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Investigation of the tissue displacement through textile pressure on soft avatar in Browzwear's VStitcher software

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ABSTRACT

Nowadays, soft avatars are used in various fields to simulate the behavior of human soft tissues in different applications. Likewise, they are also utilized in the garment industry in order to achieve a realistic testing of the fit and functionality of tight-fitting clothing. Therefore it is important that avatars in CAD programs for clothing conform to the mechanical properties of human soft tissue. The accuracy of the avatars' properties in simulating the change in shape of human tissue is crucial here, which is caused by the contact pressure that compressive or tight-fitting garments exert onto the body. In this study, Browzwear's VStitcher soft avatar Sofia was investigated and different body shapes resulting from being influenced by a legging with different levels of negative ease values were compared with non-affected natural avatar body shape. The examination of the soft avatar simulation shows that although a fast estimation of the tissue displacement can be predicted, there are some shape changes limitations compared to the natural behavior of human soft tissue.

Keywords
soft tissue simulation,
soft body physics,
garment fit,
tissue displacement

1 Introduction

Human soft tissue undergoes shape changing elastic deformations due to tight-fitting and compressive garments. The softer the tissue, the greater the change in the natural shape of a person's body. Here, the textile exerts contact pressure onto the tissue, therefore the fit of the clothing is decisive for its functionality such as supporting or lifting the tissue up [1]. In line with the state of the art in the textile chain, the development of new garments is done entirely digitally to save time, costs and resources. CAD 3D simulations which are utilized for checking a constructed pattern, selected materials and the fit of the garment are able to display compression, fit, stress, as well as strain maps. As of late, they are also able to consider the interactions between the textile garment and the human soft tissue instead of calculating the avatar in the simulation always as a continuous solid surface.

In this article, Browzwear's soft avatar simulation Sofia in VStitcher is investigated with the aim of testing its accuracy of simulating soft tissue displacement to ensure the validity of the resulting fit visualization. A tight-fitting sport legging with negative ease values was simulated once on a conventional solid avatar and once on the soft avatar to subsequently compare the resulting body shapes of the soft fabric [2].

2 Soft tissue avatar overview

To bridge the gap of digitally verifying a holistic fit, avatars must match the mechanical properties of the human body. Soft tissue avatars are a virtual representation of human soft tissue including skin, muscles and fat. In the areas of crash test simulations for the automotive industry or for ballistic and forensic examinations as well as in the medical field for surgery simulations, there are existing Finite Element Analysis (FEA) human models that simulate the mechanical properties of human tissue. Modeling biomechanical structures and systems in FEA programs requires knowledge of the forces acting on these structures and the stresses applied to the materials. The forces acting on the tissue structures, such as body weight, the counterforce of the musculature, the influence of gravity and the dynamic forces acting in the unit of time during movement, lead to stresses in the material in the form of tension and compression. The material constants serve as a measure of the dimensional stability of a material under the influence of external forces: the Young's modulus, the Poisson's ratio and the shear modulus [3,4]. The external and internal geometry of human models can be created by capturing the shape using medical imaging techniques such as MRI or CT scans and then converting this acquired data into a three-dimensional virtual model. Soft tissue avatars can be generated using a variety of techniques, including surface modeling, volumetric modeling, and Finite Element Method (FEM) simulation [5-8]. For the purpose of simulating the deformation of human soft tissue through the pressure a textile exerts, there are three main possibilities:

- First the Finite Element Analysis, as described above, can be used. FEA is a numerical method to calculate deformations of a structure under specific loads. Here, the structure, such as a human's body muscle, is divided into smaller, manageable parts which are called elements, and through solving a set of equations according to the assumed material models the deformation of each element under different loads like pressure, gravity or motion is calculated [9,10].
- The second method are multibody dynamics simulations (MBD), which are used to model the interactions and movements of several rigid bodies connected by joints and subject to external loads to simulate deformations of the human body under pressure and the interaction with other objects. Here, the force distribution, the physical deformation and the interactions with other objects are analyzed [11,12].
- The third method of simulating soft tissue avatars are soft tissue models, which capture the mechanical properties of individual human tissues for simulation. They also simulate the deformation of the tissue structures under different load cases. This method can be combined with FEA and MBD to increase the accuracy [13,14].

The choice of the model will depend on the specific needs of the simulation, including the type of tissue being modeled and especially the level of detail required. In a soft body simulation, the object's mesh or surface is divided into smaller interconnected parts, each of which can bend, deform, or bulge under external forces such as gravity, collisions, or user-applied forces. These deformations are calculated using physics algorithms that model the object's behavior as if it were made of a deformable material such as rubber or cloth. These simulations are used in a variety of applications, including animations and special effects in movies and video games, as well as in engineering and product design in order to simulate the behavior of soft materials and to study the effects of external forces on them. Soft body physics simulations require complex mathematical calculations to accurately model the behavior of deformable objects. They can be computationally intensive and require significant processing power, but they have become increasingly sophisticated and are able to produce highly realistic and convincing results [15-19].

3 Garment development and pressure maps on rigid avatar

The use of digital design, construction and simulation software has become a standard tool to increase the time and cost efficiency of the textile chain. The iterative process of sampling can be optimized by using digital samples that are compared with the first-try approach. Common CAD programs for clothing simulate the garment with a white shell that stretches around the rigid avatar without considering the material parameters of the textile as a first step. As a next step, the developer can also simulate a digital fit verification of the garment maps and textures in order to be able to identify fit issues [20]. For this investigation, a sport legging made out of stretchy jersey knit material made of 92% polyester and 8% Spandex from the VStitcher Cloud was imported . The tensile stiffness or elasticity of the textile is tested and digitized as a physical material parameter in VStitcher in the x-direction along the width and in the y-direction along the length of the material, both in Newton per meter, assuming the material to be ideal and completely linear [21]. The legging has a high-waist design for a secure and comfortable fit, and a flatlock seam is applied which reduces friction and irritation during the wearing process [22].

Fig. 1 Legging pattern VStitcher with pressure and tension map.

The heat maps shown in Fig. 1 belonging to the virtual fit testing of the basic pattern of the legging on the solid avatar indicate a very good fit. The color maps on the far right within the figure show that white to light blue means that the tension in the textile in the simulation is in the range of 0.1-0.3 g/cm and the pressure of the textile on the avatar while simulation is in the range of 0.1-0.3 g/cm². The maximum value of the maps is up to 100.00 g/cm in regards to tension and 100.00 g/cm² in regards to pressure of the textile [2]. The HOSYcan standard is used to record the pressure exerted by a textile on the body and thus to check its functionality [23]. Sportswear that exerts a certain pressure and thus a compressive effect on the body contributes to a faster regeneration of the muscles. However, it is to be noted that the recording of the compressing values can only be carried out on test persons with real samples. Therefore, it has to be considered that the values always only reflect the compression of and influence on the tissue from a test person. A possibility to close this gap and to digitally investigate the influence of clothing in the sector of sport compression in a reproducible way is the simulation on avatars which show changes of circumferences and possible changes of soft tissue [22,24]. Subsequently, the relevant circumferences for the pattern of the sport legging were measured and a negative ease of 10%, 30% and 50% was applied to the pattern in x-direction. Table 1 shows the measured circumferences on the avatar Sofia and the resulting values for the patterns with the different negative ease values.

Table 1. Measurements avatar Sofia, basic pattern and negative ease.

Sofia without influence of the clothing compression (cm)		**Pattern measurements (cm)**		**-10% ease (cm)**	**-30% ease (cm)**	**-50% ease (cm)**
Waist	100.83	Waist band	65.00	58.50	45.50	32.50
		Waist line	68.40	61.56	47.88	34.20
Hip	127.07	Hip line	96.00	86.40	67.20	48.00
Thigh	71.83					
Knee	43.44	Knee line	59.90	53.91	41.93	29.95
Calf	41.94					
Ankle	24.85	Hem line	40.00	36.00	28.00	20.00

Figure 2a-c show the 3D simulated pattern, which seems to fit when the simulation is performed in the form of a white shell. In contrast, the fit map of the leggings shows that there are areas that are too tight, that are not comfortable to wear, or are in critical condition and about to tear, clearly showing that the material needs to be stretched further than possible to cover the legs at all. However, what is not indicated by the maps is whether the fabric is compressing the body or even cutting into soft areas of the lower body such as lipid zones or muscles.

In general, therefore, it can be said with regard to digital fit testing that the calculation of the textile on a fixed avatar alone is not sufficient to perform fit testing. It can be assumed that the textile must stretch much more in the simulation on the fixed avatar than when it is worn in reality by a human with soft fabric.

Fig. 2 (a) Simulation with -10% ease on rigid avatar

Fig. 2 (b) Simulation with -30% ease on rigid avatar.

Fig. 2 (c) Simulation with -50% ease on rigid avatar.

4 Soft tissue avatar of VStitcher

The computational and material models behind the soft avatars from VStitcher, and thus behind the properties they are based on, are not published yet. It is only published by VStitcher itself that soft avatars replicate a realistic behavior and shape change from the human body when simulating clothing. The change and behavior of the specific softness of the avatar are calculated based on the pressure that the textile exerts onto the body, also taking gravity into account. There are two avatars defined as female and two as male, one each lean and one each defined as plus size [25]. Normally, avatar simulations allow different sizes of the confections and the widths and lengths to be adjusted, but not for these avatars. Neither is it possible to set the physical material properties of the avatars, which would describe the soft tissue behavior as for example in FEM simulations. Therefore, it is not possible to draw conclusions about the properties and simulation behavior of the soft avatar. There is only the possibility to select in the simulation whether the avatar should be simulated as “soft”, “medium soft” or “firm”. Neither internal geometries nor information about which geometries were taken into account, nor how detailed the soft avatar is or how high, e.g., the fat and muscle percentages are and their distribution are known. Factors such as the proportion of fat in a body have a very large influence on the softness and thus deformability of a body. All these points would be important information for evaluating the accuracy of the simulation [13].

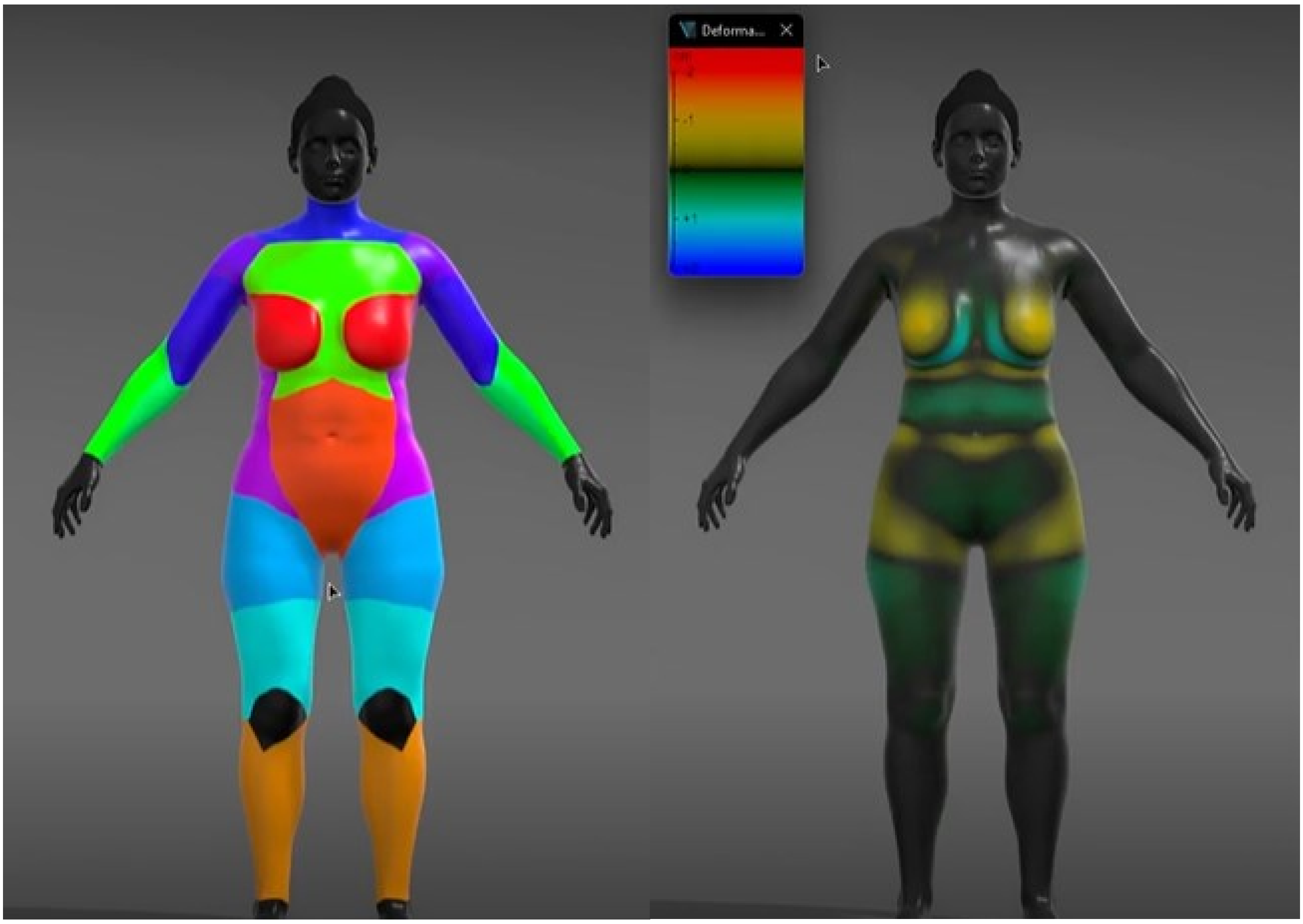

Fig. 3 Soft map and deformation map of Soft Avatar Sofia [4].

Figure 3 shows on the left side the deformation map of the soft avatars, which displays that different softness levels are applied to zones. However, the documentation does not describe a value nor meaning of the individual differentiations between these settings. To analyze the impact of the clothing on the avatar, the deformation map, as shown on the right in Fig. 3, can be used as a function, which shows the degree of deformation that each of the soft tissues of the avatar's body parts experience due to the pressure of the clothing [21].

The degree of deformation of the soft body parts is shown in colors. Red stands for the strongest deformation, blue for the least deformation. The legging pattern with the different negative ease values were then likewise simulated on the 'plus size' avatar Sofia, but as a soft avatar simulation set as 'soft'. As expected, the same fit maps for tension and pressure were observed, but the natural shape of the avatar was influenced by the garment. Figure 4 shows on the left how the simulated leggings with the 50% negative ease value deforms the soft avatar Sofia visually compared to the solid avatar's unchanging shape on the right side.

Fig. 4 Visual comparison of the fit of leggings with -50% ease, soft avatar left, solid avatar right side.

5 Evaluation circumferential dimensions

The simulation of the leggings with the different negative ease values already visually shows a strong change in the natural shape of the avatar, as can be seen in Fig. 4. It can be clearly seen that the clothing would cut into soft parts of the body, and it can be seen that the resulting fit is completely different for the soft avatar than for the solid avatar. Table 2 shows the initial recorded circumferences of the avatar and the final circumferences due to the influence of the clothing.

Table 2. Results of the circumferential measurements.

Sofia without influence of the clothing compression (cm)		-10% ease (cm)	-30% ease (cm)	-50% ease (cm)
Waist	100.83	101.94	102.73	100.81
Hip	127.07	127.03	127.05	126.99
Thigh	71.83	71.37	72.02	72.59
Knee	43.44	43.40	43.18	42.76
Calf	41.94	41.81	41.88	41.86
Ankle	24.85	24.91	24.88	24.91

From the change in circumferences, it is clear to see that the soft tissue changes its shape and is displaced by the pressure exerted from the textile. However, it is also visible on the basis of the values that the soft tissue is only moved and that, just as in real life, the volume of the body is not simply reduced due to compression everywhere, but is only shifted by the textile. The reason for the tissue volume shifts is that tissue groups, for example connective tissue, fat and muscle tissue, are incompressible and deform under the pressure of external forces only as much as the reticular fibers allow, but return to their original shape when the pressure is released [26,27]. This also explains why the circumference even increases in some cases at the previously defined circumference lines, since the garment may have pushed soft tissue towards this body area. Increasing circumferences also result from the tissue being pushed up or down when the leggings cut into it, especially at the waist.

5.1 Comparison of the resulting meshes

In order to investigate how realistically the simulation of the shape change in the simulation is, it is necessary to take a closer look at the displacement of meshes and to investigate the accuracy. For this purpose, the unaffected shape of the avatar was exported as a reference as well as the three shapes of the soft avatars without the leggings affected by the different negative ease levels were imported to the same location.

Figure 5 shows the unaffected shape of the avatar layered with the resulting shapes from simulating the leggings on the soft avatar. The reference shape of the avatar is highlighted in green, the shape influenced by the legging with -10% ease in light blue, the shape influenced by the legging with -30% in dark blue and the shape influenced by the legging with -50% ease in purple.

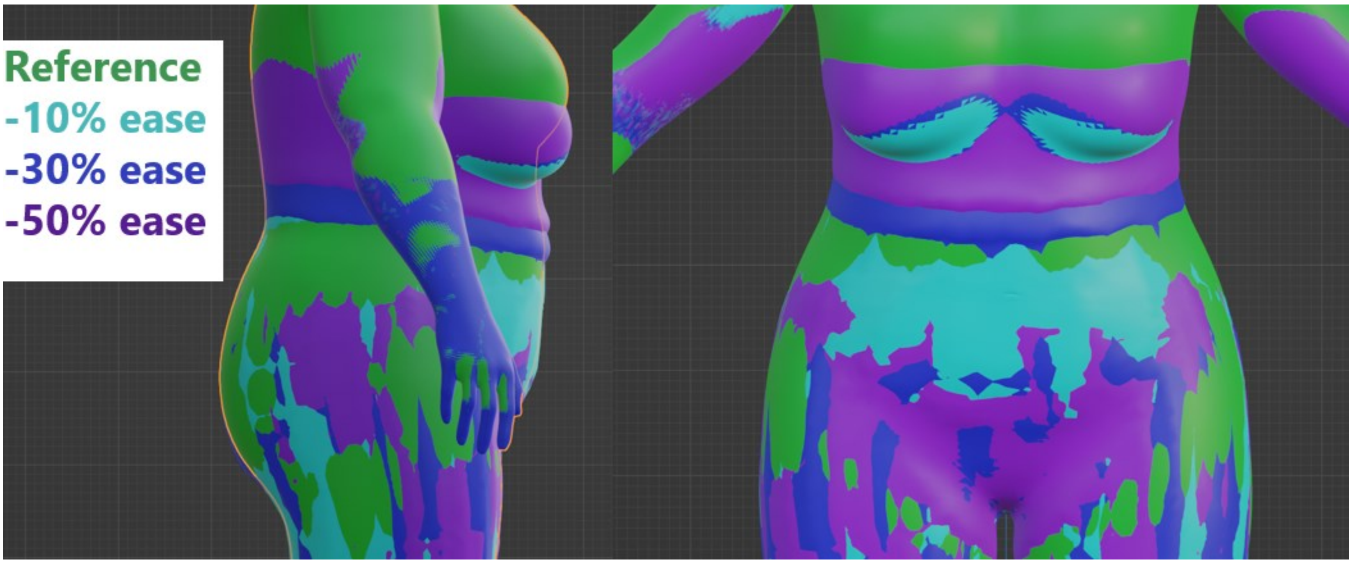

Fig. 5 Layered avatar shape comparison.

In particular, the side view image shows that the avatar’s chest area changes its shape a lot under the influence of gravity. It decreases especially in the simulation of the light blue leggings (-10%), because here the least soft tissue is pressed upwards by the leggings. The soft tissue along the waist is most depressed in the belly area. Accordingly, it is very clear in the side view from the displayed orange line of the avatar’s reference shape that the fabric in the purple (-50%) and dark blue (-30%) shapes is heavily incised, causing the appearance of bulges above the leggings.

5.2 Cross section comparison

When looking at the stacked cross-sections of the avatars, as shown in Fig. 6, it is clear from the orange reference contour of the avatar that some of the deformations of the soft avatars have edges and do not remain round, as is the case with the natural deformation of the human body by a pair of sport compression leggings.. Especially in the dark blue (-30%) and purple (-50%) shape of the avatar, angular deformations of the glutes are clearly visible. The same angular deformations of the mesh are found in the transverse section of the thighs, as shown on the right side in Fig. 6.

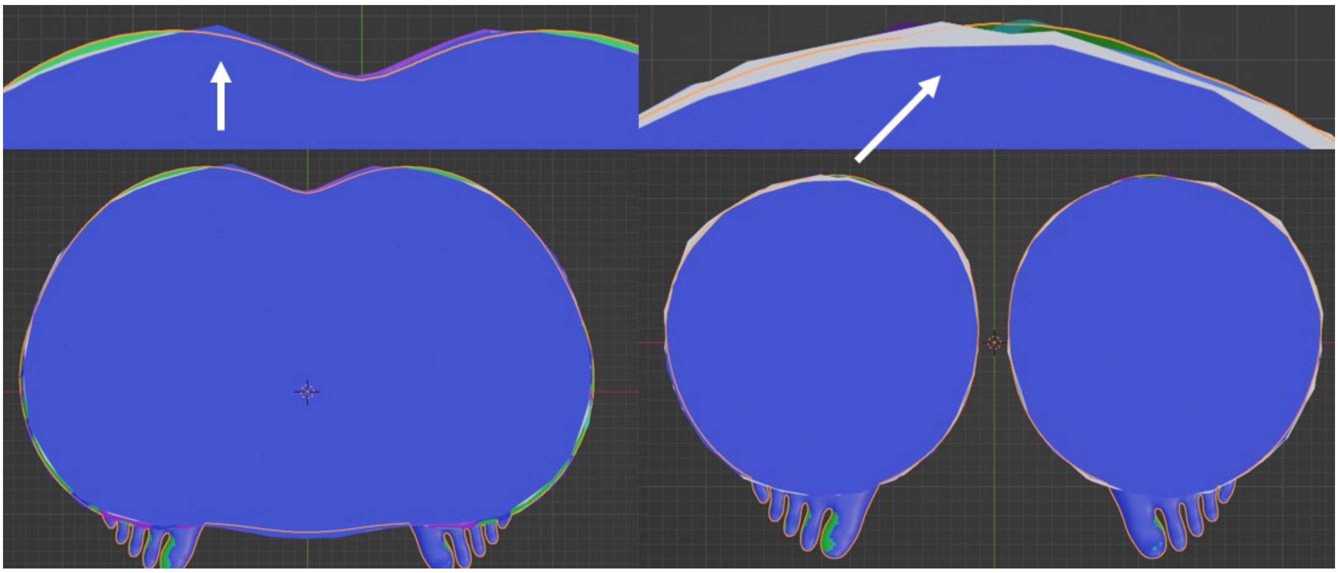

Fig. 6 Cross section comparison hip and thigh.

6 Conclusions

In this study, the behavior of a soft avatar was investigated when leggings with different negative ease values were used to exert pressure onto the avatar. Visually, it could be observed that the shape of the avatar changed, but a closer look at the meshes revealed angular shapes. Although the simulation computed very quickly and provided interesting insights into where too-tight garments cut into the fat zones, there were some limitations that should be noted.

One of the main limitations was the lack of information about the properties of the soft avatar. The avatar was simulated using an unknown method, and there was no information about the material properties or any physics behind the softness of the avatar, like Young's modulus, the Poisson's ratio and the shear modulus. This made it difficult to accurately interpret the results and draw conclusions about the behavior of the soft avatar under different conditions.

Despite this limitation, the fast calculation time of the simulation tool used in this study is a promising feature that could be useful in the design and construction process of garments. However, to fully understand the behavior of soft avatars, much more investigation and research is needed, including the development of finite element models for the application of garment fit analyses that can accurately represent the softness of human tissue for comparison and verification of the avatar in CAD clothing software. [28] These models would provide a more detailed understanding of how human tissue deforms under various conditions and would allow for more accurate predictions of how garments will fit and behave on the human body.

In summary, this study represents a preliminary investigation of the behavior of the soft avatar Sofia in Browzwear's VStitcher when subjected to the pressure of leggings with different negative ease values. While the results provide interesting predictions about the behavior of soft avatars, further research and the development of accurate models are needed to fully understand the complex behavior of human tissue and its interaction with different types of garments. To verify the behavior of the soft avatar, the simulation type, the underlying material model and its properties should be known.

Author Contributions

E. Brake – simulation, draft preparation, writing – review and editing; Y. Kyosev and K. Rose: supervision, review and editing, project administration. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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