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NEW PARADIGMS IN DESIGNING THE MEDICAL TEXTILES

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Abstract: *Foreign bodies penetrating deep into the wound at the time of tissue damage can cause chronic inflammatory responses that delay healing and can sometimes lead to the formation of granuloma or abscess. In general, a product intended for the treatment of gunshot wounds must be hypoallergenic, non-toxic and biocompatible; be able to prevent microbial contamination, to enable the gas exchange and exudate evacuation; to be flexible and adaptable to body contours; to be able to deliver, with the appropriate kinetics, important therapeutic compounds for the healing process and to be adherent. The researches were focused on performing of coupled simulations of the human body anatomy, analyse of the impact of the military weapons with different ballistic performances against human body, mathematical modeling of the electrospinning process and definition of the textile mesh parameters. The design of the technological process for obtaining the textile structures used in particular case, was performed, with the help of a dedicated software, the simulation of the main areas of interest of the human anatomy, respectively: the circulatory, bone and muscular system. The results of the simulations enabled the description of the phenomena that take place on the human body subject to the action of the 5.45 x 39 mm infantry armament at subsonic speeds and the mathematical model allowed the prediction of the control of the mesh permeability and of the neo tissue cellular growth and proliferation.*

Key words: *software, anatomy and physiology, simulation, modelling, electrospinning.*

1. INTRODUCTION

Shot wounds are characterized by an inlet and an outlet and the imaginary line joining the two orifices orients the organs affected by the projectile that passed through the body segment.

Although most wounds could be healed without major events, problems can sometimes occur are associated with failure or prolongation of the healing period. Failure in healing process of a wound within the expected time frame, usually leads to the development of a chronic lesion that cannot be easily treated due to the disruption of the orderly sequence of events associated with the natural healing process [1]. Excessive exudate production can cause, around the wound, maceration of healthy skin tissue and can inhibit the healing process. In addition, exudation from chronic wounds differs from acute wound fluid, with relatively higher levels of more corrosive and destructive tissue proteases. The odor and colour produced by the exudate can also have a negative impact on a patient's overall health and quality of life. Wound healing is a complicated process, which involves the adoption of different strategies, as a function of the types of wounds [2].

Depending on the area of the trauma, the infectious situation and the medical treatment, wound healing can be divided into different categories, including primary, secondary and sub-eschar healing.

2. WEAPONS AND HUMAN BODY INTERACTION

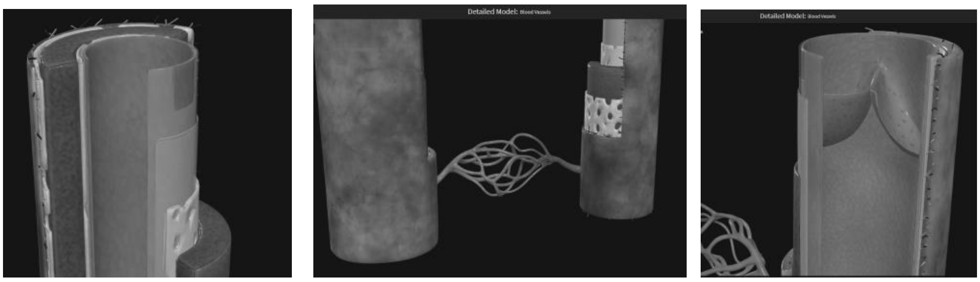
2.1. Coupled simulations of the human body anatomy

The anatomy of the circulatory system is represented by:

- blood vessel system: arteries, capillaries and veins (Fig. 1);
- lymphatic vessel system: capillaries, vessels that collect and conduct lymph and lymphoid organs.

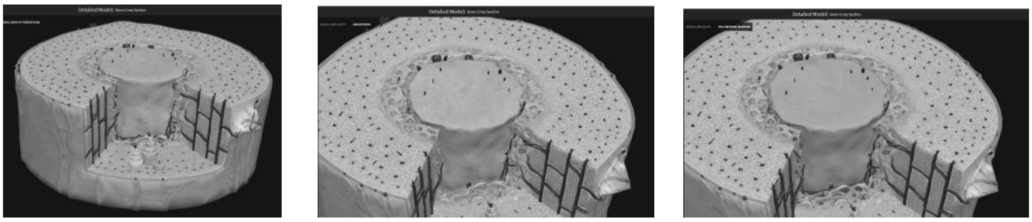
The couplings between these systems are shown sequentially in Fig.1.

The skeletal system (skeleton) consists of 206 connected bones, in most cases through the joints and is divided into: cephalic skeleton, axial (thoracic cavity, sternum, spine) and appendicular (limbs). It was considered that does not present importance the simulation of the thoracic cavity, of the sternum or of the spine as the skeletal system could be simulated together with the muscular system. However, during the simulation process the bone tissue was considered, as the protection of these anatomic parts requires bulletproof protective equipment (helmet, vest), even when it comes to instruction and training, not only in the theater of operations. The images resulting from the simulations are presented in Fig. 2. For the simulation process the associated pathologies for this system (fractures, infection) at impact with weapons (bullet, shrapnel) were considered.



a. *b.* *c.*

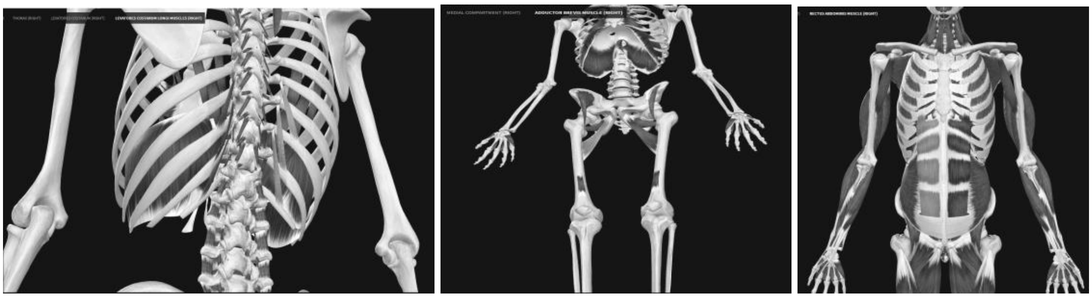
***Fig. 1**. Circulatory system: a. arthers, b. capilars, c. veins*



a. *b.* *c.*

***Fig. 2**. Bone tissue: a. periosteal fibrous layer, b. endost, c. bone marrow*

The muscular system (with 600 skeletal muscles) is especially important for the field of application, because it is involved in maintaining the basic position and movements. Although the muscles are of three types (skeletal, cardiac, smooth), for simulation, the cardiac muscle was removed, because it was considered that it is not involved in these types of situations (shooting or burns), its role intervening rather after the development of pathologies and its action represents an effect of interaction. In Figs. 3, 4 and 5 are presented layered (layer 1,3,7), from skeleton to skin, examples of skeletal muscle categories depending on location along with the skeletal system.

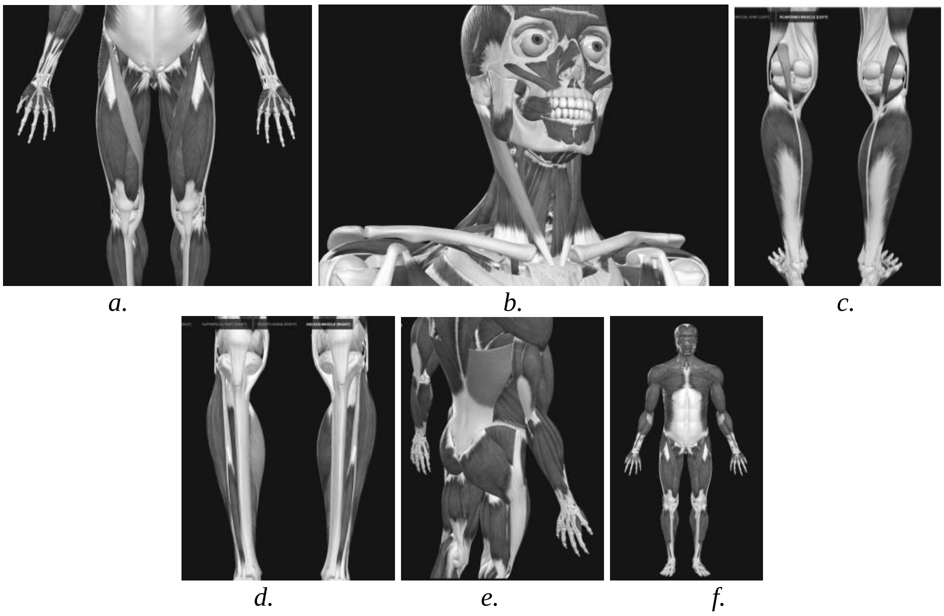


a. b. c.

***Fig. 3**. Muscular system – layer 1: a. articularis genius muscle; b. levatores costarum longi muscles; c. adductor brevis muscle.*

a. b. c.

***Fig. 4**. Muscular and bone system – layer 3: a. clavicle; b. semispinalis capitis muscle; c. vastus medialis muscle*



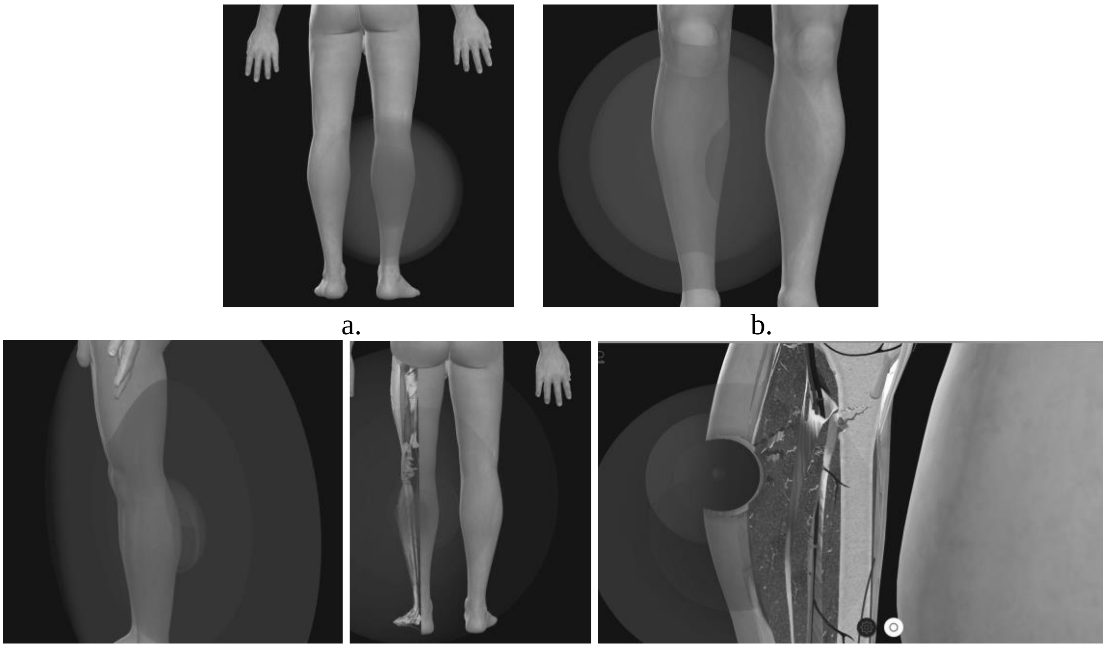
a. b. c.

d. e. f.

***Fig. 5.** Muscular and bone system – layer 7: a. Sartorius muscle; b. sternal head of sternocleidomastoid; c. plantaris muscle; d. soleus muscle; e. latissimus dorsi muscle; f. all muscles*

The simulation was performed for infantry troops using assault rifles PA Md. 86 and 63/65/90, cartridges loaded with projectiles 5.45x39 mm and with following ballistic performance: bullet mass between 3.43g (53 gr) - 3.62 g (56 gr) type FMJ, velocity: 880 m/s (2900 ft/s) and energy 1,328 J (979 ft.lbf) - 1,402 J (1,034 ft.lbf).

For simulation, the shooting distance was kept constant, 800 m. Figure 6 highlights the behavior of the human body (male) in two distinct cases, for energies developed of 1,328 J and 1,402 J respectively for impact in the area of the lower and upper limbs (constituted virtually with all anatomical systems).



a. b.

c. d. e.

Fig. 6. *Simulation of the bullet of 5.45x39 mm impact for 328 J (a., b. – right leg) and 1,402 J (c., d. – left leg; e. – right hand)*

The images obtained (Fig. 6 e. and f.) show the fracture of the left lower limb joint and the penetration of the bone in the case of the right upper limb. Future researches actions will be directed to the simulation of burns caused by artillery or aviation ammunition.

3. ABSORBANT LAYER ACHIEVEMENT

3.1 Electrospinning technological process simulation

The dates obtained as a coupled simulation results evidenced the values of the main parameters that should be considered in order to design and develop medical textiles dedicated to these types of applications, as a function of the energy absorbed at the impact of the bullets and anatomic region is between 1200-1500 joules. Moreover, the pression of the circulatory system against the textile support determine, mainly for the absorbent layer, the values imposed for the porosity, pores dimension and braking resistance.

Worldwide, the most used technology to obtain an absorbent layer for this type of wound is represented by the electrospinning process, because it allows:

a. making fibers with very small diameters (in the range of 20 nm – 20 µm) - essential for obtaining the specific functionalities of the textile structural network;

b. increasing the surface areas of the constituent entities.

Recent studies [2,3,4] have shown that, for biomedical applications, the adhesion of fibroblast cells and their migration depends on the fiber diameter.

In the case of usage as a composite absorbent layer (e.g., deep burns due to splinters, shingles, etc.) its hardness decreases proportionally with the decrease of the fiber diameter, because the surface area and implicitly the volume increase with the decrease of the diameter [3,4,5].

Despite the apparent simplicity, the mathematical modeling process is complicated, because many factors influence the fiber diameter and implicitly its final morphological structure, such as:

- solution parameters: viscosity, concentration, molecular weight, surface tension, electrical conductivity, electrical dipole moment, dielectric strength;
- process parameters: feed rate, electric field strength, distance between peak and collector, collector type, composition, temperature, relative humidity and air flow.

Empirical models are known that predict the morphology according to a single parameter of the fluid, for instance: fiber diameter and polymer concentration have a linear relationship [1,4], fiber diameter is proportional to the polymer concentration cube, jet radius is inversely proportional to cubic root of the electrical conductivity of the solution, the jet diameter is related to the feed rate (Q) in the form D ~ Q 0.04, the fiber diameter has an exponential relationship with the viscosity of the solution (exponent 0.41), the jet diameter and material properties are in relation (1) [1,2,5].

$$d = \sqrt[3]{\gamma\epsilon\frac{Q^2}{I^2}\frac{2}{\pi(2Ln(\aleph-3))}} \qquad \textbf{(1)}$$

where: γ = surface tension, ϵ = dielectric constant, Q = debit, I = the current carried by the fiber, $\aleph$ = nozzel diameter, L = the initial length of the jet.

3.2. The control of the textile mesh permeability in order to control of the cellular growths and proliferation and diferentiation of the neotissue

It is well known that nanoporous materials can be optimized by controlling pore size and distribution and a variation of the porosity in the range [75; 92] % leads to the variation of the breaking strength limit from 0.475 MPa to 1.886 MPa [1, 6, 7].

Research conducted so far by the Research-Development National Institute for Textiles and Leather specialists on fibrous materials obtained by electrospinning has led to the conclusion that the fibrous network can be characterized by the variable "average coverage", so the number of fibers that converge at a point in the network is defined by the function of probability:

$$f(x) = \begin{cases} e^{-\lambda}\dfrac{\lambda^x}{x!}, & x \in N = \{0, 1, 2 \ldots\ldots n\} \\ 0, & in\ rest \end{cases} \qquad \textbf{(2)}$$

(Poisson distribution of parameter λ>0 for a random variable X, as the limit of the binomial distribution with parameters n and p, for the particular case n → ∞ and p → 0, with np → λ).

The average number of contacts per unit length (in the case of 3D) can be calculated depending on the fiber diameter, the porosity of the material, its thickness, the cross-sectional area of the fiber and the number of layers. Experiments continue to determine the logarithmic expression associated with this number, the shape of the fiber cross section and the pore diameter. Also, the possibility of using fractal theories and the capillary model to describe the distribution of pore size and their length in the fibrous environment is studied, this being represented as a series of orthogonal fiber cells with random volumes.

Research continues in order to determine the permeability of fibrous layers with a random arrangement (depending on the volume of the fiber, its radius and the Knudsen number), especially for low working pressures.

4. CONCLUSIONS

The simulations performed so far by the Research-Development National Institute for Textiles and Leather specialists have allowed the prediction of the phenomena that take place on the human body subject to the action of the 5.45 x 39 mm infantry armament and that move with subsonic speeds. The control of the morphology and the mechanical behavior of the nanofibers is still at the beginning and the mathematical models obtained so far predicting these parameters are strictly developed for the field of use of the network.

It is necessary to deepen the specific phenomenology of this process for future modeling simulation routes, especially regarding the evolution of nanoscale structures and parameter control.

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