AERODYNAMICAL MODEL OF HUMAN NEWBORN LARYNX: AN APPROACH OF THE FIRST CRY

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Abstract: First cry has been much studied especially from an acoustical point of view. However, the mechanisms of sound production are unclear. Thus, following studies we previously performed, we extend in this present work our simulations to a more realistic geometry obtained by MRI images of a fetal larynx. This work confirms the major role of vortices and may be that of the supraglottis and the fluid flow interactions.

Introduction: Vocal folds of newborns are histologically different from children and adults. Reinke's space is not clearly individualized. As shown by Titze, this structure is absolutely needed for vocal fold vibration [1]. The hypothesis for vocal production in newborn is that the air column generates itself the acoustic waves from which the voice appears. Some other possible vibrators within the mammalian production system include the vocal tract [2].

Anatomical measurements were performed and a preliminary virtual model was designed to modelize turbulences with vocal folds in phonatory position [3]. Despite acoustic waves were not detected through this simplified geometry, those results however suggested that newborn phonation is a vortex effect coupled with a vibration of supraglottic structures.

Fig. 1: Saggital view of a MRI acquisition of a human fetal larynx. Those data were used for computing a realistic geometrical model exported to Fluent®

Material and methods: Therefore, in the present study, we have undertaken a much more realistic geometrical model based on 3D MRI images (fig. 1) of a fetal human laryngotracheal tract. These frames allowed us to build a 3D numerical model using 18 horizontal slices with 50 points on each perimeter. It was exported to Gambit® in order to build up the mesh (fig. 2) to be computed with Fluent®. Moreover, based on this 3D geometry, a 2D axisymmetric model was also built to be used with Fluent® and CARBUR. The later is a

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research code developed in our laboratory and is dedicated to the study of compressible fluid flows [4]. This code is based on the discretization of the Navier-Stokes equations by a finite volume method. A second order scheme, for both space and time, with a Van Leer slope limiter has been used to solve the set of compressible Navier-Stokes nd energy equations.

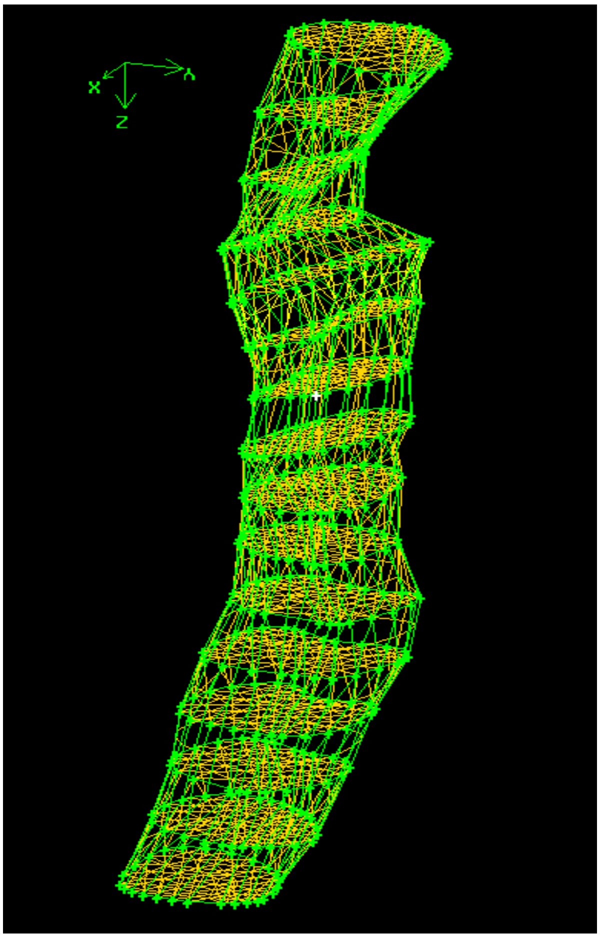

Fig. 2: Example of mesh obtained after exporting MRI slices to Gambit®.

Results: The fluid flow computations performed with Fluent® consider the flow as fully compressible and unsteady for the duration of the cry. The fluid flow is driven by a pressure drop of 6000 Pa, imposed between the inlet and the outlet of the computational domain. Furthermore, a no-slip boundary condition is imposed on the laryngotracheal wall. Several probe points have been considered in the computational domain in order to extract fluid flow characteristics such as acoustical waves, dynamical vortices, etc.

In this first step, the ability of a rigid wall configuration to produce acoustic waves is studied as well as the amplification by the supraglottic structures. In order to validate numerical results obtained on the realistic model, calculations were also performed with both CARBUR and Fluent® on a simplified geometry.

Thus, on the simplified geometry, we found highly unsteady flow with vortex generation upon the vocal folds. The main source of vortices is the Kelvin-Helmholtz's instability which appears on the shear layer. Fig. 3 shows a Schlieren of the fluid flow obtained with CARBUR where typical vortices structure are displayed. Moreover, the time evolution shows that subglottic pressure waves increase vortices shedding.

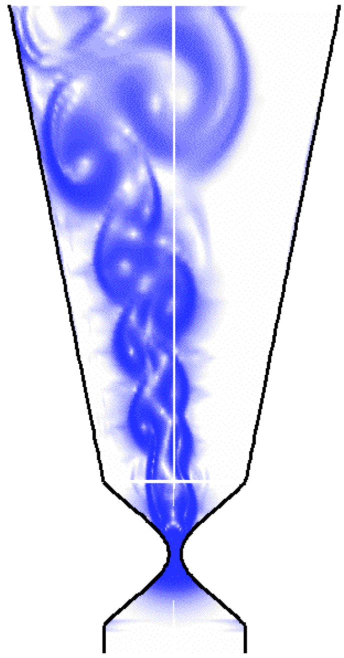

Fig. 3: Vortex structure induced by the instability behind the sharp channel expansion over the vocal folds.

We confirm with this realistic model the presence of vortices structures we observed in our previous study with a simplified geometric shape. Fig. 4, where are plotted streamlines coloured by velocity magnitude, shows the acceleration of the fluid flow in the glottic area and the

creation of vortices. One can note a boundary detachment just upon the posterior part of the glottis, where two counter rotative vortices are generated.
Whatever the code and the geometrical model, the maximum velocity just upon the glottis is about 110 m/s.
Computations are actually in process to determine the implication of these vortices in sound generation.

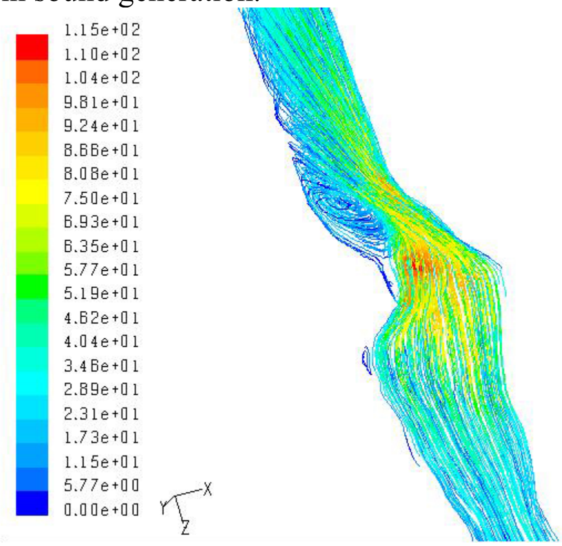

Fig. 4: Streamlines coloured by the velocity magnitude on the 3D realistic model.

In a second step of our study, fluid-structure interaction will be considered using a dedicated research code we have developped [4]. This code is based on the coupling of CARBUR and MARCUS. The later, another research code developed in our laboratory, deals with the dynamics of deformable structures [4]. The space discretization is carried by a finite element method, whereas, the temporal time discretization is achieved with the Newmark's algorithm. The numerical coupling between the fluid flow and the structural dynamics models is performed through boundary conditions. The fluid flow imposes a pressure distribution on the structure boundary, which in return imposes a new geometry to the fluid domain [4].

Conclusion and perspectives: Sound production by the neonatal larynx is a multifactorial problem, which needs the understanding of multiphysic phenomena such as the vortex sound generation, the coupling between the aerodynamic and the supraglottic structures. Our numerical simulations have pointed out the vortex generation upon the glottis and an amplification of the vortex shedding by the pressure waves. We also observed a high degree of instability of the outflow, which let us suppose that fluid-structure interaction phenomena may occur. The next step will be to calculate the sound radiation due to source terms previously identified [5].

Keywords: newborn, phonation, vocal folds, aerodynamic, modelization, fluid-structure interaction.

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