

# A Virtual Anatomical 3D Head, Oral Cavity and Teeth Model for Dental and Medical Applications

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**Abstract.** This paper presents a new hierarchical, modular and scalable mesh model of the human head, neck and oral cavity created by using anatomical information and computerized tomography (CT) data taken from the Visible Human Project. The described model, which is an extension of the MPEG-4 head model, covers the full geometry of the back of the head and the main organs of the oral cavity. The modular nature of the model makes it adaptable as a whole or per module, to any corresponding data of a specific human by means of a Finite Element Method (FEM). Our publicly available model can be used for creating virtual dental patient models as well as in other related applications in medicine, phonetics etc.

**Keywords:** anatomical head/oral cavity modelling, teeth model, finite element method, virtual patient, synthetic human head model, anatomical node.

## 1 Introduction

Human head modelling techniques can be classified to automatic, semiautomatic and manual ones, the latter being the most labor intensive.

The first attempt to model a human face was made by F.I. Parke [13]. The first, publicly available, simplistic but accurate generic face model, namely the CANDIDE model, was created by M. Rydfalk [15]. Its current version (CANDIDE-3)

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created by J. Ahlberg [1] incorporates new 3D vertices making the model more realistic and almost compliant with the MPEG-4 standard. Starting from skeletal muscle modelling using ellipsoids introduced by F. Scheepers [16], J. Wilhelms et al. [18] extended this idea for anatomy-based modelling and animation of humans and animals, using a multilayered structure consisting of bones, muscles and skin. K. Kaehler et al. [7] have constructed virtual face muscle models using fiber arrays (linear segments) for real-time physics-based facial animations. The Interactive Modelling—Anthropometry method (reconstruction from feature vertices) utilizes software tools for 3D ‘sculpting’ of a generic face mesh. After defining anthropometric facial landmarks, either from a pair of orthogonal 2D photos [9] or from a series of photographs [14], it uses an RBF-based interpolation for defining the rest (non-landmark) vertices in the generic model. Moreover, the creation of face-head models based on statistical data describing human face-head variations across individuals has been proposed [4].

All previously described modelling methods have focused on external head structures. O. Engwall [6] and M. Cohen et al. [3] have applied semi-automatic modelling methods on Magnetic Resonance Image (MRI), Electropalatography (EPG) and Electromagnetic Articulography (EMA) data, in order to obtain intraoral models for speech generation simulation. Using similar data sources, P. Badin et al. [2] created a speech oriented vocal tract model, by connecting 2D midsagittal contours of tongue and lips to create three-dimensional articulatory models. Stone et al. [17] used tagged Cine-Magnetic Resonance Imaging (tMRI) data for tongue modelling, while Y. Laprie et al. [8] utilized X-rays for this purpose.

None of the previously mentioned methods has produced a generic model for the variety of tissues comprising the oral cavity (teeth, tongue, larynx, etc.), along with the human head and neck, for use as an archetypal head-oral cavity model. To this end, a first attempt is described in [11], where we presented such a combined model created using real anatomical data for the inner anatomical structures and the well known CANDIDE face model.

In essence, our aim was to create an extension of the MPEG-4 head model that includes the oral cavity and the neck. Such an extension has the additional advantage of ensuring back compatibility to the MPEG-4 standard. Facial Definition Parameters (FDPs) and Facial Animation Parameters (FAPs) of the MPEG-4 were designed to quantify and normalize essential facial features and motions. In this paper, a number of new Definition Parameters, related to the structures that are not included in the MPEG-4 standard are proposed, as can be seen in Sect. 2. In addition to model creation, we have developed a Finite Element Method (FEM) based technique for registering the archetypal head-oral cavity model to 3D mesh or volumetric data (target data), corresponding to a specific individual.

The paper is structured as follows. Section 2 describes our head modelling approach. Section 3 deals with the detailed modelling of the constituting parts of our model. Section 4 describes the synthesis of the modules in a functional entity with a proposed extension of the MPEG-4 FDPs to cover the oral cavity, while Sect. 5 describes a FEM based approach for the personalization and registration of our model towards any given real person data. Conclusions follow in Sect. 6.

## 2 Anatomical Head/Oral Cavity Modelling

This section presents the approach used for head modelling, the data, model principles and structure.

### 2.1 Source Data and Their Preprocessing

Our modelling source was the publicly available anatomical data of a male cadaver originating from the Visible Human Project, National Institute of Health (NIH), USA [12]. Due to the geometrical complexity and interconnections of the human tissues to be modelled we adopted manual modelling, which allows the right selection of anatomically important vertices. The transversal 377 head slice images were turned to a cubic volume by means of a linear interpolation along the  $Z$  axis by a factor of 3 due to the different pixel spacing along this direction. After histogram equalization we were able to visually identify the various internal tissues/organs and by using the mouse, we have obtained the 3D coordinates of any internal or external landmark point of interest.

### 2.2 Head Modelling Principles

In our oral cavity modelling procedure, the anatomical structures to be modelled consist of various tissues (e.g. jaws, teeth, lips, cheeks). In order to accurately model these tissues physically, one would have to represent all their inner substructures (muscles, nerves, tendons, veins etc.) in detailed shapes and in the same arrangement as they occur inside the human body. Obviously, this task requires an enormous effort. However, for most target applications, such a detailed modelling is not required. Thus, we have chosen to model only the external surface of the structures of interest, which are of great importance in visual applications.

During modelling, we have assumed that any 3D surface of a prototype human head tissue has planar symmetry with respect to the  $YZ$  plane in the neutral posture and expression defined by the MPEG-4 standard. We enforced this symmetry by proper small modifications of the acquired 3D model vertices in order to eliminate naturally occurring asymmetries on the male cadaver head. This enforced symmetry of the head organ surfaces is an adopted idealization of the reality, since our aim was not to create a model of the real Visible Human male head and its organs, but to produce a generic head model with generic organ models that are based on real data that can be adapted to any head of the general population.

The number of vertices selected to model the various parts of the head was kept to a minimum in order to express the basic anatomical geometry. This choice allows for model compatibility with the CANDIDE/MPEG-4 external face models and ensures low computational effort in handling its personalization. An overly detailed model would be good for artistic visualization, but would be very difficult to personalize and rather slow to animate.

### 2.3 Hierarchical and Scalable Model Structure

Our proposed synthetic human head model structure is based on the notion of nodes used in Virtual Reality Modelling Language (VRML). Each node, named *Anatomical Node (AN)*, is a 3D surface representation of a human head organ, which is anatomically distinct from the neighboring ones. The 3D surface geometry of each such node is given by a set of 3D vertices forming triangles. The anatomical nodes can be combined to build more complex structures, i.e., other anatomical nodes, thus creating a hierarchical model structure, as shown in Fig. 1. 3D vertices belonging to anatomical nodes, that are uniquely identified in head image data and describe the anatomical structure geometry are called *Head Definition Parameters (HDPs)*. Our model HDPs corresponding to MPEG-4 vertices are the same with the MPEG-4 FDPs, while new vertices describing the neck and oral cavity geometries are introduced in section 3. The neck feature vertices complement the HDPs, while the oral cavity feature vertices are called *Oral Cavity Definition Parameters (OCDPs)*, as described in section 3. Some of the FDPs shown in MPEG-4 are at the same time also OCDPs (e.g., the tongue and teeth FDPs). The proposed head and oral cavity model is a multiresolution one, i.e. its structure contains anatomy representations at multiple levels of detail.

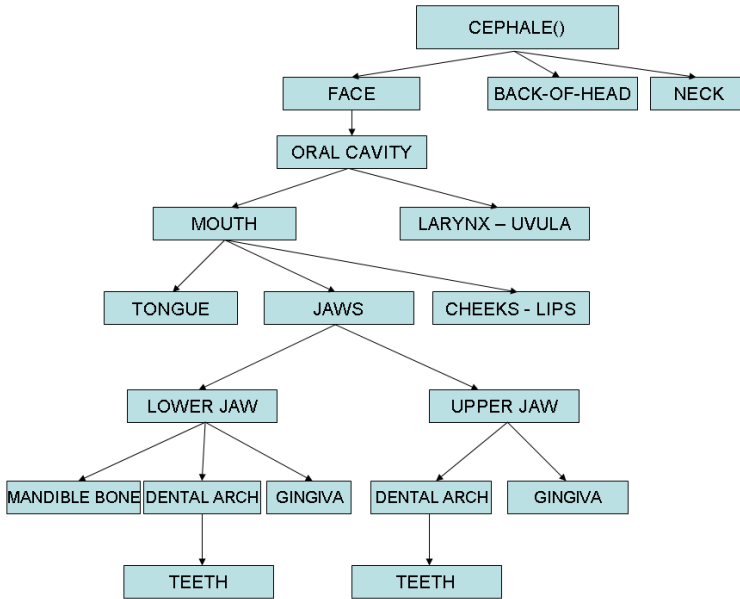
The top level head-neck-oral cavity node is called CEPHALE(), from the Greek word ‘KEPHALI’ (meaning head). The hierarchical and modular nature of the CEPHALE() model is depicted in Fig. 1, where we can see the names of the 11 nodes that comprise the model and are placed inside the parenthesis of the top level node name.

## 3 CEPHALE Node Models

This section deals with the details of modelling for all the constituent parts.

### 3.1 Head Model

Using the MPEG-4 FDPs, we formed the anatomical node CEPHALE(Face), which consists of 106 3D vertices and 188 triangles that depict a face in the frontal pose and neutral expression. Next, we have created the CEPHALE(BackOfHead-Neck) node by defining landmark vertices on the skin outside the parietal, occipital and temporal bones of a human head in such a way, so as to enforce symmetry with respect to the *YZ* plane. Subsequently, we have modelled the neck by selecting vertices, so as to encompass the full length of CEPHALE(Larynx) node starting from the perimeter vertices of the head (Sect. 3.4). The CEPHALE(BackOfHead-Neck) and CEPHALE(Face) nodes form the CEPHALE(Head) node. The HDPs are shown by bold dots. Their numbering is included in the CEPHALE() VRML file. The same visualization approach will be used for all HDPs and OCDPs presented in this section.



**Fig. 1** Head/oral cavity anatomical node hierarchy

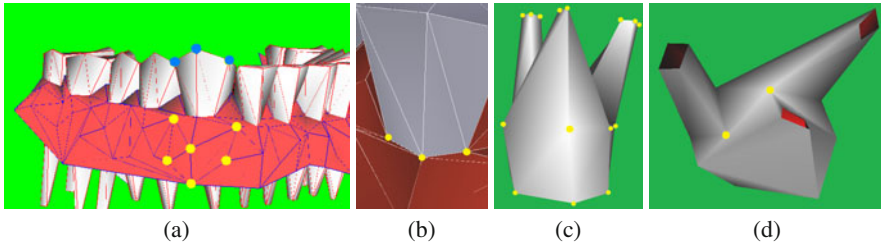
### 3.2 Lower Jaw Model

The node `CEPHALE(LowerJaw)` comprises the mandible bone node `CEPHALE(Mandible)`, the lower gingiva node `CEPHALE(GingivaMandible)` and the teeth of the mandible jaw node `CEPHALE(TeethMandible)`.

For modelling gingiva, a gingival attachment model corresponding to the gingiva attached to each tooth was built. The mesh created by synthesizing these building blocks for all teeth covers the entire gingival tissue of the gingiva of the mandible (internal-external), thus generating the anatomical node `CEPHALE(GingivaMandible)`.

Although we have developed much more detailed teeth models [10], we have decided to use crude teeth models, so that their level of detail is compatible with the one of the rest of `CEPHALE()` model. Hence, we modelled the visible part (crown) of any tooth uniformly (i.e. with the same topology), effectively anchoring it with the gingiva part. Each tooth root was modelled as a pyramidal surface ending in a square. Figure 2 shows details of the previously described modelling procedure.

Combining all the previously described tooth models, we have created the anatomical node of the mandibular teeth node `CEPHALE(TeethMandible)`. In total, the mandible anatomical node `CEPHALE(LowerJaw)` consists of 560 vertices that form 854 triangles.



**Fig. 2** (a) A close up view of the gingiva-teeth interconnection, (b) Gingival attachment detail, (c) The model of a tooth with three roots (vertices can be seen as dots), (d) The dots suggest the separation points of the roots

### 3.3 Maxilla Model

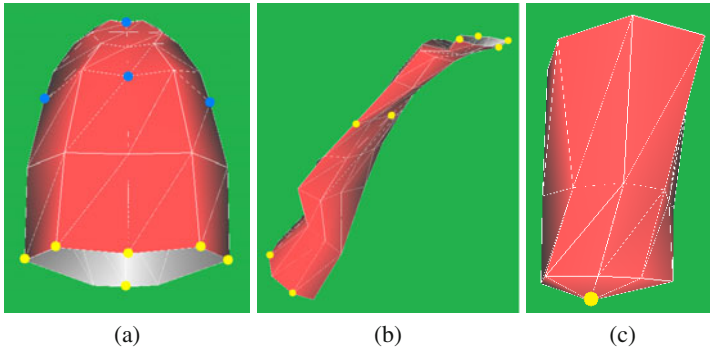
The node CEPHALE(Maxilla) comprises the upper external surface of the gingiva and hard palate tissues, that form the anatomical node named CEPHALE(GingivaUp) and the teeth of the maxilla forming the anatomical node CEPHALE(TeethUp).

The upper external gingival surface was modelled as previously described (3.2), while the hard palate was modelled using a set of 31 perimetric vertices delimiting the maxilla gingiva-crown attachment and another set of 32 vertices lying on two elliptic curves, which run parallel to the perimeter line formed by the apex of the tooth—gingival attachment along the dental arch. All these lines form a hat-like structure which is gradually deformed at its back side, in order to form the back end of the palatal bone, where the laryngeal entrance and the uvula are located. For modelling the upper teeth, we followed a similar procedure to that of Sect. 3.2. Due to anatomical particularities of the male cadaver (e.g., missing teeth), special care has been taken, along with assistance from experienced dentists, in order to correctly depict both the position and the convergence of the teeth along the dental arch, thus achieving orthodontic accuracy. The final anatomical node of the upper gingiva CEPHALE(Maxilla) is comprised of 490 vertices forming 788 triangles.

### 3.4 Modelling of Oral Cavity Organs

For modelling the internal surface of cheeks and lips, we followed the topology of their corresponding external part depicted on the CEPHALE(Face) node. This was achieved by taking vertices along the inwards pointing surface normal vectors of the lower part of the CEPHALE(Face) node. The vertex set obtained this way was enriched with a few more vertices at the perimeter of the internal cheek tissue, in order to avoid hole creation when assembling the internal cheeks-lips surface CEPHALE(CheeksLipsInternal) with each of the CEPHALE(GingivaMandible) and CEPHALE(GingivaUp) surfaces.

Tongue, larynx and uvula play a special role in speech articulation. For modelling their tube-like surfaces, we have used coronal and sagittal cross sections of the respective organ, placed at characteristic surface curvature locations and we have

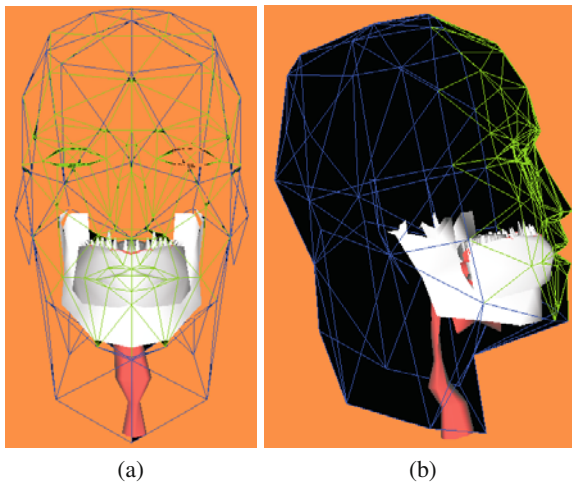


**Fig. 3** Models of the oral cavity organs with FDPs—FAPs (dots at the top in a) and OCDPs—OCAPs (other dots) animation vertices for (a) Tongue, (b) Larynx and (c) Uvula

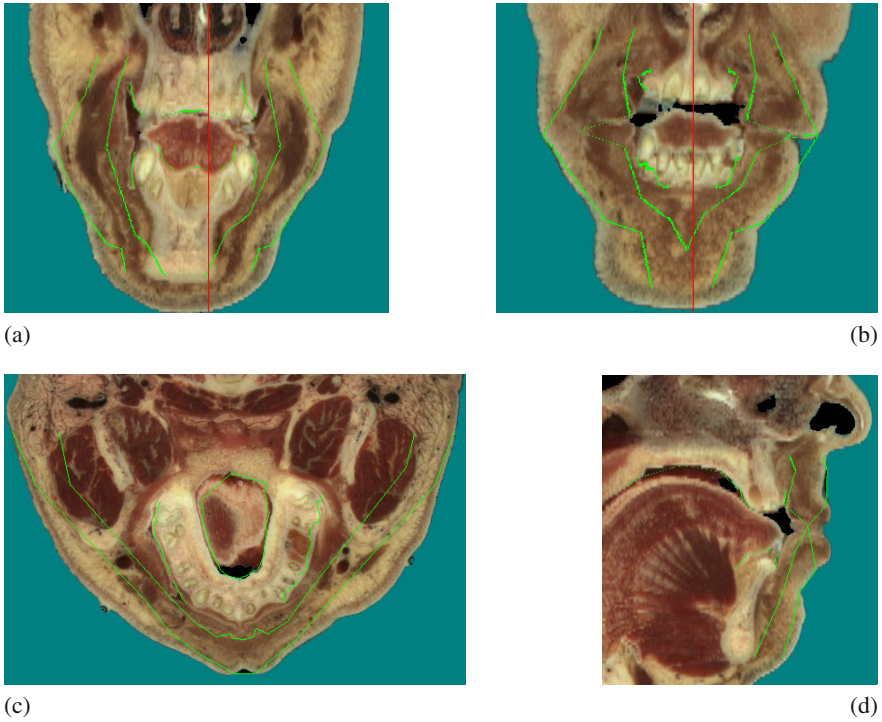
selected a number of vertices at their section borders. The models produced are depicted in Fig. 3 along with the newly introduced Oral Cavity Animation Parameters (OCAPs) and OCDPs.

#### 4 Overall Head—Oral Cavity Model and Its Animation Parameters

By combining all the previously mentioned CEPHALE(“NodeName”) nodes we have created the CEPHALE() node that depicts the archetypal human face, head, neck and oral cavity anatomical structures, which consists of 1378 vertices that form 2217 triangles. Figure 4 shows the overall newly created CEPHALE() model.



**Fig. 4** The combined head—oral cavity model (CEPHALE()) with the outer surface (head) depicted in wireframe for visualizing the inner structures: (a) front view, (b) side view



**Fig. 5** Coronal and transversal views of the Visible Human Male Head at various planes of the oral cavity organ with superimposed the CEPHALE() node (contour lines)

For visualization purposes we superimposed the models on the cadaver head volume, as in Fig. 5. The CEPHALE() model accuracy is very good on the area enclosed by the cheeks and lips, but is not so good on the cheeks and lips themselves, due to the limited number of model vertices on these formations. This problem can be remedied by using a twin-resolution CEPHALE() model, where the higher resolution one will be matched to the head/oral cavity surfaces by employing deformable models.

## 5 CEPHALE() Model Personalization Using a Finite Element Method

In many instances, it is desirable to adapt the prototype CEPHALE() model, so that it matches another 3D head surface model of similar geometry. In our case, we have utilized a model adaptation method based on finite elements [5]. Given ‘target’ positions for landmark vertices (FDPs/HDPs/OCDPs) obtained by visual inspection on any 3D facial/head data sets, our corresponding model developed,





**Fig. 6** (a) CEPHALE(HeadBackNeck) and CEPHALE(Face) adapted to the Visible Human Male head surface consisting of 49470 vertices by using 64 ‘driving’ vertices, (b) The same model adapted to a 3D head wireframe model (Washington) consisting of 5828 vertices by using 62 ‘driving’ vertices

e.g. the CEPHALE(Face) node, can be ‘adapted’ to it fast and seamlessly. Example results of this procedure are given in Fig. 6.

## 6 Conclusions

In this paper, we have presented the new prototype CEPHALE() model of the human face and oral cavity, based on anatomical and CT data of a real male cadaver oral cavity (Visible Human Project). Our modular-hierarchical design greatly enhances the flexibility of the final model, making it a useful tool in scientific applications that involve the human head-oral cavity interaction, such as speech articulation and pathology, virtual dentistry etc. The constructed model is freely available to the scientific community in the form of VRML files at <http://poseidon.csd.auth.gr/>.

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