Palaeomechanical investigations of ballistic injury patterns and weapon efficiency on the basis of Bronze Age finds.

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Résumé

The complex and highly dynamic processes which led to traumata on prehistoric human bones are difficult to determine by employing merely conventional methods and classical experimental approaches. In order to resolve this issue, an innovative methodological process (Palaeomechanics) was developed, which investigates the relationship between the external mechanical forces affecting the bone vis-à-vis specific injury patterns as well as the effects on the causative weapon types.
Palaeomechanic is a transdisciplinary suite of non-invasive methods covering 3D-imaging and 3D-reconstructions combined with the Finite Element Method (FEM), originally used in engineering sciences. The FEM enables to numerically verify or falsify initial hypotheses concerning mechanisms of injuries based on material properties and loading conditions.

The discovery of around 12.000 bones with numerous injuries as well as various weapon finds in the Tollense Valley in Northeast Germany hint at an armed conflict of unusual scale dating to ca. 1300-1250 BC. Among the lesions, stabbing and projectile traumas dominate. Since 2010 the site is under interdisciplinary investigations, financially supported by the German Research Foundation (DFG). In addition, the research project "Palaeomechanical investigations concerning the coherence of injury patterns and weapon efficiency on the basis of Bronze Age human bones and weapons", (funded by the DFG since 2017), has engaged in the trauma analysis.

The injuries correspond to a range of late Bronze Age weapons found in the valley including numerous flint and bronze arrowheads. Case studies, focusing in particular on the characterization and differentiation of wounding characteristics caused by projectiles, demonstrate the benefits of high-resolution imaging and 3D-reconstruction combined with digital and numerical simulations of the mechanism of injury.

Digital microscopy, micro-CT imaging and digital weapon matching were carried out, to obtain information about internal and external modifications of the bone structures cause

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by ballistic trauma as well as for the use-wear analysis of the arrowheads.

The FEM generated data concerning the influence of projectile and possible amour properties, velocities, impact-forces and the angle of the attack on a trauma. Non-linear parameters were applied to carry out real-time-deformation and collision-analysis to allow the simulation of likely attack scenarios. Results of these simulations are possible deformations and cracking characteristics of weapons as well as the characteristics and depth of the penetrating injury, the development of microfractures and the maximum shooting distance.
The results of the presented case studies will be integrated with ongoing palaeomechanical analyses.

Mots-Clés: 3D, Ballistics, Bronze Age, Armour, Finite Element Method, Injury patterns, Micro, CT, Palaeomechanics, Tollensetal, Trauma, Weapon efficiency