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BIOLOGY

Anatomical models manufactured with Styrofoam waste as a low-cost ecological tool for practical teaching of comparative anatomy

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ABSTRACT: New teaching tools can expand the pedagogical alternatives for teaching comparative anatomy. This study evaluated the potential of Styrofoam waste for the manufacture of viable didactic models to teach comparative anatomy. From a primary block, the sculpting was started with a knife or cutter. After this, the edges were removed with sandpaper until the final anatomical shape of the organ was obtained. The surface of the sculpture was then covered with paper soaked in an aqueous solution of white glue. After drying, a layer of resin was applied, followed by polishing to even out the surface. The models are finished with paint and waterproof sealant. Through the teaching prototypes, it was possible to enlarge naturally small organs and structures to larger dimensions that favor practical teaching. This facilitates the didactic approach to anatomical details unavailable in traditional specimens. In addition, its use minimizes the risks to human health from exposure to the toxic products used to preserve cadavers and contributes to preserving the environment. The effectiveness of injected resin models for teaching anatomy is already known, which makes the use of synthetic anatomical models a valid methodology, but they may have limitations in many countries due to their high cost and difficulty of access. Our proposal offers an effective, low-cost alternative for teaching comparative anatomy in practice. When combined with other techniques, Styrofoam waste proved to be viable for the manufacture of teaching prototypes.
Key words: Styrofoam™, environmental conservation, education, morphology.

Modelos anatômicos fabricados com resíduos de isopor como ferramenta ecológica de baixo custo para o ensino prático de anatomia comparada

RESUMO: Novas ferramentas didáticas podem ampliar as alternativas pedagógicas para o ensino da anatomia comparada. O objetivo deste estudo foi avaliar o potencial do resíduo de isopor para a confecção de modelos didáticos viáveis para o ensino de anatomia comparada. A partir de um bloco primário, a escultura foi iniciada com uma faca ou cortador. Em seguida, as arestas foram removidas com lixa até se obter a forma anatômica final do órgão. A superfície da escultura era então coberta com papel embebido em uma solução aquosa de cola branca. Após a secagem, foi aplicada uma camada de resina, seguida de um polimento para uniformizar a superfície. Os modelos são acabados com tinta e selante à prova de água. Através dos protótipos didáticos, foi possível ampliar órgãos e estruturas naturalmente pequenos para dimensões maiores que favorecem o ensino prático. Isso facilita a abordagem didática de detalhes anatômicos indisponíveis em espécimes tradicionais. Além disso, seu uso minimiza os riscos à saúde humana pela exposição aos produtos tóxicos utilizados na conservação dos cadáveres e contribui para a preservação do meio ambiente. A eficácia dos modelos de resina injetada para o ensino da anatomia é já conhecida, o que torna a utilização de modelos anatômicos sintéticos uma metodologia válida, mas estes podem ter limitações em muitos países devido ao seu elevado custo e dificuldade de acesso. A nossa proposta oferece uma alternativa eficaz e de baixo custo para o ensino da anatomia comparada na prática. Quando combinados com outras técnicas, os resíduos de isopor revelaram-se viáveis para a fabricação de protótipos didáticos.
Palavras-chave: Isopor®, conservação ambiental, educação, morfologia.

INTRODUCTION

Anatomy is an essential part of the medical school curriculum and is accepted as the basis for other subsequent subjects. It is usually taught as a combination of lectures followed by practical sessions in laboratories (COLAK et al., 2021; DIDIO, 2002). For centuries, the cadaver was used as the only tool for teaching anatomy (DINIZ et al., 2006; SIMIONATO et al., 2019). Nonetheless, the scarcity of teaching material from cadaveric preparations has been the main problem in practical classes, negatively impacting student learning (CUSTERS, 2010). Various strategies have already been tested to replace and/or complement the use of dissected specimens (MERINI et al., 2014; TRELEASE, 2002, 2016). However, most of them are expensive to acquire due to heavy import taxes or do not maintain the true similarity necessary for effective academic learning.

Changes in anatomy teaching have definitely taken hold in the post-pandemic era (PATRA et al., 2022). Various non-traditional methodologies have already been implemented, but recently the use of artistic approaches such as living anatomy (ASAD et al., 2023),

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3D imaging software (BLÁZQUEZ-LLORCA et al., 2023; KAPOOR & SINGH, 2022; KRISHNASAMY & NARAYAN, 2023) and social media (BRANDÃO et al., 2022; SADEGHINEZHAD, 2022, 2023) have been notably boosted by the SARS covid-19 pandemic. In addition, didactic prototypes produced from "biscuit" modeling have already been used in the practical teaching of human (FREITAS et al., 2020; MERINI et al., 2014) and animal anatomy (SOUZA et al., 2015). The limitations related to the anatomical inaccuracy of this technique have prompted research into alternative materials for producing more effective and economically viable anatomical models. The use of Styrofoam™ to manufacture anatomical models is scarce. Few articles have reported the partial use of this raw material to manufacture didactic prototypes used in practical human anatomy classes (ARAÚJO JUNIOR et al., 2014; BEZERRA et al., 2022) and paleontology through the replication of foraminifera fossils for teaching (MACHADO FILHO et al., 2011).

The Styrofoam™ is a molded thermoplastic expanded with polystyrene, which is highly versatile and can be used in various industry segments. Despite being 100% recyclable, there is very little interest in adopting reverse logistics and recycling due to its high volume and low weight, which makes difficult to implement the collection of this waste by sorting organizations and social collectors (MORAIS & VIDIGAL, 2021). The large volume that the product provides when disposed of inappropriately directly harms the environment (ALMEIDA et al., 2014; SIMÕES & SANTOS, 2012). Reflecting the current context of teaching animal anatomy and the growing concern for best practices in environmental conservation, this study evaluated the potential of Styrofoam waste for manufacturing viable didactic models for teaching comparative anatomy. This should expand the resources for teaching animal anatomy in places where access to cadavers is restricted, as well as contributing to environmental conservation.

MATERIALS AND METHODS

Raw material collection

The raw materials used to make the prototypes were collected from household waste and construction work sites. However, this waste was usually in the form of panels of different thicknesses, which were glued together with Styrofoam adhesive.

Sculpture

The sculpture began with the contour of the organ applied to the surface of a block of Styrofoam waste with a highlighter (Figure 1A). Then, using a knife or cutter, controlled notches were made until the characteristic morphological appearance of the organ was obtained (Figure 1B). Specific details can be obtained using pre-molded Styrofoam waste, such as disposable coffee cups or general-purpose packaging. The sculpting phase was completed using sandpaper of different grits to remove the edges left by the knife and even out the surface (Figure 1C).

This stage *Paper gluing* consisted of applying one or two coats of small fragments of paper (20 - 75g/m^2 depending on the complexity of the sculpture's carvings) soaked in an aqueous solution of polyvinyl acetate - PVA glue (white glue) until the surface of the sculpture was completely covered (Figure 1D). The - white glue was blended with water at room temperature in a 1:1 ratio to make it easier to apply. After coating the entire surface, a layer of undiluted white glue was applied to seal it. The coated

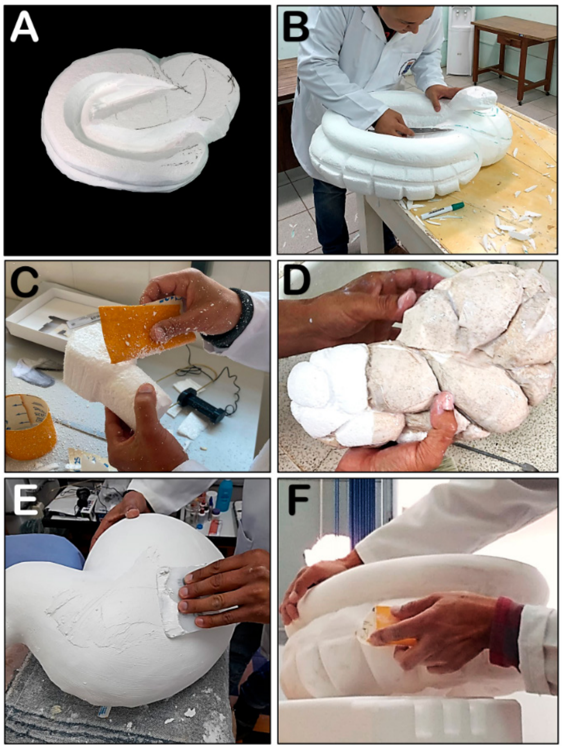

Figure 1 - *Sculpting stage*: A - From the outline of the organ on the Styrofoam block, the anatomical features of the organ were sculpted using the knife or cutter (B); C - Polishing the sculpture to remove the edges left by the cutter. *Paper gluing stage*: D - Applying the paper fragments soaked in white glue. *Resin coating stage*: (E) Applying the acrylic paste to the surface of the prototype with a spatula; F - Polishing to even out the surface of the sculpture.

sculptures were left to rest (at room temperature and in the shade) until the glue had completely polymerized.

Resin-coating

To obtain a smooth and uniform surface, a layer of acrylic paste was applied to the entire sculpture. This component was made from a combination of hydrated aluminum silicate (industrial talc) and acrylic PVA paint in a 1:1 ratio. The entire surface received a 2-3 mm thick layer of putty. Larger, flatter surfaces were resin coated with acrylic paste using a spatula (Figure 1E). For smaller, less accessible surfaces, a long-bristled brush was used. After polymerization, the surface was polished using sandpaper of decreasing grain size (Figure 1F).

Painting and finishing

In the initial painting phase, “primer” was applied to the entire surface of the prototypes with a compressed air gun to prevent texturing caused by the bristles of the brushes (Figure 2A). PVA acrylic paints diluted with water were used, according to the manufacturers’ recommendations. The pigments were chosen, trying, whenever possible, to mimic the natural color of the various organs and tissues. The vascular structures were highlighted in shades of blue and red. Tubular and nervous structures were painted in other shades (green and/or yellow). The ligamentous structures were differentiated in light tones. The “light and shade” technique was applied, giving the models a three-dimensional appearance, emphasizing volume and depth on the surface (Figure 2B). Specific morphological details were also added at this stage (Figure 2C - box).

The prototypes were finished by applying two layers of white glue followed by a layer of waterproof plastic resin. A soft bristle brush was used for this (Figure 2D). For some models, it was necessary to mimic the natural characteristics of the tissue (enamel on the dental crown, for example). Therefore, specific ultra-gloss enamel paints or general finishing varnish were used.

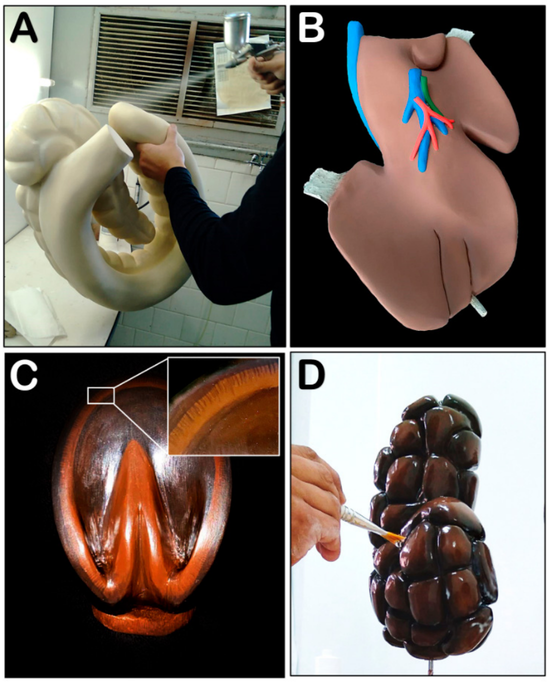

Figure 2 - *Painting stage*: A - Sculptures prepared with “primer” for painting; B - Shading technique to emphasize depth and relief on the surface of the organ; C - Application of morphological details through painting on an equine hoof model (Box) - Detail of the corio-lamellar junction of the ungueal capsule; D - Finishing the model with the application of waterproof plastic resin.

RESULTS

Limitations

In this study, few organs were unfeasible to make prototypes of. The natural fragility of Styrofoam made it impossible to replicate complex morphological details. Examples include parts of the skeletal system such as eyeball and the skull). In addition, it was more difficult to sculpt lobed organs, such as the livers and lungs of carnivores and swine. In these prototypes, the sculpture was made in isolated parts that were later joined together to recover the shape of the entire organ.

Climatic factors negatively affected the resin coating and painting stages. Temperate climates characterized by cold and humid days, such as southern Brazil (Figure 3A1-A2), slowed down the polymerization of the acrylic putty, causing artifacts in the paint (Figure 3B). The solution to these problems was to ensure that the prototypes were dried in drying oven with controlled temperature and humidity.

In contrast, days with high temperatures and low humidity accelerate the polymerization process of the resin, which causes cracks and fissures on the surface of the model (Figure 3C). Under these conditions, the resin-coating should be carried out in a cool place, protected from direct sunlight and wind. In addition, before initial painting, the surface should be thoroughly cleaned to remove acrylic putty residue and dust. This prevents the paint layer from peeling off when the finishing resin is applied (Figure 3D).

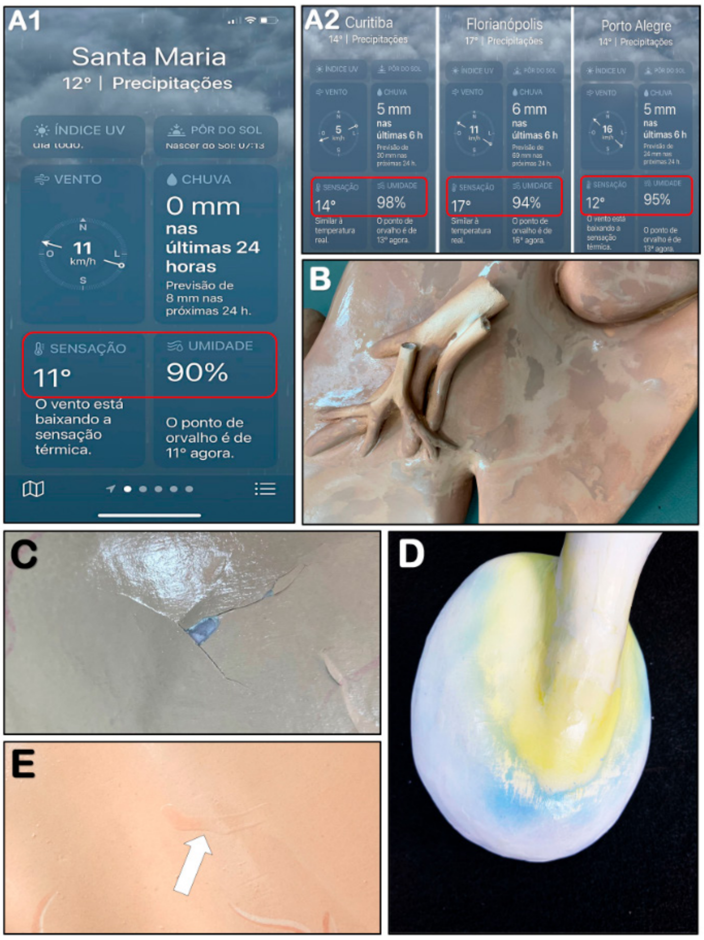

Figure 3 - Limitations: A1/A2 - Meteorological data on air temperature and relative humidity in the southern region of Brazil collected on August 9, 2023; B - Paint artifacts caused by excess moisture in the resin layer; C - Cracks caused by incomplete polymerization of the resin; D - Paint detachment caused by the presence of residual dust and dirt on the surface of the sculpture; E - Waterproof plastic resin artifact caused by improper application.

The waterproof plastic resin has increased resistance to handling and minor mechanical shocks. It should be applied quickly and effectively with an ultra-soft bristle brush to avoid texturizing the surface of the finished model (Figure 3E).

General aspects

Extensive knowledge of anatomy was fundamental to ensuring the morphological accuracy of the prototypes. This made it possible to replicate morphological details in the sculptures, such as impressions of other organs on the surface, which are not usually seen in natural specimens in teaching collections. Most of the prototypes produced in this study were on a 1:1 scale (Figure 4A, B1-B2, E, F, G, H1-H2, I1-I2-I3). However, among the many positive aspects of this methodology, we can also highlight the possibility of enlarging naturally small organs and structures to dimensions more suitable for practical teaching of animal anatomy. This can be easily achieved with models of teeth enlarged at 15:1 scale (Figure 4C and D) and middle ear ossicles enlarged at 30:1 scale (Figure 4J). In addition, it was possible to replicate aspects of the variant anatomical arrangements, expanding the didactic possibilities of these models in practical classes in comparative anatomy and other disciplines.

Choosing the grammage of the paper in advance was important to increase the resistance of the soft Styrofoam surface in the finished sculpture.

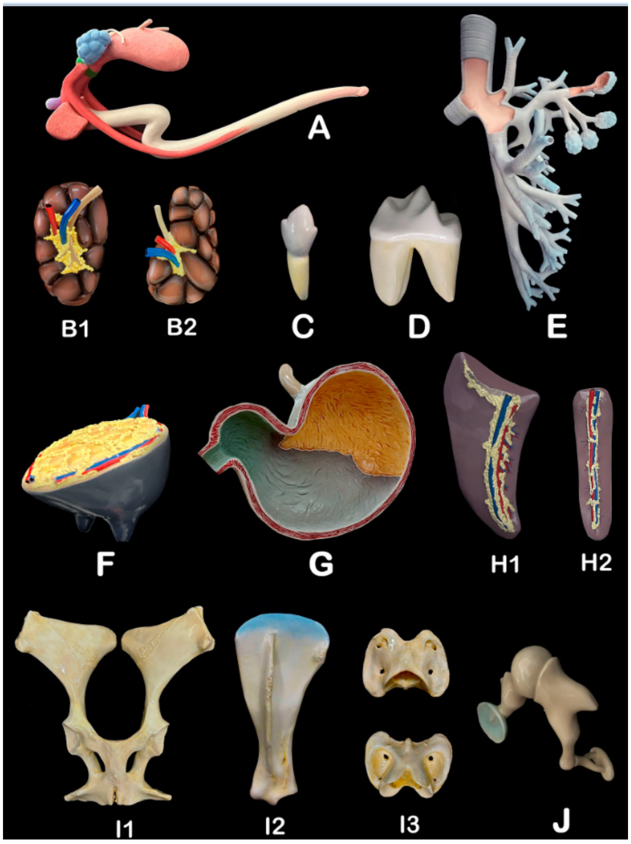

Figure 4 - Finished models: A - Bovine penis and accessory sex glands; B1/B2 - Bovine kidneys; C - Dog incisor tooth; D - Dog molar tooth; E - Equine bronchial tree; F - Mare mammary gland; G - Equine stomach; H1 - Equine spleen; H2 - Swine spleen; I1 - Equine hip bone; I2 - Equine scapula; I3 - Equine atlas; J - Equine auditory ossicles.

"Thick" papers such as Kraft paper, found in the trade as "brown packaging paper", were useful in this process. It was also important to define the number of layers of paper to be applied, depending on the size of the model. For larger, flat surfaces, up to two evenly distributed layers of paper were used. For models with smaller surfaces, containing grooves and folds that made gluing difficult, smaller fragments of thin paper were applied with a brush dipped in white glue.

Financial investment

Financial control was an important part of this study to validate this proposal as a low-cost tool. The fixed cost referred to the purchase of equipment for sculpting and painting (knives, cutters, air compressor and paint gun), as well as accessories for storing and displaying the models. Although these items are part of the routine equipment list in anatomy departments for carrying out other anatomical techniques, we decided to purchase them in order to calculate the total fixed cost. The variable cost referred to the purchase of materials for specific use in this study (resins, glues, paints and others). The details are described in table 1.

DISCUSSION

As part of understanding animal anatomy, an appreciation of the architecture of the body of different domestic and wild species is essential knowledge for veterinary students. However, concern about the social impacts caused by the use of dead or live animals in undergraduate teaching has led to changes in approaches to technical-scientific education, recognizing the need for changes in the methodological proposals established in teaching

Table 1 - Description the investment (dolar) to manufacture synthetic models from Styrofoam waste.

	-----------------ITEM-----------------	-----------PURCHASE DATE----------	--------------VALUE--------------
Fixed costs	Handy type polyfoam cutter	06/08/2021	$ 31.5
	Airbrush	10/05/2022	$ 37.0
	Air compressor	20/06/2022	$ 181.3
	Air compressor hoses and fittings	31/03/2022	$ 26.7
	Knives	01/04/2022	$ 6.8
	Air compressor filter dryer	10/03/2022	$ 26.5
	Air gravity spray gun	07/03/2022	$ 49.5
		TOTAL	$ 359.3
Variable costs	Polyvinyl acetate pva white glue	02/07/2022	$ 3.8
	Styrofoam glue		$ 3.5
	Paint roller	23/03/2022	$ 13.2
	Sandpaper	31/05/2022	$ 67.5
	Spatula	16/03/2022	$ 4.8
	Hydrated aluminum silicate	30/11/2021	$ 11.6
	Acrylic PVA paint	01/12/2021	$ 41.2
	Ultra-gloss varnish	23/02/2022	$ 32.6
		TOTAL	$ 178.4
	TOTAL INVESTIMENT	U$ 537.7	

practice (FREITAS et al., 2020). Although some reasons still justify the use of cadavers in practical anatomy classes, alternative methods that complement teaching on cadavers should be encouraged. In addition, depending on the purpose or subject of the practical classes, didactic prototypes can be used to complement teaching on cadavers, especially for structures that are difficult to visualize or access through dissection. In addition, it can be assumed that the use of didactic anatomical prototypes as alternative learning tools, together with advances in tissue fixation and preservation techniques, will help to reduce the use of cadavers in the long term.

Studies that have investigated students' perceptions of human anatomy practical classes suggested that "cadaveric stress" causes different levels of distress, affecting academic performance in the course (MAZZOGLIO-Y-NABAR & ALGIERI, 2023). In addition to the traditional nuisance caused by the evaporation of toxic gases from cadaver preservative solutions, there is an ethical issue that cannot go unmentioned. The contributions in this context postulate that the circle of moral reflections extended to animal cadavers must be carefully observed. These advances are related to the animal welfare policies implemented in universities and research centers, as well as the increased awareness of these practices by civil society.

Significant technological advances combined with easy access to technology have made it possible to use virtual platforms to study anatomy (SENOS et al., 2022; SILVA et al., 2022). What was once an unproven trend has become a robust methodology with excellent results since the SARS covid-19 pandemic. In this scenario, other possibilities for teaching animal anatomy have been enhanced during the pandemic, for example, delivery anatomy kits (MACHADO et al., 2022). However, it is necessary to consider the limitations that restricted access exclusively to dry parts of the skeletal system or cry dried organs, as it was not possible to include specimens that required preservation in solutions. In view of this, the use of viable synthetic models has proved promising for practical teaching of animal anatomy due to the versatility of the collection's use. In addition, the possibility of sculpting organs that retain the anatomical precision of their contours and volumes is also a breakthrough in this study.

The scarcity of cadaveric material coupled with the impossibility of making didactic preparations that preserve the original volumes and contours of the organs in situ may benefit from the methodology proposed in this study. Models made from alternative raw materials such as Styrofoam® made it possible to produce organs at different scales. It was possible to replicate organs from real size, maintaining the anatomical accuracy of the natural shape and volume, to super-sized scales, making it possible to study naturally inaccessible structures and organs. Thus, it is possible to assume that this didactic tool will improve the traditional way of presenting anatomical parts in practical classes, stimulating learning. The use of cadavers as a teaching tool is still widespread for teaching animal anatomy in veterinary schools around the world (TRÉZ & LOPES NAKADA, 2008). Some authors still consider practical classes taught on cadavers to be an indispensable qualitative condition for teaching anatomy (BIASUTTO et al., 2006; GHOSH, 2017). However, it is increasingly difficult to receive healthy specimens that meet the conditions for teaching, to the detriment of the legislation in force in many countries (including Brazil), which prohibits the euthanasia of animals intended for teaching (COSTA et al., 2012; SOUZA et al., 2015). In addition, several studies have shown that a significant proportion of veterinary students are very uncomfortable with the euthanasia of animals for teaching purposes (DINIZ et al., 2006; MIRAULT-PINTO et al., 2005). Therefore, the implementation of substitute methods that oppose the full use of cadavers should be strongly encouraged. There is a pressing need to consider other teaching resources because the discomfort that the traditional method causes students is becoming more and more frequent in the classroom.

In recent decades, the production of Styrofoam™ has increased dramatically due to its many applications. The characteristics that have made Styrofoam™ so attractive also come at a high cost to the environment. The packaging industry alone consumed 46.9% of global Styrofoam™. Consequently, the accumulation in the environment has also increased alarmingly (UTTARAVALLI et al., 2020). When it comes to the pollution of oceans and other bodies of water by microplastics, EPS is often chosen singled out as a key element in environmental degradation. In Brazil, up-to-date environmental impact data is unavailable, but the presence of Styrofoam™ has been widely recorded as a common component of marine litter (ALMEIDA et al., 2014; SIMÕES & SANTOS, 2012). As EPS disintegrates into very small fragments, in addition to maintaining its rigid floating form, it has a direct impact on marine ecosystems in several coastal countries, affecting human health as a result.

Despite its great potential, the use of Styrofoam™ has been strongly discouraged because it is not environmentally sustainable (KULAKOVSKAYA et al., 2023). Among its many limitations, we can highlight the fact that it is too light to allow reverse logistics in recycling systems. In addition to causing environmental problems at the end of its useful life, it should be noted that the Styrofoam™ production process consumes a lot of energy, with a number of associated negative environmental impacts (MARTEN et al., 2018). The reuse of Styrofoam™ waste has become a topic of growing interest, stimulating various integrative actions in many countries. Thus, the use of synthetic and sustainable anatomical models that oppose the integral use of cadavers adds to other complementary pedagogical strategies as well as contributing to environmental conservation.

CONCLUSION

As far as we know, this study is the first to use Styrofoam waste as the exclusive raw material for producing didactic prototypes for teaching anatomy. When combined with other techniques, Styrofoam waste showed great versatility for manufacturing the prototypes. Its texture and density were suitable for sculpting, allowing high quality and precision to be achieved in the finished pieces (Figure 4). It is therefore conceivable that the use of Styrofoam waste as a raw material for making synthetic models could fill this gap, integrating the environmental and economic aspects of implementing this methodology.

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DECLARATION OF CONFLICT OF INTEREST

The authors declare that there is no conflict of interest that could be perceived as prejudicing the impartiality of the study.

AUTHORS' CONTRIBUTIONS

Conceptualization: João Vlademir dos Santos Roberts; Luciano de Morais-Pinto. Project administration: Luciano de Morais-Pinto. Data curation: João Vlademir dos Santos Roberts; Vítor Pires Pereira. Investigation: João Vlademir dos Santos Roberts; Luciano de Morais-Pinto. Methodology: Luciano de Morais-Pinto. Writing–original draft: João Vlademir dos Santos Roberts; Vítor Pires Pereira; Luciano de Morais-Pinto. Writing-Review & Editing: Luciano de Morais-Pinto.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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