



**Natural food mastication capability in preschool children according to their oral condition: a preliminary study**

**Short title:** Mastication capability in preschool children

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## ABSTRACT

This study investigated, for the first time, the masticatory capability of preschool children using natural foods, and the impact of an early oral health alteration (early childhood caries: ECC) on the granulometry of ready-to-swallow food boluses.

Thirteen children with ECC were compared to 13 preschool children with a healthy oral condition. Oral health criteria and NOT-S scores (Nordic Orofacial dysfunction Test-Screening) were recorded. For each child, number of masticatory cycles (Nc), chewing time (Ti), and frequency ( $Fq=Nc/Ti$ ) were recorded during mastication of raw carrot (CAR), cheese (CHS) and breakfast cereals (CER) samples. Food boluses were collected by stopping children at their food-dependent individual swallowing threshold (Nc), and the median food bolus particle size value (D50) was calculated. Correlations were sought between oral health and masticatory criteria.

In the ECC group, mean Fq values were significantly decreased for all three foods ( $p \leq 0.001$ ) and mean D50 values were significantly increased ( $p \leq 0.001$ ) compared to the control group (i.e. D50 CAR=  $4384\mu m \pm 929$  vs.  $2960\mu m \pm 627$ ). These alterations were related to the extent of ECC. The NOT-S mean global score was significantly increased in children with ECC ( $2.62 \pm 1.37$  vs.  $1 \pm 0.91$  in the control group,  $p \leq 0.01$ ), due to “Mastication and swallowing” domain impairment.

This study gives granulometric normative values for three foods in preschool children and shows the impact of ECC on D50 values. The progression of children’s masticatory capability after dental treatment, and the impact of such modifications of sensory input on future eating habits should be explored.

**Keywords:** Preschool Children; Dental Caries; Mastication; Particle Size; Food Oral Processing; Swallowing

## 1 INTRODUCTION

Mature mastication and its influencing factors have been widely studied in adults (El Osta et al., 2014; Tada & Miura, 2018; Woda, Mishellany, & Peyron, 2006). However, the masticatory function, and especially the capability to form a food bolus, has been little explored in early childhood under “real” conditions (with natural foods in particular), while it is a crucial period for mastication skills acquisition. The introduction of diverse and increasingly hard food textures (Ferrazzano et al., 2019; Linas et al., 2019) is considered to have a substantial impact on mastication maturation (Wilson, Green, & Weismer, 2012b) and to influence the future food preferences and eating habits of the individual. Indeed, the ability to adjust the shape of the masticatory mandibular movements and the force of masticatory muscular contraction to food textural properties gradually improves during the first years of life, especially through stimulation of proprioceptive periodontal and pulpal receptors of the positioning deciduous dentition, and subsequent cortical memorization (Almotairy, Kumar, Trulsson, & Grigoriadis, 2018; J. P. Lund, 1991; James P Lund & Kolta, 2006). Proper physiological development of oral function is essential to achieve mature mastication characterised by fine and specific adaptation of the motor program to the physical properties of the food.

Little is known about mastication in children with altered dentition, but it may be hypothesised that any alteration of sensory information from teeth could modify the masticatory capability, defined as the capacity to produce a bolus suitable for safe swallowing and further digestion (Laguna & Chen, 2016). To address this issue, a study model with defined oral health alterations would be useful. Recent works have focused on children with early childhood caries (ECC), which has become a significant public health concern worldwide (Chen, Gao, Duangthip, Lo, & Chu, 2019), especially affecting socioeconomically disadvantaged families. Early caries impact children's wellbeing, nutrition, growth and development, and families' quality of life (Feitosa, Colares, & Pinkham, 2005; Schroth, Levi, Sellers, et al., 2013; Schroth, Levi, Kliwer, Friel, & Moffatt, 2013; Tinanoff et al., 2019; Vania et al., 2011). In particular, growth chart alteration or increased risk of iron deficiency anaemia or vitamin deficiencies (Schroth, Levi, Sellers, et al., 2013; Schroth, Levi, Kliwer, et al., 2013; Vania et al., 2011) are frequently observed in children with ECC. Such deficiencies might be due to poor diet, which could be associated with sociocultural and

environmental determinants and/or with food selection induced by mastication difficulties or pain. They might also result from insufficient oral fragmentation of foods during deficient mastication, leading to altered nutrient absorption. Some previous studies showed a decrease in masticatory performance in school-aged and preschool children with caries by assessing their ability to break down standardized pieces of silicone chewed for a fixed number of cycles (Barbosa, Tureli, Nobre-dos-Santos, Puppim-Rontani, & Gavião, 2013; Barrera, Buschang, Throckmorton, & Roldan, 2011; Consolação Soares et al., 2017; de Morais Tureli, de Souza Barbosa, & Gavião, 2010). However, because silicone material is not suitable for swallowing and further digestion, the masticatory performance obtained under such conditions cannot be related to the physiological eating behaviour when consuming real foods (van der Bilt, 2011; Woda et al., 2006). To date, the state and characteristics of ready-to-swallow food boluses have never been explored in children, while it is known that adults with multiple caries swallowed raw carrot boluses containing a greater proportion of large particles (Decerle, Nicolas, & Hennequin, 2013; Woda et al., 2006). Recently, alterations of masticatory kinematic behaviour have been observed in children with severe early childhood caries (ECC) in comparison with children with a healthy oral condition (Collado et al., 2017; Linas et al., 2019), but it remains unknown if such modifications are sufficient for the production of a food bolus suitable for swallowing and further transformation for nutrient absorption (van der Bilt, 2011; Woda et al., 2006). In particular, these young children decreased their masticatory frequencies (number of cycles per second) for three different calibrated solid foods (raw carrot, cheese and breakfast cereals) (Linas et al., 2019). Nonetheless, the number of cycles performed before swallowing was repeatable for a given food for each child, making it possible to predetermine the individual swallowing threshold and collect ready-to-swallow food boluses for granulometry analysis.

The present study aimed to measure, for the first time in children, the impact of oral health on their masticatory capability using natural foods. After recording the kinematic parameters, the granulometry of food boluses collected at the time of swallowing after mastication of three different natural foods was compared between children with severe ECC and children with a healthy oral condition within the same age range. Relationships between masticatory and oral health-related parameters were explored.

## 2 MATERIAL AND METHODS

This cross-sectional observational study was designed in accordance with Good Clinical Practice and with the ethical standards (ICH expert working group, 1996). All procedures performed in this study were in accordance with the local Ethical Committee (CECIC, 2010/06; IRB Number 5044). Children and parents, or legal representatives, received oral and written information regarding the design and goals of the study, the potential benefits and constraints related to their participation, and information about data confidentiality. They all signed a consent form.

### 2.1 *Participants*

Children from 36 to 71 months, without developmental disorders and with strict deciduous dentition, who were visiting the special dental care unit of the University Hospital of Clermont-Ferrand (France) between May 2016 and May 2017 for treatment of Early Childhood Caries (ECC) were included (“ECC group”). Children of the same age range who were visiting the dental unit for their routine dental examination and without any oral problems were included in the “control group”. 13 children were included in each group. Explanations about the calculation of the required number of subjects is detailed in the “Statistical analysis” section (2.6).

### 2.2 *Experimental procedures and data collection*

The descriptive variables and study criteria were collected by the two investigators (dental practitioners). At the first appointment, general health-related data (age, height and weight) and oral health criteria, detailed in the following section, were gathered during children’s clinical examination and an interview with the caregivers. A second session, within the following month, was organized according to the participants’ schedule for the mastication evaluation tests. It was planned between meals, in the mid-morning or mid-afternoon. Children were invited to masticate samples of three solid foods with different textures that are commonly used in the research laboratory: cheese (CHS), breakfast cereals (CER), and raw carrot (CAR). For each child, 12 calibrated food samples were prepared: four samples of the breakfast cereal Fitness® Nature

(Nestlé) ( $1 \text{ g} \pm 10\%$ ), four of the raw carrot and four of the cheese Emmental Meule d'or® (Entremont). Cylindrical samples of carrots and cheese were obtained using a cutter (diameter 2 cm/thickness 1 cm,  $3 \text{ g} \pm 10\%$ ) (Linas et al., 2019). During the mastication tests, children sat at a small table with their feet on the floor and one video camera was placed about one meter in front of them, in order to frame the children's face and shoulders. The children chose the food sample order in which they wanted to chew them. Then, they chewed all samples of a given food in a row. The children were encouraged to express any difficulty upon refusal or uneasiness with the food samples, and tests were stopped at will.

As young individuals are supposed not to be mature enough to stop themselves and spit out the food bolus right before swallowing (Gisel, 1991), the masticatory kinematic parameters had to be recorded for each child in order to determine the individual swallowing threshold. This threshold allows the collection of a ready-to-swallow food bolus for further granulometric analysis. Consequently, four mastication sequences were video recorded for each tested food. The first two masticatory sequences allowed live recording of the natural number of cycles needed before swallowing ( $N_c$ ) (Linas et al., 2019). This number was later verified by individual viewing of the video sequences (Imovie® software) in random order by two dental practitioners also involved in a previous study (Linas et al., 2019). Both investigators were trained in recording masticatory kinematic parameters according to the routinely used procedures in mastication studies in the research laboratory (Nicolas, Veyrune, Lassauzay, Peyron, & Hennequin, 2007). Agreement between the values measured by the two investigators was ensured for each mastication sequence (inter-individual variation of less than 10%). If the results varied between them by more than 10%, consultation with a third reader was organized and the sample recording was registered as uninterpretable if any doubt remained. During the next two masticatory sequences, each food bolus was collected for further granulometric analysis, by stopping the child at the predetermined number of cycles ( $N_c$ ) needed before swallowing. Each food bolus was collected in a receiving cup, and the child was asked to take a small amount of water and spit it out with the remaining particles. If a food bolus seemed incomplete, the child was asked to chew another sample. For one child, food boluses were all incomplete and were not analysed. The collected food boluses were then stored for at least 24 h at  $-18^\circ\text{C}$ .

The particle size distribution of each food bolus was determined by manual sieving. For CAR and CHS boluses, a watery sieving was performed. Each bolus was defrosted and particles were separated by rinsing

them onto a stack of nine sieves with apertures of 7.1, 6.3, 4, 2.5, 2, 1.4, 1, 0.8 and 0.4 mm (Saulas, France), using a gentle hand shower. Each sieve was then dried with a paper towel and put into a ventilated oven at 37°C for 6 minutes. For CER food boluses, particle size distribution was assessed using dry sieving. Each bolus was poured onto a 0.3 mm nylon cloth, washed with running water for defrosting, saliva elimination and particle spreading and then left in a ventilated oven for 1 h at 37°C. The dried bolus was poured onto the stack of sieves described above and manually sieved using a paintbrush. For both sieving procedures, the particles retained by each sieve were weighed.

## **2.3 Oral health criteria**

### **2.3.1 Oral state**

The dmft index (decayed, missing, filled teeth index) was used to evaluate children's carious status (World Health Organisation, 2013).

International Caries Detection and Assessment System scores (ICDAS) specified the extent of decay, and the clinical consequences of caries were evaluated with the pufa index (visible pulp, ulceration of the oral mucosa due to root fragments, fistula or abscess) (Monse, Heinrich-Weltzien, Benzian, Holmgren, & van Palenstein Helderma, 2010; Shoaib, Deery, Ricketts, & Nugent, 2009). The severity of ECC was defined according to the criteria specified by the American Academy of Pediatric Dentistry (American Academy of Paediatric Dentistry, 2016).

The presence of orofacial dysmorphology was controlled in both groups, as it could modify dental occlusion and thus alter mastication (Marquezin, Kobayashi, Montes, Gavião, & Castelo, 2013). It was checked using the different occlusal deviations of the "dental health" component of the Index of Orthodontic Treatment Need (IOTN) (Brook & Shaw, 1989). In this study, they were clustered in dento-maxillary disharmony, eruption or number anomalies, and sagittal, vertical and transversal dimension abnormalities.

### 2.3.2 *Occlusal parameters*

The number of posterior (post-canine) and anterior (incisor and canines) functional units (FUs) was obtained by counting the number of pairs of antagonist teeth with at least one occlusal contact visible after chewing on a 200 µm articulating paper for 2-3 cycles (Owens, Buschang, Throckmorton, Palmer, & English, 2002).

### 2.4 *Orofacial dysfunction criteria*

The frequency of orofacial dysfunction was assessed using the French version of the NOT-S questionnaire (Nordic Orofacial Test-Screening) (Bakke, Bergendal, McAllister, Sjögreen, & Asten, 2007). This two-part questionnaire consists of a structured interview exploring “sensory function” (I), “breathing” (II), “habits” (III), “chewing and swallowing” (IV), “drooling” (V), “dryness of the mouth’s” (VI) functional domains, and a clinical examination evaluating “face at rest” (1), “nose breathing” (2), “facial expression” (3), “masticatory muscle and jaw function” (4), “oral motor function” (5) and “speech” (6). The “chewing and swallowing” domain contains the 5 following dysfunction items: “Does not eat with the mouth (nasogastric tube, gastrostomy or other)”, “Do you find it difficult to eat foods with certain consistencies”, “Does it take you 30 minutes or more to eat a main meal”, “Do you swallow large bites without chewing” and “Do you often cough during meals”. Each domain is scored 1 if at least one dysfunction (one item within each domain) is noted. The total score ranges from 0 to 12.

### 2.5 *Mastication evaluation criteria*

Data collection of mastication evaluation criteria was possible for the food samples accepted and masticated by children. Food refusals were analysed separately.

#### 2.5.1 *Mastication capability: Bolus granulometry at the time of swallowing*

The food bolus granulometry criterion was the median particle size value (D50 value) calculated for each food bolus collected at the moment of swallowing (Nc). For each sample, a cumulative curve was drawn from the particle mass falling through each sieve. The D50 value, defined as the median particle size, was



extracted from this curve by pinpointing the theoretical sieve size that would let 50% of the particle mass pass through. Hence, the higher the D50 value is, the greater the proportion of large particles in the food bolus.

### 2.5.2 *Masticatory behaviour: food refusals, kinematic parameters, and quality of muscular function*

For each food, the number of food refusals was noted and reasons were classified in “Don’t like”, “Don’t know/Never tried”, “Painful” and “Too difficult to eat”.

Masticatory behaviour was evaluated by three kinematic parameters. The chewing time ( $T_i$ , in seconds) was measured from the moment the food was placed into the mouth until the last food bolus manipulation just before complete swallowing. The number of masticatory cycles ( $N_c$ ) was the number of chewing actions, with and without lip closure, corresponding to biting movements (tongue and perioral muscles manipulation movements were not counted). The chewing frequency ( $F_q$ ) was calculated by the ratio  $N_c/T_i$ .

The “quality of muscular function” was assessed on the video recordings, using a clinical tool developed by speech therapists (Pires, Giugliani, & Caraméz da Silva, 2012). The two investigators, trained in orofacial functional evaluation as part as their specialty skills requirement, reached an agreement for each video recording. This scale contains 5 items: incision, lip competence, masticatory pattern (unilateral or bilateral), masticatory movements and use of perioral muscles. The predominant use of tongue to manage the food was added to these items for the present study. Every parameter was scored 1 if performed correctly and 0 otherwise.

For these parameters as well as for kinematic ones, the muscular activity in the anterior region of the oral sphere was closely observed to distinguish biting movements from food manipulation by soft tissues. In particular, when the food is managed mostly by soft tissues, obvious contractions of the lips and cleaning movements of the tongue in the vestibules are noticeable through lips and cheeks. Tongue protrusion is also visible in case of predominant use of the tongue. Conversely, strong contractions of the mandibular elevator muscles are observed when the food is crushed between the teeth. When the pattern is mostly unilateral, a stronger contraction is recognizable on the predominant side of mastication.

## 2.6 Statistical analysis

The required sample size was estimated from a preliminary pilot study that measured the mean D50 value for raw carrot (D50 CAR) between children with healthy teeth and children with ECC (eight first included children of each group). The mean D50 CAR value was higher in the ECC group than in the control group (4.55  $\mu\text{m}$  versus 3.08  $\mu\text{m}$  respectively) (SD = 0.98). Calculations were based on this difference for a continuous criterion with independent values and indicated the need for at least 10 subjects for each group ( $\alpha = 5\%$ ,  $\beta = 10\%$ , epiR package 0.9–30). As children could refuse certain food samples, leading to missing data, thirteen children were finally included in each study group.

A statistical analysis was conducted using SPSS® (IBM, v20). The significance threshold value was set at  $p < 0.05$ . The number of FUs and the NOT-S mean scores were compared between both groups with a series of Mann Whitney U tests. For each food, the individual repeatability of masticatory parameters (Ti, Nc, Fq and D50) was verified (Wilcoxon-Sign-Rank test). Food sample refusal rates (Fisher's exact test) and masticatory parameters (Mann Whitney U test) were compared between groups for each food. In addition, effect size was measured by ( $\eta^2$ ) (*partial eta squared*). For the masticatory criteria, all recorded data of all subjects included in the study were analysed. Missing data corresponded to food sample refusals. Potential correlations were sought for all children between dmft scores, number of FUs, NOT-S scores and masticatory parameters (Spearman's test).

## 3 RESULTS

### 3.1 Descriptive data

Thirteen children suffering from ECC (9 girls and 4 boys), and thirteen children with healthy oral state (5 girls and 8 boys) were included in the study. Children with ECC all exhibited the severe form of the disease. Data regarding general and oral health are gathered in Table 1. Both groups were similar in age, weight and height (U tests of Mann Whitney, NS), and sex (Fisher's exact test, NS). Both groups were comparable concerning the presence of dysmorphology (Fisher's exact test, NS) (Table 1).

### 3.2 *Oral state and occlusal parameters*

For the ECC group, the mean dmft score was  $11.54 \pm 4.41$  (Table 1).

Children from the ECC group had a significantly lower number of posterior FUs than the children from the control group ( $3.31 \pm 1.03$  vs.  $4.00 \pm 0$  respectively, U test of Mann Whitney,  $p \leq 0.05$ ) (Table 1). The difference was not significant for anterior FUs (U test of Mann Whitney, NS).

### 3.3 *Orofacial dysfunction*

The description of domain-by-domain dysfunction frequencies (number of children affected by each dysfunction) is detailed in Figure 1. The NOT-S mean global score was significantly higher for children with ECC than for children from the control group ( $2.62 \pm 1.37$  vs.  $1 \pm 0.91$ , U test of Mann Whitney,  $p \leq 0.01$ ). The only specific domain to be significantly altered in children with ECC (higher mean scores) compared to children from the control group was the “Mastication and swallowing” domain ( $0.69 \pm 0.48$  vs.  $0.15 \pm 0.38$  respectively, U test of Mann Whitney,  $p \leq 0.01$ ). When detailing this domain, only 2 children from the control group took longer than 30 minutes to eat their meal and no other dysfunction item was scored for this group. In the ECC group, 9 children (out of 13) showed an altered “chewing and swallowing” domain (NOT-S IV): Item-by-item detail for these children is given in Table 2. The other four children did not have any dysfunction in this domain.

### 3.4 *Mastication evaluation criteria*

During the mastication sequence, children did refuse some food samples. Mastication results presented in the following sections correspond to the number of children that accepted the food samples and were able to spit out interpretable food boluses for granulometric analysis. One child had difficulty to spit out complete food boluses that were all not interpretable.

The food bolus granulometry (D50) and the masticatory kinematic parameters (Ti, Nc and Fq) and) did not differ significantly between the two corresponding replicates for each food (Wilcoxon-Sign-Rank test, NS), regardless of the group.

### 3.4.1 Mastication capability: bolus granulometry at the time of swallowing

For the three foods, the food boluses collected in children with ECC consisted of a greater proportion of large particles, as indicated by significantly higher D50 mean values, compared to the food bolus collected after mastication in children from the control group (U test of Mann Whitney,  $p \leq 0.001$ ). For example, the D50 value for raw carrot was  $4384 \mu\text{m} \pm 929$ , compared to  $2960 \mu\text{m} \pm 627$  in children from the control group (U test of Mann Whitney,  $p \leq 0.001$ ). The detail of D50 mean values obtained from the food samples accepted and masticated by both groups of children is given in Table 3. Figure 2 gives a box-plot representation of D50 values in both groups for the three foods.

### 3.4.2 Masticatory behaviour: food refusals, kinematic parameters, and quality of muscular function

The frequency and distribution of food refusals were comparable for both groups (Fisher's exact test, NS).

Details of reasons for refusals according to the food are detailed in Table 4.

Mean chewing times for CER and CHS were significantly higher in the ECC group (U test of Mann Whitney,  $p \leq 0.001$  and  $p \leq 0.05$ , respectively) (Table 5). Mastication in children with ECC was characterized by a lower chewing frequency for all tested foods (U test of Mann Whitney,  $p \leq 0.001$ ).

Regarding the quality of muscular function while masticating, "Lip incompetence while masticating" was the only altered muscular function observed in children from the control group (4 children/13). Among 13 children with ECC, nine presented one or more alterations in their "quality of muscular function". Six children presented impaired incision, four presented lip incompetence, seven presented unilateral mastication, one presented predominant vertical masticatory movements and four presented a predominant use of their tongue to crush the food.

### 3.5 Correlations between masticatory parameters and oral health criteria

For the three foods, the dmft scores were negatively related to chewing frequencies (Fq CER:  $\rho = -0.63$ ,  $p \leq 0.001$ ; Fq CHS:  $\rho = -0.57$ ,  $p \leq 0.001$ ; Fq CAR:  $\rho = -0.56$ ;  $p \leq 0.001$ ) and positively correlated with D50 values (D50 CER:  $\rho = 0.42$ ,  $p \leq 0.01$ ; D50 CHS:  $\rho = 0.69$ ,  $p \leq 0.001$ , D50 CAR:  $\rho = 0.63$ ,  $p \leq 0.001$ ).

Moreover, the number of posterior FUs was positively correlated with the chewing frequency measured for carrot ( $\rho = 0.36$ ,  $p \leq 0.05$ ) and cereals ( $\rho = 0.34$ ,  $p \leq 0.05$ ). It was negatively related to D50 CHS ( $\rho = -0.42$ ,  $p \leq 0.01$ ) and D50 CAR ( $\rho = -0.37$ ,  $p \leq 0.05$ ).

Finally, the global NOT-S score was negatively correlated to the chewing frequency for the three test food (Fq CER:  $\rho = -0.57$ ;  $p \leq 0.001$ , Fq CHS:  $\rho = -0.64$ ;  $p \leq 0.001$ , Fq CAR:  $\rho = -0.56$ ;  $p \leq 0.001$ ), and positively correlated with the cheese D50 ( $\rho = 0.51$ ;  $p \leq 0.001$ ) and the carrot D50 ( $\rho = 0.51$ ;  $p \leq 0.001$ ).

## 4 DISCUSSION

This preliminary study is the first to assess the granulometry of food boluses collected at the time of swallowing in preschool children, after masticating natural foods with different textures. Similarly to adults (Decerle et al., 2013), young children's ability to reduce different foods was altered in the presence of caries when compared to children with healthy teeth. Both chewing frequency and granulometric alterations of the food bolus were related to the extent of caries, and particularly with the loss of posterior functional dental units responsible for a reduced sensory input from the teeth receptors. Masticatory behavioural adaptations were not sufficient to compensate for this deficiency.

In particular, the present study showed that increasing chewing time is not sufficient for children with ECC to produce a state of food fragmentation comparable to that of children with healthy teeth. Indeed, the food particle size analysis showed a significant increase of the mean D50 values in the presence of ECC for all three of the tested foods. However, the difference is more important for carrot and cheese compared to cereals, suggesting the impact of the type of food tested on masticatory capability should further investigated. The D50 "normality threshold" (maximum value of D50 to define a "normal" capacity for fragmenting foods) is still unknown in children, while in adults this value, the masticatory normative indicator (MNI), was estimated at 4000  $\mu\text{m}$  for raw carrot (Woda et al., 2010). In the present study, the

mean D50 value obtained for carrot boluses in children with ECC exceeded the MNI determined in adults, whereas children with healthy teeth produced boluses with a mean D50 value around 3000  $\mu\text{m}$  ( $4384\mu\text{m} \pm 929$  in children with ECC vs.  $2960 \mu\text{m} \pm 627$  in children from the control group). Acquiring more data for children according to their age and stage of dental development would make it possible to determine the mean progression of D50 values throughout childhood according to each food. Moreover, there is little data available regarding the quantitative and qualitative changes in saliva secretion throughout infancy and childhood, although it is crucial for food bolus formation (Dezan, Nicolau, Souza, & Walter, 2002; Negoro et al., 2000). Existing studies on children with ECC have only focused on the bacteriological and immunological aspects of saliva (Bachtiar, Gultom, Rahmasari, & Bachtiar, 2018; Letieri, Freitas-Fernandes, Valente, Fidalgo, & de Souza, 2019) or on the link between saliva properties and glucose retention risk (Negoro et al., 2000). The role of saliva parameters on mastication in young children would require further investigation. Impaired masticatory capability can also cause swallowing difficulties, mainly due to inadequate food fragmentation and production of insufficiently lubricated particles that can then escape to the upper respiratory airways. Clinical experience suggests that unpleasant or even traumatic experiences of food aspiration often lead children and/or parents to exclude that food from their diet. In this study, swallowing difficulties were observed in at least five children with ECC out of 13, as “cough occurring at almost every meal” (item NOT-S IV E) or “swallowing of large bites without chewing” (item NOT-S IV D) were reported by their parents on the orofacial dysfunction test screening (NOT-S). Given the strong correlation between the NOT-S scores and the physiological measurements (D50 and chewing frequency) observed in this study, it can be emphasised that this clinical test could be used as a reliable tool to screen for masticatory deficiencies (Collado et al., 2017; Linas et al., 2019). This accessible tool could be particularly useful to detect masticatory deficiencies in young children or in patients with special needs, in order to adapt their diet and guide their functional rehabilitation.

In addition to masticatory kinematic parameter alterations, various masticatory behaviour modifications depending on the food physical characteristics were observed during the study. As previously shown, some children with ECC exhibited a predominant use of their tongue and lips to crush cheese against the palate, and let breakfast cereals soften in saliva (Linas et al., 2019). Half of the children with ECC included in this study also adapted to their oral health deficiency by adopting a strictly unilateral mastication (Mc Donnell,

Hector, & Hannigan, 2004). During the mastication tests, some food refusals were due to mastication difficulties (declared as “painful” or “too difficult to eat”), suggesting that food selection may be another adaptation strategy. In order to protect their child from food aspiration, parents also reported excluding some foods at home, such as meat, from the child’s diet or modifying food textures by mixing or mincing food, for example. The occurrence of all these behavioural adaptations and diet modifications throughout children’s development may lead to maxillary growth alteration, an aggravating factor of dysfunction (Limme, 2010).

Whether children exclude certain foods from their diet or swallow a food bolus containing large particles, this could potentially modify the contact area with digestive enzymes and nutritional consequences may be expected (Schroth, Levi, Sellers, et al., 2013; Schroth, Levi, Kliewer, et al., 2013; Vania et al., 2011). Early childhood caries is currently considered a chronic disease due to persistent psychosocial feeding risk factors and associated risk of caries relapse and related oral infection (Gussy, Waters, Walsh, & Kilpatrick, 2006). The functional impact of oral pathologies, such as ECC, may also expose children to long-lasting nutritional risks due to persistent mastication impairment and/or subsequent diet adjustments. Previous data has suggested that mastication difficulties persisted in this population three months after extensive dental treatment under general anaesthesia (Collado et al., 2017). Some authors have addressed the evolution of mastication after dental rehabilitation in children (Serra, Gambareli, & Gavião, 2007) but none in children with ECC. In particular, it is still unknown if and how children’s capacity to produce a food bolus suitable for swallowing and digestion could recover post-operatively, regardless of the type of treatment provided (prosthesis or conservative treatment). A one-year follow-up mastication study is ongoing in children with ECC, while keeping in mind that these evolutions remain dependent on psycho-socio-cultural determinants.

## 5 CONCLUSIONS

For the first time, masticatory capability while masticating natural foods was compared between preschool children with and without ECC. This study suggested that oral condition, and in particular sensory information from teeth, was an important determinant of mastication behaviour and capability. In the presence of dental caries, children’s ability to reduce different foods was altered. Children also modified their masticatory behaviour such as increasing their chewing time, resorting to unilateral mastication or

even refusing certain foods. Nutritional consequences can be expected, whether children exclude certain foods from their diet or swallow a food bolus containing large particles. Comprehensive dental treatment may include nutritional guidance and mastication rehabilitation programs.

#### **AUTHORS' CONTRIBUTIONS**

**Natacha Linas** performed most of the masticatory tests and data acquisition, contributed to data analysis and interpretation and to the drafting of the manuscript. **Marie-Agnès Peyron** contributed to the design of the study and critically revised the manuscript. **Caroline Eschevins** contributed to data acquisition and critically revised the manuscript. **Martine Hennequin** contributed to the conception of the study and critically revised the manuscript. **Emmanuel Nicolas** contributed to the design of the study, contributed to data analysis and interpretation and critically revised the manuscript. **Valérie Collado** conceived and design the study, performed part of the masticatory tests and contributed to data acquisition, analysis and interpretation and to the drafting of the manuscript. All authors approved the final manuscript.

#### **ETHICAL STATEMENT**

**Declarations of interest:** The authors declare that they do not have any conflict of interest

**Ethical Review:** This prospective observational comparative study was designed in accordance with Good Clinical Practice (*International Clinical Harmonization. Guideline for good clinical practice 1996*, s. d.) and was approved by the local ethical committee (CECIC, 2010/06; IRB Number 5044).

**Informed consent:** Parents or legal guardians, and children, received oral and written information explaining the study's design and the possible benefits and constraints related to their participation, and were asked to sign a consent form. Moreover, the document specified that all data collected during the children's usual follow-up would be used anonymously for research purposes.

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Accepted Article

**TABLES**

**Table 1:** General and oral health-related data for the ECC and control groups.

<b>Criteria</b>	<b>ECC group (n=13 children)</b>	<b>Control group (n=13 children)</b>	<b>Statistical differences</b>
<b>Girls/Boys ratio (n/n)</b>	9/4	5/8	<i>Fisher's exact test, NS</i>
	<i>mean ± SD (min-max)</i>	<i>mean ± SD (min-max)</i>	<i>Mann-Whitney U test</i>
<b>Age (months)</b>	57.5 ± 6.5 (46-67)	56.9 ± 10.3 (36-71)	NS
<b>Weight (kg)</b>	17.2 ± 2.2 (14.6-23.3)	18.8 ± 2.7 (13.7-23)	NS
<b>Height (cm)</b>	107.7 ± 4.1 (102-116)	109.5 ± 7.5 (93-120)	NS
<b>dmft index</b>	11.54 ± 4.41 (3-18)	0	p≤0.001
decayed	10.85 ± 3.89 (3-16)	0	p≤0.001
missing	0.38 ± 0.77 (0-2)	0	NS
filled	0.31 ± 1.11 (0-4)	0	NS
<b>ICDAS scores</b>			
ICDAS 0 ( <i>Sound</i> )	9.15 ± 4.16 (3-17)	20 ± 0 (20-20)	p≤0.001
ICDAS 1 ( <i>1<sup>st</sup> enamel visual changes</i> )	0	0	NS
ICDAS 2 ( <i>Clear enamel visual changes</i> )	0	0	NS
ICDAS 3 ( <i>Localized enamel disruption</i> )	0	0	NS
ICDAS 4 ( <i>Dark area on underlying dentine</i> )	4.77 ± 2.42 (2-10)	0	p≤0.001
ICDAS 5 ( <i>Distinct cavity with exposed dentine</i> )	0.23 ± 0.83 (0-3)	0	NS
ICDAS 6 ( <i>Large cavity with exposed dentine</i> )	5.46 ± 3.62 (0-12)	0	p≤0.001
<b>PUFA score</b>			
Visible pulp (p)	5.38 ± 3.55 (1-14)	0	p≤0.001
Ulceration (u)	0	0	NS
Fistula (f)	0,08 ± 0,28 (0-1)	0	NS
Abscess (a)	0	0	NS
<b>Occlusal parameters</b>			
Anterior functional units	3.23 ± 2.42 (0-6)	4.92 ± 1.75 (2-6)	NS
Posterior functional units	3.31 ± 1.03 (1-4)	4.00 ± 0 (4-4)	p≤0.05
<b>Dysmorphologies</b>	<i>n</i>	<i>n</i>	<i>Fisher's exact test, NS</i>
Dento-maxillary dysharmony	0	0	
Eruption or number anomalies	0	0	
Sagittal dimension abnormality	0	2	
Transversal dimension abnormality	2	1	
Vertical dimension abnormality	2	4	

*ECC: Early Childhood Caries; dmft: decayed, missing, filled, teeth index; ICDAS: International Caries Detection and Assessment System; PUFA: visible pulp, ulceration of the oral mucosa due to root fragments, fistula or abscess; NS: no statistical difference (p>0.05).*

**Table 2:** Detail of the impaired “chewing and swallowing” NOT-S IV domain (5 items) for the nine children (out of 13) of the ECC group.

Children from the ECC group with an impaired NOT-S IV domain									
	Child 1	Child 2	Child 3	Child 4	Child 5	Child 6	Child 7	Child 8	Child 9
<b>NOT-S IV items (“chewing and swallowing” domain)</b>									
NOT-S IV A “Does not eat with the mouth”									
NOT-S IV B “Have difficulties with certain food consistencies”		x	x		x	x	x	x	x
NOT-S IV C “Take 30 minutes or more to eat a main meal”	x	x		x	x		x	x	
NOT-S IV D “Swallow large bites without chewing”					x				x
NOT-S IV E “Cough often during meals”			x	x		x			

*ECC: Early Childhood Caries, NOT-S: Nordic Orofacial Test-Screening*



**Table 3:** Comparison of the food related D50 value between the ECC group and the control group.

		<b>ECC group (n=13)</b>	<b>Control group (n=13)</b>	<b>Statistical differences between groups</b>	<b>Effect size</b>
<b>Tested food</b>		<i>D50 (μm)</i>	<i>D50 (μm)</i>	<i>Mann-Whitney U test</i>	$\eta^2$ ( <i>partial eta squared</i> )
		n=12 (1 R)	n=12 (1 NI)		
<b>CER</b>	<i>mean ± SD</i>	<b>1120 ± 222</b>	<b>929 ± 186</b>	<i>p</i> ≤0.001	0.186
	CI	1027 - 1214	848 - 1009		
		n=11 (2 R)	n=10 (2 R + 1 NI)		
<b>CHS</b>	<i>mean ± SD</i>	<b>4596 ± 1617</b>	<b>2237 ± 756</b>	<i>p</i> ≤0.001	0.470
	CI	3879 - 5313	1883 - 2591		
		n=9 (4 R)	n=10 (2 R + 1 NI)		
<b>CAR</b>	<i>mean ± SD</i>	<b>4384 ± 929</b>	<b>2960 ± 627</b>	<i>p</i> ≤0.001	0.465
	CI	3922 - 4847	2666 - 3253		

*CAR: raw carrot samples; CER: cereals samples, CHS: cheese samples; ECC: Early Childhood Caries; CI: Confidence interval; n correspond to the number of children with no food refusal. R: number of refusals, NI: number of not interpretable food boluses.*

Tested food			Don't like	Don't know / Never tried	Painful	Too difficult to eat	Total number of refusals
CER	ECC group (n=13)	<i>n</i>	0	0	1	0	1
	Control group (n=13)	<i>n</i>	0	0	0	0	0
CHS	ECC group (n=13)	<i>n</i>	2	0	0	0	2
	Control group (n=13)	<i>n</i>	2	0	0	0	2
CAR	ECC group (n=13)	<i>n</i>	1	1	1	1	4
	Control group (n=13)	<i>n</i>	1	1	0	0	2

**Table 4:** Food related frequencies and reasons for food refusal during the mastication test in both groups.

*CAR: raw carrot samples; CER: cereals samples, CHS: cheese samples; ECC: Early Childhood Caries*

**Table 5:** Comparison between groups of the kinematic parameters values for each food.

Tested food	Parameters	ECC group (n=13)	Control group (n=13)	Statistical differences between groups	Effect size
		mean ± SD (CI)	mean ± SD (CI)	Mann-Whitney U test	$\eta^2$ (partial eta squared)
CER		n=12 (1 refusal)	n=13 (No refusal)		
	<i>Ti</i> (s)	<b>27.46 ± 7.87</b> (24.13 – 30.78)	<b>20.00 ± 4.51</b> (18.18 – 21.82)	<i>p</i> ≤ 0.001	0.264
	<i>Nc</i> (n)	25.79 ± 6.96 (22.85 – 28.73)	27.38 ± 5.93 (24.99 – 29.78)	NS	0.016
	<i>Fq</i> (n/s)	<b>0.97 ± 0.23</b> (0.87 – 1.07)	<b>1.37 ± 0.22</b> (1.28 – 1.46)	<i>p</i> ≤ 0.001	0.456
CHS		n=11 (2 refusals)	n=11 (2 refusals)		
	<i>Ti</i> (s)	<b>24.59 ± 10.59</b> (19.90 – 29.28)	<b>17.95 ± 5.21</b> (15.64 – 20.27)	<i>p</i> ≤ 0.05	0.142
	<i>Nc</i> (n)	25.32 ± 12.87 (19.61 – 31.03)	24.00 ± 7.77 (20.55 – 27.45)	NS	0.169
	<i>Fq</i> (n/s)	<b>1.05 ± 0.25</b> (0.94 – 1.16)	<b>1.38 ± 0.18</b> (1.31 – 1.46)	<i>p</i> ≤ 0.001	0.389
CAR		n=9 (4 refusals)	n=11 (2 refusals)		
	<i>Ti</i> (s)	44.17 ± 29.33 (29.58 – 58.75)	34.82 ± 15.33 (28.02 – 41.61)	NS	0.042
	<i>Nc</i> (n)	45.06 ± 20.71 (34.76 – 55.36)	48.82 ± 17.32 (41.14 – 56.50)	NS	0.010
	<i>Fq</i> (n/s)	<b>1.08 ± 0.22</b> (0.97 – 1.19)	<b>1.48 ± 0.25</b> (1.36 – 1.59)	<i>p</i> ≤ 0.001	0.403

CAR: carrot sample; CER: cereals sample, CHS: cheese sample; ECC: Early Childhood Carie. CI: Confidence Interval; n correspond to the number of children with no food refusal; NS: no statistical difference (*p* > 0.05)

## FIGURE LEGENDS

**Fig. 1** Domain-by-domain orofacial dysfunction frequency in both ECC and control groups (n=13 per group). From I to VI: structured interview items; from 1 to 6: clinical examination items

**Fig. 2** Box-plot representation of D50 values at swallowing in both groups of children for the three foods tested (CER: cereals, CHS: cheese, CAR: raw carrot).

Figure 1

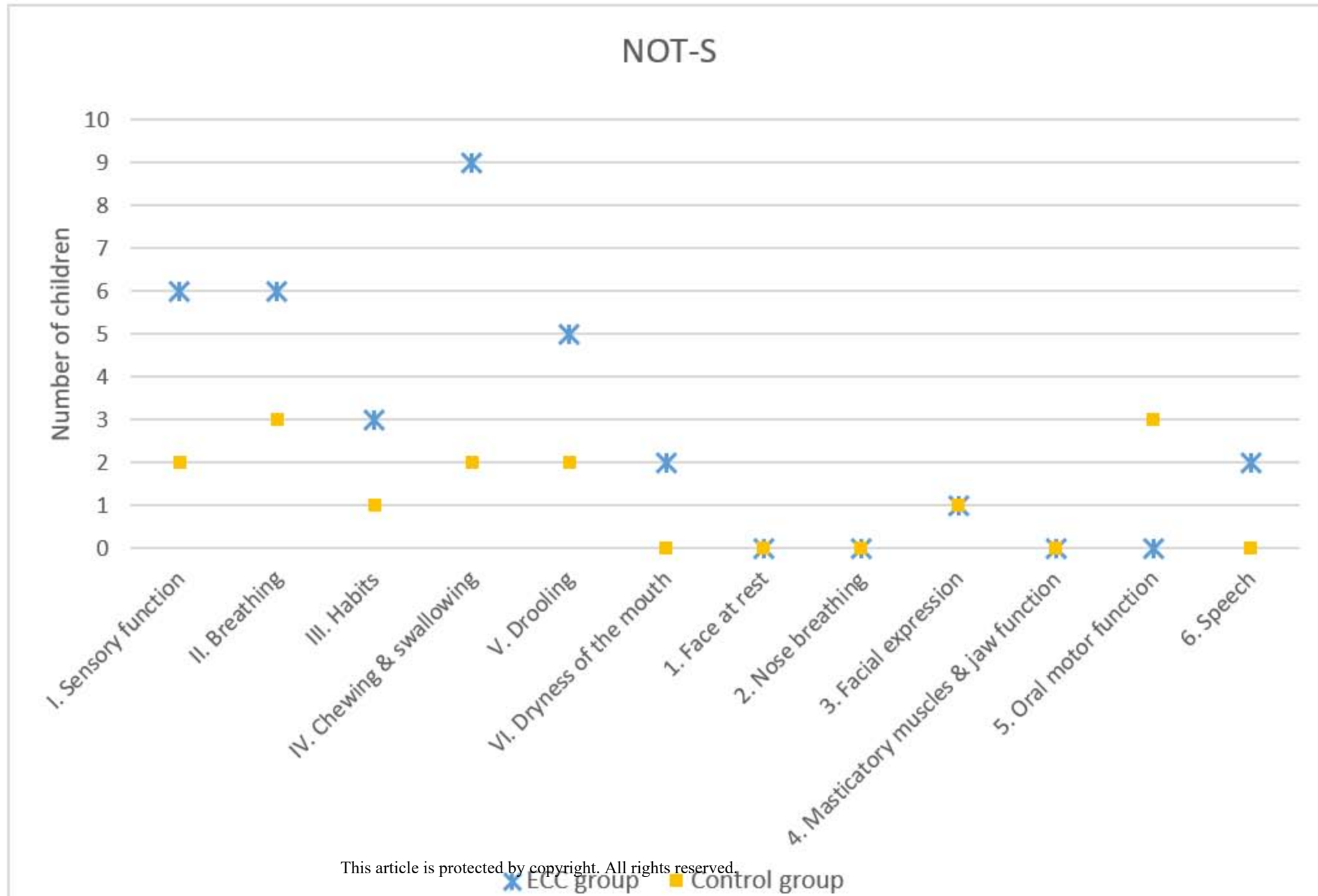


Figure 2

