Analysis of Nonlinear Spring Characteristics in Human Hair Cell Bundle

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Abstract. This study presents a preliminary study on the adaptive bistable stiffness of hair cell bundle structure in a human cochlea. Hair cell bundle structures inside the human auditory system consists of conical bundle structures constituting multiple tiny long cylinders called Stereocilia. Their primary function is to send electrical impulse signals to the brain in response to the vertical oscillation produced by the travelling wave propagation on the basilar membrane of the cochlea and to shift the region of better sensitivity through their mechanical adaption capability. In this study, the harmonic balance method was employed to understand the amplifying of the movements of hair cells over broad frequency ranges, and hair cell's dynamic behaviors induced by bistable stiffness characteristics are projected on phase diagrams, and Poincare maps concerning the bifurcation.

Introduction

The hair cell bundle in the human auditory system feature a conical bundle structure consisting of multiple tiny long cylinders called stereocilia, that lean on each other with tip links in the hair cell. The primary function of the hair bundle structure is to send biologically induced electrical impulse signals to the brain in response to the vertical oscillation produced by the traveling wave propagation on the basilar membrane of the cochlea, as shown in Fig. 1(a). Typically, the hair bundle structures of the cochlear outer vestibular hair cells in human auditory systems consist of multiple tiny long cylinders (e.g., approximately 100 in a human ear) called Stereocilia that lean on each other with tip links in the hair cell, as shown in Fig. 1(b). The primary function of hair bundles originates from the dynamics of the tip link (elastic gating spring) connected to transduction channel gates, as shown in Fig. 1(b). Typically, the main function of the hair bundle structure is to send bio-electrical impulse signals to the brain in response to the vertical vibration produced by travelling wave propagation on a basilar membrane of the cochlea. The hair cell bundle structure has nonlinear spring characteristics called bistability showing negative stiffness. Because it is hypothesized that the sensitivity of our hearing can be increased over a broad frequency ranges, the detail mechanism is still uncertain [1]. The objective of this study is therefore to investigate this nonlinear stiffness and mechanical adaptation of the hair cell structure. The harmonic balance method (HBM) is used to analyze the nonlinear frequency responses and compared with the numerical integration method. The hair cell's dynamic behaviors induced by bistable stiffness characteristics are also projected on phase diagrams, and Poincare maps concerning the bifurcation.

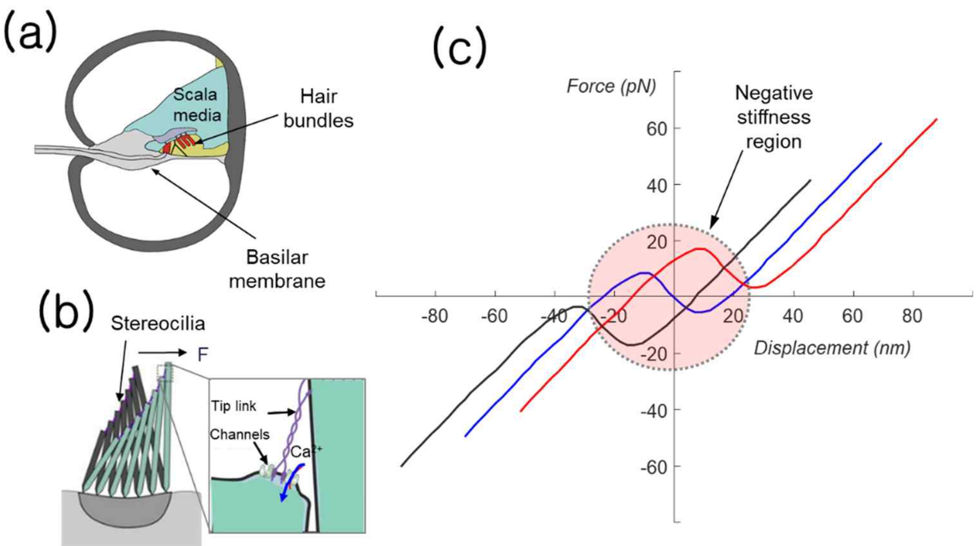

Figure 1: Bundle structures in cochlea outer hair cells and its nonlinear spring characteristics [2].

References

[1] Gi-Woo Kim and Mai Van Ngoc, "Nonlinear Frequency Analysis of Hair Cell Bundle Structure with Negative Stiffness Characteristic", ICAST2019: 30th International Conference on Adaptive Structures and Technologies October 7-11, 2019, Montreal, QC, Canada

[2] Martin P, Mehta A D and Hudspeth A J, "Negative hair-bundle stiffness betrays a mechanism for mechanical amplification by the hair cell", Proc. Natl Acad. Sci., USA, Vol.97, pp. 12026–31, 2000