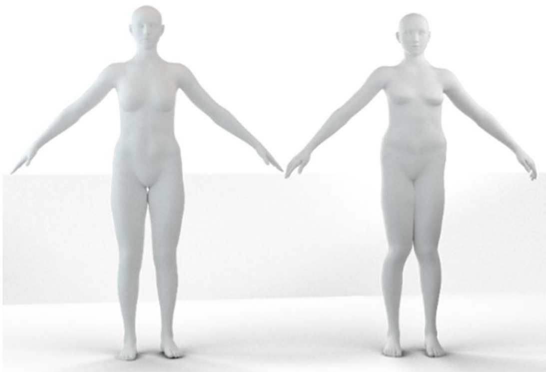

Fig 14. Final form changes

5. Modeling Coveroids

The next concern is how does the Coveroid get attached to the Humanoid model. There are various methods, and some may introduce more issues than others. Table 4 relates how each method is looking to attach the Coveroid to the Humanoid. The Humanoid skin may or may not be exported depending on application. We studied the relationships between landmarks used for designing apparel and those used for rigging Humanoids and how this relates to the software.

Table 4: Humanoid Animation method with cover landmarks

	Coveroid attachment method
HAnim v2	Define site nodes for attachment points for Coveroids
Stitched Puppet	Not mentioned
Methods with ISB references	Not mentioned
OSSO system	Not mentioned
Graphical Body Model	None
Blend Shape with CMU skeleton	Coveroids as defined texture
Tracked Body in Unity	Using default body rig with specified attachment landmarks
Mixamo	Manually setting attachment points to Humanoid after rigging
MDD	Manually setting attachment points to Humanoid after rigging
SMPL	Not mentioned

Pattern drafting creates balance lines that relate to the front and back of Covers / Coveroids. The lines also help a 3D designer see the imbalances in the draft. Lines are the balances with front and back, but they shift with posture. The results of locking the upper thoracic / lower cervical bone with shoulder movement, implies that the chest and back cannot just be adjusted for a contour needed to be a proper posture. Fitting shows poor fit but in relation to the inaccurate bone position due to the bone structure of rig definition. Showing in Figure 15, the upper back curve/ hump is the beginning to help a brand with an aging or sedentary demographic.

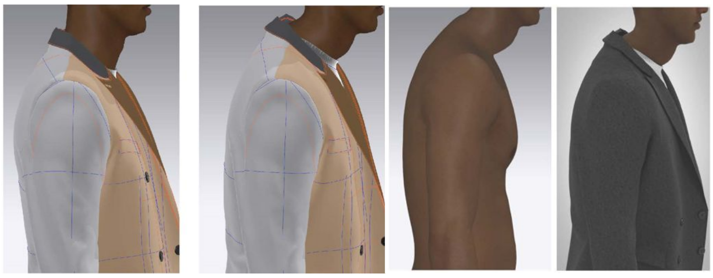

Fig 15. Balance lines and results of locking the upper thoracic / lower cervical bone

A Designer is not able to test fit against a Humanoid with two few joints attached to the long segments mimicking fuse vertebrae as shown in Figure 16. When trying to test posture if the rig is inflexible in all three zones, particularly in the upper neck and back, c1 – c7 and t1 – t12, moving the “bones” to try and match the spine visually, can reduce the breasts due to depth and volume shifts. Stomach and pelvic tilt become unstable in relation to shifts of segments. The back may have the correct shape, but the front could lose the Humanoid shape required.

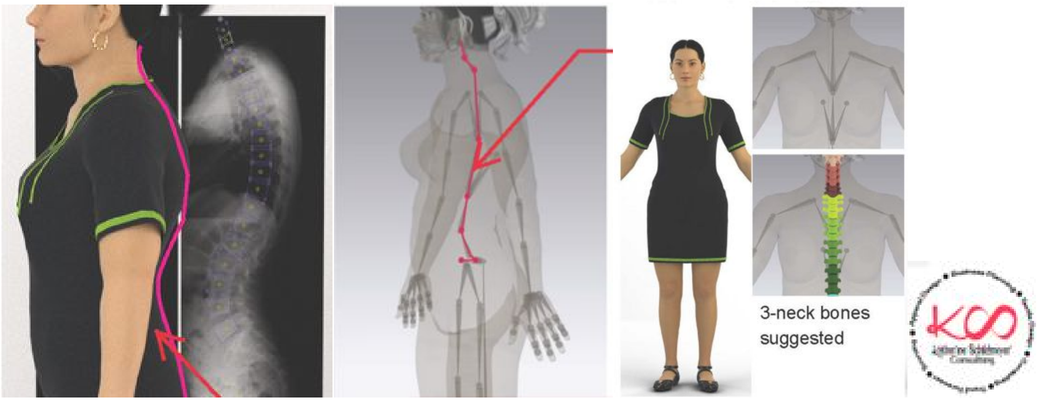

Figure 16: Spine and front not matching and front view

Currently, neck bones and joints do not assist the designer in placing accurate center back and center front neck landmarks. As noted previously, three neck joints are recommended as shown in Figure 17.

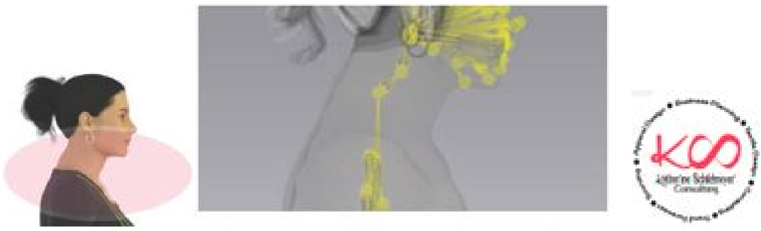

Fig 17. Neck bones detail

Extant tools neck bones and joints do not assist a designer in placing accurate center back and center front neck landmarks. We recommend three neck joints to assist designer with landmarking. For example, Browzwear currently offers this structure in the neck but is not available for third party forms or imported FBX (a commonly used file format for digital content). This creates a cross platform interoperability challenge within the product development sectors, creating rendering anomalies between all programs, if developed with a global team using different software. The areas of impact for the neck, are Cover (clothing) balances, collar shaping, shoulder angles, bust depth, hips to waist placement and tilt – front and back, neck locations, and dimensions, and posing factors for cross demographic development for the Cover (clothing).

6. Conclusion

Successful digital production creation depends on an appropriate torso in the in the Humanoid's rig and stable landmarks on its mesh. Given the discretion to define vertebral joints and segments to model the human, Made-to-Measure fit preference, or Ready-To-Wear fit recommendations of Covers can be more accurate. Defining stable landmarks on the Humanoid' mesh and vertebral joint centers and segments in its rig enables precision fit of Coveroids for a specified range of movement. Any standard will need to require a rigging that is stable to Humanoid even while utilizing the data between platforms and retains the original rig for users. The limitation of bone reductions and smoothing will cause lossness or increases in the exterior and the impact the fit of the Coveroid. While this may be acceptable for animation for marketing, gaming, and AR/ VR, this will not be acceptable for Coveroid product development due to the physical nature versus digital nature.

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Annex A: Comparisons of landmark definitions across global standards

Table 5: Comparison of landmark definitions

Clothing - Digital fittings - Part 2: Vocabulary and terminology used for attributes of the virtual human body		H-Anim Humanoid animation (drives ISO 18825 Digital Fittings)	Basic human body measurements for technical design - Part 1: Body measurement definitions and landmarks	Size deisgnation of clothes Part 1: Anthropometric definitions for body measurement	Humanoid to Coveroid Landmarking for Dynamic Study of the Torso Hypothesis for correlating rig joints to cross-sectional measurement planes for dynamic study of the torso, inclusive of gender, age, and dysmorphia. *Copyright© 2022 Fashion Should Empower Research Group*		
ISO 18825-2:2016		ISO / IEC 19774-1: 2019	ISO 7250:1:2017(E)	ISO 8559-1:2017-03			
Digital Standards			**Manual Standards**				
2.1 Virtual Body Landmarks	2.3 Virtual Skeletal Structure - for Virtual Bones	Part 1: Humanoid animation (Hanim architecture)	5 - Landmarks	3 - Terms and definitions and 5 - Basic body measurements			
	Virtual JOINT Landmarks	Annex B - Feature points for the human body		Apparel Mapping Landmarks			
Stable Spinal Neck Joints							
	2.3.6	81	5.11	3.19	Highneck Joint	1	C1 - Derived as the virtual center of a line connecting the Tragions (ear notch, Nuchal or Nuchale) between the ears. Top joint at base of skull.
2.1.2		11			Mid Neck Joint	2	C3 - Adams' apple or midpoint between C1 & C7
2.1.5	2.3.7	10	5.3	3.16	Lowneck Joint	3	C7 - Identified as the last cervical vertebrae just before the start of thoracic vertebrae.
Stable Armscye Joints							
2.1.6	2.3.8	15, 20	5.2	3.1.1	Shoulder	4	Acrominum as the outer edge of scapula projected to the skin surface.
		97, 96		5.4.7 / 5.4.4	Highchest Joint	5	NOTE** Methods to better identify this position are required. Shoulder joint connecting arm to torso. POSSIBLY as mid point between front neck and underarm (deltoid area).
2.1.3	2.3.7	12		3.18	Front Lowneck	6	Suprasternal notch located as the mid-point between left & right clavicals.
Stable Mid & Lower Torso Spinal Joints *Skeletal joints approximated through geometrically constrained relationships with underam & crotch.*							
		16, 18, 21, 23			Underarm Joint	7	NOTE** Methods to better identify this position are required. Approximated as average of front and back axilla points in both x and y.
		88		3.1.12	Sternum Joint	8	Approximated at 12.5% of the distance from underarm to crotch.
		24?	5.18	3.1.15	Ribcage Joint	9	T10 - Approximated at 25% of the distance from underarm to crotch.
		28, 30			High-Waist Joint	10	T12 - Approximated at 37.5% of the distance from underarm to crotch.
2.1.12	2.3.11	Derived ?		3.1.22	Low-Waist Joint	11	Iliac - Approximated at 50% of the distance from underarm to crotch.
		35, 32	5.7		Abdomen Joint	12	Approximated at 62.5% of the distance from underarm to crotch.
		36, 33	6.1.6	3.1.16 / 3.1.23	High-Hip Joint	13	Approximated at 75% of the distance from underarm to crotch.
		42, 46			Low-Hip Joint	14	Approximated at 87.5% of the distance from underarm to crotch.
2.1.16		38	5.4	3.1.26	Crotch Joint	15	NOTE** Methods to better identify this position are required. Approximated as the highest palbable point on perineum. Note** sometimes crotch is above gluteal fold but never below.Pelvis tilt affects location of this point.
Dynamic Morphological Torso Surface Landmarks *Known to relocate with posture, movement, and manipulation from covers.*							
2.1.4		82, 83		3.17	Side Lowneck	16	NOTE** Methods to better identify this position are required. Point defining the width of the neck on the top of the shoulder. Located on an arc going over the body between the cross-sectional shoulder plane.
2.1.8		22, 17		3.1.13	Front Axilla	17	Divisional point between arm and torso.
2.1.9		16, 21		3.1.14	Back Axilla	18	Divisional point between arm and torso.
		31, 29	5.18		Apex or Thelion	19	Bust, Thelion, or Apex - most anterior point of the breast or pectoral mound.
		26,27			Preferred Waist	20	Preferred waist anterior, preferred waist posterior
		35, 32	5.7		Stomach	21	Greatest protrusion (depth) of the lower torso region on the front of the body.
		36, 33	6.1.6	3.1.16 / 3.1.23	Buttocks	22	Greatest protrusion (depth) of the lower torso region on the back of the body.