Multibody approach to model toothbrush bristles elasto-kinematics

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EXTENDED ABSTRACT

This paper deals with a comparison on different methods to model and simulate a toothbrush bristles elasto-kinematics during the brushing operations. Since the 1960s, research in the field of periodontology and dental hygiene has focused on the description of brushing. Brushing is understood as a specific procedure that aims to remove biofilms from vertical and occlusal tooth surfaces and as much as possible from interdental spaces. The most common question about toothbrush development is the estimation of contact force for the assessment of cleaning performance and safety [1]. If the amount of contact forces is too high, it could damage the teeth or gums, but if it is too low it produces insufficient cleaning. Multibody models are able to provide information about contact forces, sliding forces, bristles deformation, and can be a valid tool for improving the design of bristles Figure 1a shows an example of a modern silicone toothbrush[1] used as reference, while Figure 1b shows the toothbrush deformed due to the interaction with a flat surface. Each bristle bends as a result of the contact force between its tip and the surface of the tooth. The amount of bending depends on the ratio between the length of the bristle and the distance between its root and the tooth surface, so the bends depend on the normal and tangential contact forces. Since brushing is a periodic movement applied to the bristle root, when the motion is inverted, the bending sign changes. However, when the inversion of the motion occurs, the bristle cannot reach the undeformed straight configuration. The bending sign changes due to buckling when the bristle tip is jammed within the interstitial spaces between adjacent teeth, while in other cases the bristle is subjected to a three-dimensional motion out of the bending plane.

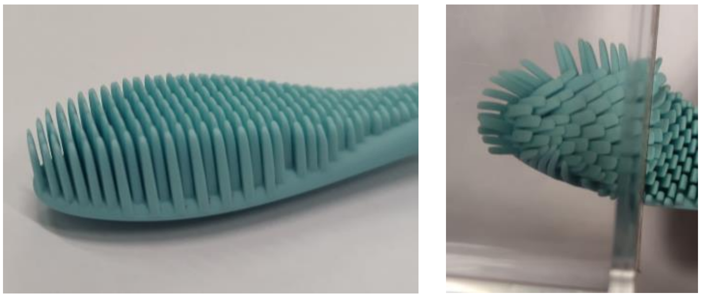

Figure 1: a) Toothbrush adopted for the study; b) Example of bristles deflection

Due to the amount and typology and the non-linear contact mechanics [2], the bristle's deformation cannot be studied using linear models or with two-dimensional approaches. Nonlinear beam models are computationally demanding since exact closed-form expressions are not available for complex large deformations [3]. Discretized multibody methods could evaluate bristles deformation and could manage many contact points, with relatively short computation times.

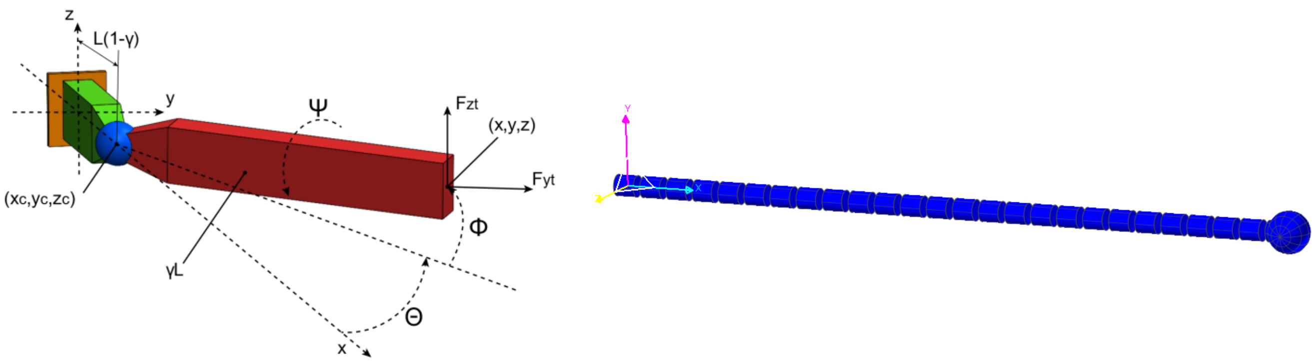

Figure 2: a) Howell 3D Pseudo-Rigid Model; b) Discrete Felxible Model.

A simplified but accurate model of a bristle that contacts a flat surface may be deduced using the pseudo-rigid body (PRB)

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[1] Toothbrush with rectangular bristles having the base section 1 mm x 2 mm and a mean length of 10 mm.

approach, based on multibody equations [4]. This approach is often used to design compliant mechanisms [5, 6], whose mobility is granted by the elastic deformation of the parts rather than by articulating standard kinematic joints. According to this strategy, the flexible structure is revised as a multi-rigid-body assembly with hinges and springs to deduce a surrogate standard mechanism that behaves similarly to the actual one. Since the kinematics of the compliant structure depends on external loads, the PRB embodiments depend on specific boundary conditions and applied loads as well [7, 8]. The Larry Howell PRB 3D model [9] splits the beam into two segments connected by a torsion spring (Figure 2a). The dimension of the segments depends on the initial length of the beam and the load combination at the tip (or better, on the ratio between horizontal and vertical loads). The stiffness constant depends on the material properties, on its and again on the load combination applied at the tip. The second approach to study bristles kinematics is the discrete flexible approach, based on more detailed rigid body discretization and elastic lumped-elements (Figure 2b). This method is more accurate for describing body deformation, but requires a higher computational effort and the results could be compared to PRB's.

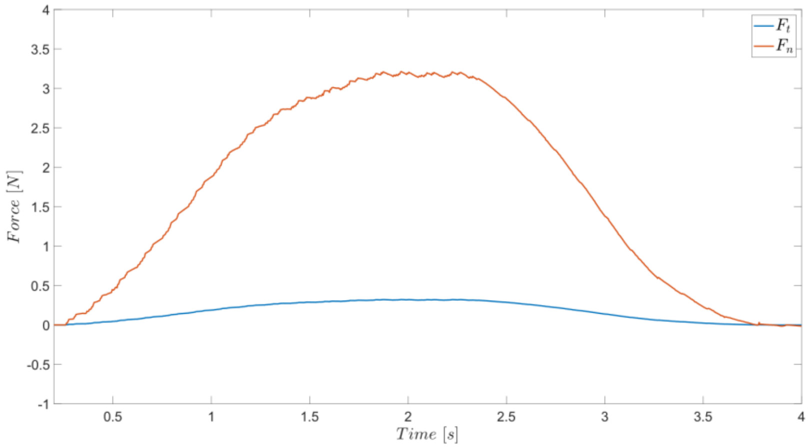

Figure 3: An example of Normal and Tangential Contact Forces during the cleaning of the toothbrush on a flat surface

In any case, both methods are compared with quantitative experimental results, reproducing the cleaning of the toothbrush on reference surfaces. Sliding and contact forces results from PRB method and discrete flexible method are compared to assess the validity of the model (Figure 3). Due to this method, the load acting on the teeth to minimise the wear that the toothbrush causes on them.

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