Introduction
The study of the Human Kinematics is an exciting field, and many unknowns remain to be determined and explored. Indeed, very little accurate data on human kinematics and bone morphology is readily available. Therefore, both industrial and fundamental researchers still need reliable data for their own applications. One of the main goals of the VAKHUM project is to produce data according to well-defined protocols, and to make this data available to users. Full documentation about the data's accuracy will also be available.

Kinematics is a typical 3D phenomenon, while textbooks can describe it only in a 2D way. Useful information is then lost for the students (pre- or -post- graduate). The VAKHUM project will use the above data to develop tutorials on Functional Anatomy. These tutorials will be integrated into a virtual reality environment accessible through the Internet.

Potential fields-of-application are numerous: industry using virtual models for testing (e.g. car safety, prosthesis), education (e.g. training of medical and bioengineering students, retraining of post-graduate professionals), fundamental research (e.g. better understanding of the human kinematics in biomechanics), virtual worlds (e.g. populating virtual worlds with accurate humans for the video game industry).

The VAKHUM project is a consortium of seven partners from five European countries including multi-disciplinary expertises: mechanical engineers, medicine, university professors, medical imaging, software engineers, multi-media experts and database engineers (the name of these partners can be found at the project website, see below for address).

Methods
Morphological data of human bones is collected from medical imaging, mainly by computerised tomodensitometry (CT-Scan). After segmentation, the latter allows the construction of very accurate 3D bone models (Fig. 1).

Several kinds of data will be available from the VAKHUM database. Not only the raw image data, but also both surface and finite-element models will be included in several formats. Surface models are useful for, for example, 3D animations (see next chapter) and/or education. Finite elements meshes are used to simulate the deformation and the mechanical stresses induced within living tissues by different motor tasks. They are essential in research, but also in clinical applications such as the evaluation of the risk of bone fracture, or the planning of complex musculo-skeletal surgery. Finite elements simulations are also useful to teach musculo-skeletal biomechanics.

[Figure 1. 3D bone models. Left: sacral bone, right: close-up on the acetabulum of an iliac bone.]

Kinematics data are collected as well. On one hand, motions of the human lower limb have been studied during several normal daily activities (walking, running, stair climbing, and so on) performed by volunteers. On the other hand, data about joint kinematics of the hip, knee and ankle joints were collected in vitro. Our aim is to combine the above morphological data with joint kinematics collected in vitro by 3D electrogoniometry and in vivo using stereophotogrammetry (Fig. 2). The main theoretical problem is to find a satisfactory registration procedure to combine the different kinds of datasets.

Musculoskeletal system. A pilot study is performed to determine the feasibility of the integration of muscle information in the project...
results. Muscle data collection is including medical imaging and dissections.

Educational tutorials are written for both medical and bioengineering students using the data collected by the project. The tutorials will be downloadable from the database in several European languages. Topics will address subjects like basic physics laws applied in Biomechanics, functional anatomy, study of different joints and tasks. These tutorials should be integrated in interactive multimedia animations that would allow the students to navigate in a 3D environment and manipulate the bone objects (Fig. 3).

Results (preliminary)

Several datasets for the lower limbs morphology have been collected and partly processed. A preliminary version of these models is available from http://www.ulb.ac.be/project/vakhum. Kinematics data has been collected as well for several volunteers and specimens. The consortium is now tackling the difficult problem of data registration of all 6 degrees-of-freedom available from the kinematics dataset with the 3D morphology (Fig. 4). The main problem is the difference of morphology between the subjects (volunteers and cadavers). Currently the registration procedure is used to synchronise the goniometer data using the spatio-temporal information from the stereophotogrammetry. Further registration will need to include registration of more degrees-of-freedom.

Morphological 3D surface models are animated using the results of the registration. First results are visible at the above URL.

Figure 2. Left: experimental in vitro setup for joint kinematics data collection. Right: in vivo stereophotogrammetry. Reference plates are visible on the specimen. These plates included 3-mm aluminium balls that are used for registration of the 3D bone models with the kinematics data. 3D electrogoniometer and 3D digitiser are used in this setup. The volunteer on the right is climbing up stairs while the task is recorded by video cameras.

Figure 3. Multimedia presentation will include a fully interactive 3D environment (on the right). A teacher (top left) will teach the topic related to the selected class.
Discussion - Conclusions

Final version of the database should be available during the last months of 2001. This database should allow both academics and industries to access various kinds of data that would be useful for their own needs. One of the project partners is involved in the numerical simulation of car-crash testing (Fig. 5). This partner is exploiting the data to integrate realistic virtual dummies into its virtual cars. Constraints on the dummies will be then analysed. Another aspect to be prospected is the simulation of a collision between cars and virtual pedestrians.

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