

1 **Article**2 **Swallowing safety and efficiency after open partial**
3 **horizontal laryngectomy: a videofluoroscopic study**4 **Nicole Pizzorni** ^{1,*}, **Antonio Schindler** ¹, **Micol Castellari** ¹, **Marco Fantini** ², **Erika Crosetti** ² and
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12 **Abstract:** Dysphagia is common after open partial horizontal laryngectomy (OPHL). Mechanisms
13 causing lower airways' invasion and pharyngeal residue are unclear. The study aims to examine
14 physio-pathological mechanisms affecting swallowing safety and efficiency after OPHL. Nineteen
15 patients who underwent an OPHL type IIa and arytenoid resection were recruited.
16 Videofluoroscopic examination of swallowing was performed. Ten spatial, temporal, and scalar
17 parameters were analyzed. Swallowing safety and efficiency were assessed through the Dynamic
18 Imaging Grade of Swallowing Toxicity (DIGEST) scale. Swallowing was considered unsafe or
19 inefficient for a DIGEST safety or efficiency grade ≥ 2 , respectively. Videofluoroscopic measurements
20 were compared between safe vs. unsafe swallows, and efficient vs. inefficient swallows. Seven
21 patients (36.8%) showed an unsafe swallowing and 6 patients (31.6%) an inefficient swallowing.
22 Unsafe swallows had worse laryngeal closure ($p=0.028$). Inefficient swallows presented a longer
23 pharyngeal transit time ($p=0.009$), a shorter hyoidomandibular distance during swallowing
24 ($p=0.046$) coupled with reduced pharyngoesophageal segment opening lateral ($p=0.012$), and a
25 worse tongue base retraction ($p=0.017$). In conclusion, swallowing safety was affected by incomplete
26 laryngeal closure, while swallowing efficiency was affected by increased pharyngeal transit time,
27 reduced hyoid elevation together with upper esophageal sphincter opening, and incomplete tongue
28 base retraction. Rehabilitative and surgical approaches should target the identified physio-
29 pathological mechanisms.

30 **Keywords:** open partial horizontal laryngectomy, supracricoid laryngectomy, dysphagia,
31 swallowing, videofluoroscopy
32

33 **1. Introduction**

34 Open partial horizontal laryngectomies (OPHLs) are conservative surgical techniques aimed to
35 the treatment of laryngeal carcinomas in early-intermediated T stage [1]. Conversely to total
36 laryngectomies, main laryngeal functions (i.e., respiration, phonation, and swallowing) are
37 preserved, thanks to the sparing of at least one functioning crico-arytenoid unit with the
38 corresponding arytenoid and the intact inferior laryngeal nerve of the same side; therefore, the need
39 of a permanent tracheostoma is avoided. Among the OPHLs, OPHL type II is characterized by the
40 resection of the entire thyroid cartilage, with the inferior limit represented by the upper edge of the
41 cricoid ring. Different types of OPHL type II exist, differentiated by the amount of supraglottis
42 removed, and their extension to include one arytenoid (+ARY). In OPHL type IIa, the thyrohyoid
43 membrane is entered horizontally from above, and the pre-epiglottic space and epiglottic cartilage
44 are transected so that the suprahyoid part of the epiglottis is spared. On both sides, the inferior
45 constrictor muscles are incised, the piriform sinuses dissected, the inferior horns of thyroid cartilage

46 cut, and the ventricular and vocal folds divided down to the lower limit of resection in the subglottic
47 region. The trachea is mobilized by blunt dissection along the anterior tracheal wall and a cervico-
48 mediastinal release of the trachea is performed. The cricoid is pulled up to the level of the hyoid bone
49 to achieve the laryngeal reconstruction by a cricothyroidoepiglottopexy.

50 Swallowing is a complex sensorimotor behaviour involving the coordinated contraction and
51 inhibition of the musculature of the mouth, the tongue, the pharynx, the larynx, and esophagus
52 bilaterally in a short interval (0.6-1.0 s) [2]. During the oral and the pharyngeal phase of swallowing,
53 different events occur under voluntary or involuntary control. The timing of swallowing events and
54 the intensity of muscular contraction are modulated based on the characteristics of the bolus to
55 swallow, thanks to the sensory-motor integration at the level of the central pattern generator in the
56 brainstem. In case of the failure of the occurrence of a swallowing event, or of an aberrant sequence,
57 timing, and intensity of these events, swallowing safety and efficiency may be impaired. Safety refers
58 to the ability to transfer the bolus from the mouth to the stomach without penetration or aspiration
59 into the lower airways; efficiency refers to the ability to transfer the bolus from the mouth to the
60 stomach without post-swallow pharyngeal residue [3]. Pulmonary complications (e.g., aspiration
61 pneumonia) and nutritional complications are consequences of impaired swallowing safety and
62 efficiency, respectively. Moreover, swallowing complications comprise reduction of quality of life,
63 limitations to social participation, and negative affective responses [4].

64 Swallowing function after OPHL type II has been extensively investigated in the literature [5-6].
65 The incidence of dysphagia is approximately of 100% immediately after surgery, but, usually,
66 swallowing function recovers spontaneously in 3 to 6 months post-operatively, with the majority of
67 the patients achieving a free oral diet [6]. Nevertheless, chronic aspiration, especially with liquids,
68 and post-swallow residue, especially with solids, are often detected even in the long-term, and
69 increase the risk of aspiration pneumonia and death [7]. Studies investigating swallowing function
70 in patients who underwent an OPHL mainly focus on signs of dysphagia (i.e., penetration, aspiration,
71 residue). However, there is a paucity of studies assessing the mechanisms causing these signs. In
72 1996, Woisard et al analyzed the pathophysiology of swallowing in 14 patients one year after OPHL.
73 Several mechanisms were found, the most frequent being reduced tongue base retraction, reduced
74 laryngeal elevation, reduced laryngeal anteriorization and faulty in the backward movement of the
75 epiglottis [8]. However, the mechanisms underlying reduced safety and efficiency were not
76 investigated. In 2005, Yüçetürk et al used videofluoroscopy to assess swallowing in 10 patients who
77 underwent an OPHL type IIb (with the resection of the whole epiglottis) at least 6 months after
78 surgery [9]. Nine spatial and one temporal measures were analyzed and compared to those of 13
79 healthy controls. Results showed a statistically significant difference between the two groups for the
80 hyoidomandibular distance during swallowing and at rest, higher in patients than in controls, and
81 for the hyoidvertebral distance during swallowing, lower in patients than in controls. Due to the
82 small sample size and the low number (2/10) of patients with aspiration, no comparisons were made
83 between patients with and without signs of dysphagia. In 2008, Lewin and colleagues assessed
84 swallowing outcomes in 27 patients who underwent an OPHL type II using videofluoroscopy [10].
85 Patients were on average assessed at 4 weeks after the surgery, and re-assessed after 7 weeks from
86 the first videofluoroscopic study. Three mechanisms (hyolaryngeal excursion, tongue base retraction,
87 and neoglottic competency) were rated as normal or impaired. No temporal or biomechanical
88 objective measurements were gained. At the first assessment, reduced hyolaryngeal excursion was
89 identified in 45% of the patients, decreased base of tongue retraction in 27% of the patients, and
90 neoglottic incompetence in 100% of the patients. Results were stable at the second assessment. To the
91 best of our knowledge, no studies investigated the association between mechanisms and the presence
92 of signs of dysphagia in patients with an OPHL type IIa. Therefore, mechanisms causing lower
93 airways' invasion and post-swallow pharyngeal residue in this population are still unclear.

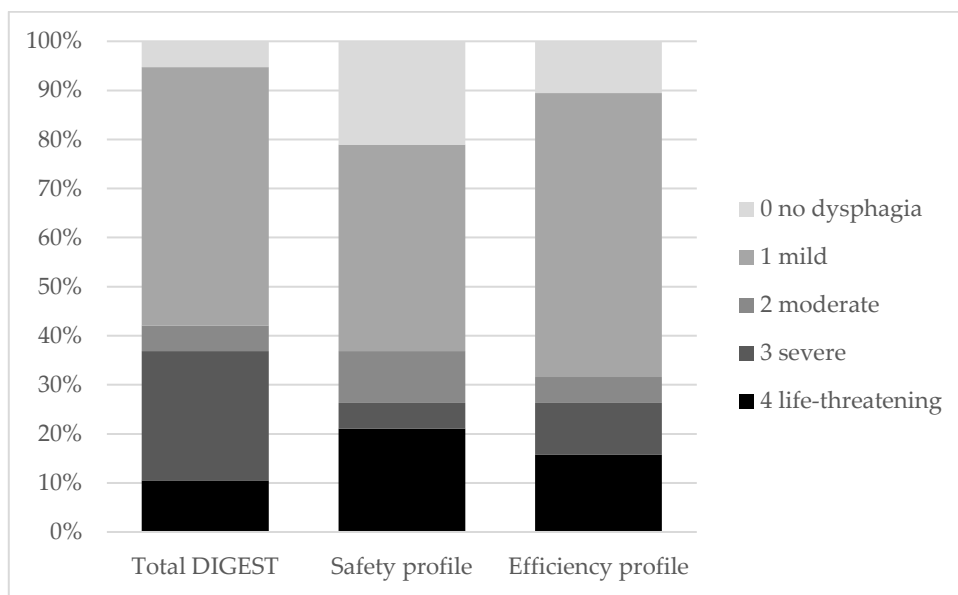
94 The study aims to examine videofluoroscopic variables associated with the impairment of
95 swallowing safety and efficiency after OPHL type IIa +ARY. Based on the previous studies, the
96 hypothesis is that the hyoidomandibular and the hyoidvertebral distances during swallowing, the
97 tongue base retraction, and the laryngeal closure may be significantly impaired in patients with an

98 unsafe or inefficient swallowing compared to those with a safe and efficient swallowing. The
 99 knowledge of the mechanisms causing dysphagia in the long-term will provide a basis to identify
 100 targeted and effective rehabilitative and surgical strategies to improve functional outcomes,
 101 potentially reducing the rate of pulmonary complications and the impact of quality of life.

102 **2. Results**

103 Based on the Dynamic Imaging Grade of Swallowing Toxicity (DIGEST) scores [11], 7 (36.8%)
 104 patients who underwent an OPHL type IIa +ARY showed an unsafe swallowing (DIGEST safety
 105 profile ≥ 2) and 6 (31.6%) patients had an inefficient swallowing (DIGEST efficiency profile ≥ 2). Only
 106 1 patient had no signs of dysphagia (total DIGEST score 0) at the videofluoroscopic assessment of
 107 swallowing. The distribution of the 19 patients in the DIGEST levels is reported in Figure 1. Four
 108 patterns of swallowing proficiency were identified and depicted in Figure 2.

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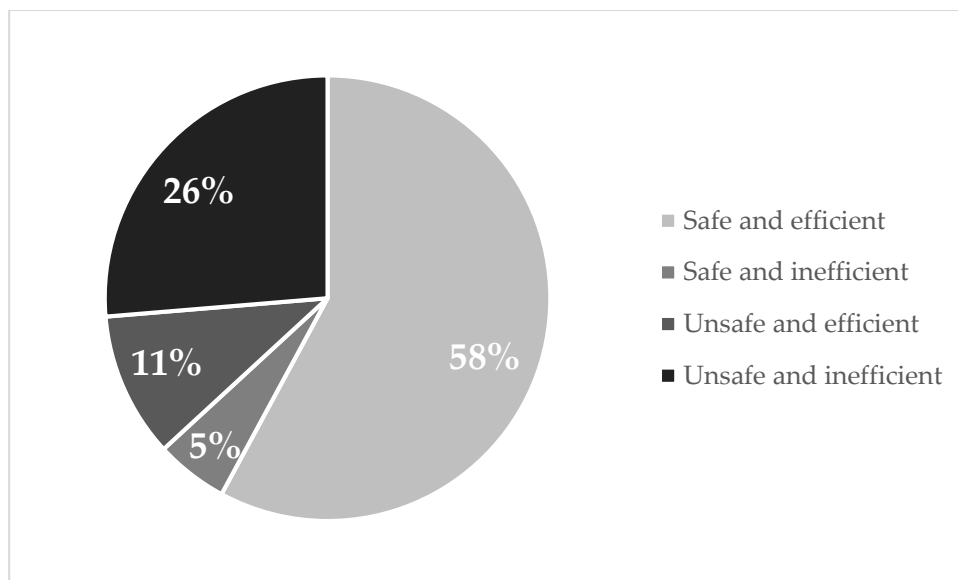


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Figure 1. Distribution of the 19 patients with OPHL type IIa +ARY in the DIGEST levels

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Figure 2. Swallowing patterns of the 19 patients with OPHL type IIa +ARY

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116 2.1. Swallowing safety: comparison of videofluoroscopic variables

117 Patients with safe swallowing had comparable age to patients with unsafe swallowing (median
 118 65 IQ range 10.5 vs median 71 IQ range 15, $p=0.340$), whereas had a significantly longer follow-up
 119 period (median 31.5 months IQ range 29.3 vs median 7 months IQ range 15, $p=0.017$). Comparisons
 120 of videofluoroscopic measures between patients with safe and unsafe swallowing are reported in Table
 121 1. A significant difference was found only for the laryngeal closure (LC) with liquids and solids.
 122 Patients with unsafe swallowing showed a more impaired laryngeal closure during swallowing than
 123 patients with safe swallowing.

124 **Table 1.** Comparisons of videofluoroscopic measures in patients with safe and unsafe swallowing

		SAFE		UNSAFE		p
		median	IQ range	median	IQ range	
TPT (s)	solid	0.32	0.08	0.32	0.40	0.711
	semisolid	0.32	0.10	0.36	0.20	0.299
	liquid	0.40	0.11	0.36	0.04	0.650
POD (s)	solid	0.24	0.08	0.24	0.08	0.482
	semisolid	0.24	0.07	0.28	0.04	0.837
	liquid	0.28	0.04	0.24	0.08	1
POL (mm)	solid	8.5	2.75	8	3	0.837
	semisolid	12	4	11	5	0.196
	liquid	11	4.5	12	4	0.592
HMS (mm)	solid	4	8	2	14	0.837
	semisolid	1	35	6	14	0.100
	liquid	0	15	4	6	0.196
HMR (mm)	solid	27	7.5	26	12	0.773
	semisolid	27	12.5	32	1	0.482
	liquid	26	10.5	22	16	0.384
HVS (mm)	solid	65	11	62	4	0.384
	semisolid	66	12.5	64	1	0.967
	liquid	66	15	60	2	0.482
LC	solid	1	1.75	3	1	0.013*
	semisolid	1	1.75	3	3	0.227
	liquid	2.5	1.75	4	1	0.028*
EM	solid	1	1	2	0	0.068
	semisolid	1	0.75	2	1	0.100
	liquid	1	1	2	0	0.120
IPS	solid	0	0.75	0	1	0.837
	semisolid	0	0	0	0	0.837
	liquid	0	1	0	0	0.432
TBR	solid	1	0.75	2	1	0.261
	semisolid	1	1	2	1	0.196
	liquid	2	1	2	1	0.650

* $p<0.05$ 125
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LEGEND. TPT total pharyngeal transit time, POD pharyngoesophageal segment (PES) opening duration,
 POL PES opening lateral, HMS hyoidomandibular distance during swallowing, HMR hyoidomandibular

128 distance at rest, HVS hyoidvertebral distance during swallowing, LC laryngeal closure, EM epiglottic
 129 movement, IPS initiation of pharyngeal swallowing, TBR tongue base retraction
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131 2.2. Swallowing efficiency: comparison of videofluoroscopic variables

132 Analogously to the safety analysis, patients with efficient swallowing had comparable age to
 133 patients with inefficient swallowing (median 66 IQ range 11 vs median 67.5 IQ range 15, $p=0.701$),
 134 but a significantly longer follow-up period (median 30 months IQ range 26.5 vs median 6.5 months
 135 IQ range 15, $p=0.009$). Comparisons of videofluoroscopic parameters between patients with efficient
 136 and inefficient swallowing are shown in Table 2. Significant differences were found for 4
 137 videofluoroscopic measures; patients with inefficient swallowing had a longer total pharyngeal
 138 transit time (TPT) with semisolids, a narrower pharyngoesophageal segment opening lateral (POL)
 139 with semisolids, a greater hyoidmandibular distance during swallowing (HMS) with liquids, and a
 140 more incomplete tongue base retraction (TBR) with solids.

141 **Table 2.** Comparisons of videofluoroscopic measures in patients with efficient and inefficient
 142 swallowing

		EFFICIENT		INEFFICIENT		p
		median	IQ range	median	IQ range	
TPT (s)	solid	0.32	0.08	0.36	0.37	0.152
	semisolid	0.32	0.08	0.40	0.19	0.009*
	liquid	0.40	0.14	0.36	0.06	0.898
POD (s)	solid	0.24	0.1	0.24	0.1	0.898
	semisolid	0.24	0.04	0.28	0.05	0.072
	liquid	0.28	0.08	0.28	0.07	0.831
POL (mm)	solid	9	3.5	8	3	0.639
	semisolid	12	4	9.5	4	0.012*
	liquid	12	5	10.5	3.5	0.467
HMS (mm)	solid	4	8	2	12.5	0.898
	semisolid	2	4	6	12.5	0.282
	liquid	0	1	6	1	0.046*
HMR (mm)	solid	28	8	26	14.25	0.831
	semisolid	28	1	33	13	0.210
	liquid	24	8.5	29	13.5	0.416
HVS (mm)	solid	66	9.5	6	0.75	0.072
	semisolid	66	12	6.3	1.05	0.282
	liquid	66	15	6.1	0.7	0.179
LC	solid	2	2	3	3	0.323
	semisolid	1	1.5	3.5	3	0.087
	liquid	3	2.5	3.5	2	0.467
EM	solid	1	1	2	1	0.521
	semisolid	1	1	2	1	0.244
	liquid	2	1	2	1	0.701
IPS	solid	0	0	0.5	1.25	0.210
	semisolid	0	0	0	0.25	0.765
	liquid	0	1	0	1.5	0.898

TBR	<i>solid</i>	1	0	2	0.25	0.017*
	<i>semisolid</i>	1	1	2	0.25	0.072
	<i>liquid</i>	2	1	2	0.25	0.323

* p<0.05

LEGEND. TPT total pharyngeal transit time, POD pharyngoesophageal segment opening duration, POL pharyngoesophageal segment opening lateral, HMS hyoidomandibular distance during swallowing, HMR hyoidomandibular distance at rest, HVS hyoidovertebral distance during swallowing, LC laryngeal closure, EM epiglottic movement, IPS initiation of pharyngeal swallowing, TBR tongue base retraction

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149 3. Discussion

150 This study firstly investigated mechanisms underlying an impairment of the safety and the
151 efficiency of swallowing in patients with OPHL type IIa +ARY, through the analysis of temporal,
152 spatial and ordinal videofluoroscopic measurements. Thus, it provides a better understanding of the
153 physio-pathological changes of swallowing in this population and their clinical relevance.

154 The age and the time from surgery to videofluoroscopic assessment were compared between
155 patients with an impaired safety or efficiency and patients with functional swallowing. The age was
156 comparable in patients with safe vs. unsafe swallowing, and in patients with efficient vs. inefficient
157 swallowing. The literature shows inconsistent findings on the effect of age on functional outcomes
158 after OPHL. Two studies have demonstrated no significant influence of age at surgery on swallowing
159 function [12-13]. On the other hand, Benito and colleagues demonstrated that the risk of aspiration
160 increases in patients who underwent an OPHL >70 [14]. Analogously, Naudo and colleagues reported
161 a significantly association between age and aspiration [15]. Time from surgery to follow-up
162 significantly differed in both the safety and the efficiency comparisons. Although patients had at least
163 a 5 months follow-up period, and studies in the literature show that the recovery of swallowing is
164 generally completed within 3-6 months after surgery [5-6], compensatory mechanisms may
165 consolidate even after this time period.

166 Swallowing safety was impaired in the 36.8% of the sample, with a statistically significant
167 difference only for the laryngeal closure parameter. Patients with unsafe swallowing had poorer
168 laryngeal closure. Normally, the closure of the laryngeal vestibule during swallowing is achieved
169 thanks to the concomitant epiglottic inversion, hyo-laryngeal elevation, aryepiglottic fold bunching,
170 arytenoid adduction, base of tongue posterior movement, and pharyngeal constriction [16-18]. Due
171 to the anatomical changes of this district, after an OPHL type IIa +ARY, the sphincteric action of the
172 neolarynx is provided by the approximation of the mobile arytenoid cartilage (rotating forward and
173 inward) and the epiglottis (tilting backward) [8]. Other configurations are described in the literature,
174 but are rarely observed [19]. Analogously to our findings, an inadequate closure of the laryngeal
175 vestibule entry was observed by Logemann et al in patients who were not eating at 2 weeks after an
176 OPHL type I (or supraglottic laryngectomy), when compared to the patients who restored oral
177 feeding at the same time-point [20]. Indeed, they identified two critical factors in the recovery of
178 swallowing: (a) the airway closure at the laryngeal entrance (i.e. the space between the arytenoid
179 cartilage and the base of the tongue), and (b) the contact of the base of tongue with the posterior
180 pharyngeal wall.

181 The closure of laryngeal vestibule may be targeted through both a swallowing therapy and
182 surgical rehabilitative approaches. Supraglottic and super-supraglottic maneuvers are two breath-
183 holding swallowing maneuvers aiming to improve the extent and the duration of the laryngeal
184 vestibule closure. Their efficacy on both swallowing kinematics and the rate of laryngeal penetration
185 and aspiration was proved in a cohort of patients with oropharyngeal dysphagia from different
186 etiologies and a cohort of patients with radiation-induced dysphagia [21-22]. Surgical approaches
187 comprise the endoscopic injection of different materials into the preserved arytenoid or into the
188 superior face of the cricoid ring [23]. The choice of the most appropriate injection site and the material
189 is based on a careful fiberoptic endoscopic examination of swallowing. Preliminary results from a
190 case series of 7 patients with an OPHL type IIa +ARY showed a complete recovery of the lower

191 airways' protection during swallowing in 4 patients, and a partial recovery with occasional aspiration
192 with liquids in 2 patients [23].

193 Swallowing was considered inefficient in the 31.6% of the sample. Patients with inefficient
194 swallowing had a longer total pharyngeal transit time, a narrower upper esophageal sphincter (UES)
195 lateral opening, a greater hyoidmandibular distance during swallowing, and a poorer contract
196 between tongue base and posterior pharyngeal wall. An interaction between these mechanisms can
197 be found, highlighting their cooperation in reducing swallowing efficiency. Indeed, the opening of
198 the UES not only relies on the inhibition of the cricopharyngeus muscle's contraction, but also on the
199 generation of adequate pharyngeal pressures and the anterior-superior motion of the hyolaryngeal
200 complex [24-26]. Pharyngeal pressures depends on the action of the velopharyngeal valve, the
201 protrusion of tongue base, and the contraction of pharyngeal constrictors [27]. Pharyngeal pressures
202 influence the pharyngeal transit time [28]. Therefore, it can be speculated that incomplete tongue base
203 retraction resulted in a reduced pharyngeal pressure, prolonging the duration of the total transit time
204 and reducing the UES lateral opening. The increased hyoidmandibular distance during swallowing
205 coupled with a comparable distance at rest suggests a deficit in the hyoid elevation in patients with
206 an inefficient swallowing, resulting in a further negative impact on the UES opening. The reduced
207 UES opening and the incomplete tongue base retraction lead to post-swallow residue in pyriform
208 sinuses and valleculae. No studies have assessed the association between videofluoroscopic
209 measurements and post-swallow residue in patients after OPHL; however, studies exist on other
210 populations. Pauloski and colleagues highlighted an association between a reduced tongue base or
211 posterior pharyngeal wall movement and the pharyngeal residue in patients with head and neck
212 cancer after the completion of radiotherapy [29]. Another study on patients with oropharyngeal
213 dysphagia found a reduction of the mean peak pharyngeal pressure in patients with an incomplete
214 tongue retraction, and a strong association with the presence of post-swallow pharyngeal residue
215 [30].

216 In swallowing therapy, the Shaker head lift exercise [31] and the Mendelsohn maneuver [32] are
217 strengthening exercise proved to increase the hyoid elevation and the UES opening in patients with
218 oropharyngeal dysphagia. Moreover, the effortful swallow [33] and the tongue hold swallow [34]
219 were found to improve the contact between the base of tongue and the posterior pharyngeal wall. As
220 for laryngeal closure, fat injections have been proposed in patients who underwent an OPHL type I
221 for the correction of the tissue loss at the level of the base of tongue, with promising results on the
222 improvement of the swallowing efficiency [35-36].

223 Strengths of the study are the highly homogeneous cohort and the use of objective measures for
224 the study of swallowing mechanisms. Only patient who underwent an OPHL type IIa +ARY, which
225 is the most performed type of OPHL [37] in our caseload, were included. Objective videofluoroscopic
226 measures are reliable and repeatable, reducing the subjectivity related to the use of perceptual
227 variables. Although the fiberoptic endoscopic evaluation of swallowing and the videofluoroscopy
228 are both considered gold-standard for the assessment of swallowing function [38], only the
229 videofluoroscopy can allow to investigate the pathophysiological mechanisms causing the signs of
230 dysphagia. Nevertheless, the study has some limitations. First of all, the sample size is limited to 19
231 patients. The sample size in comparable or even larger than other studies in the literature assessing
232 swallowing mechanisms after an OPHL [9-10]. However, the statistical power may be inadequate to
233 highlight some of the differences that were found not to be statistically significant in the study.
234 Moreover, the number of patients with a safe vs. unsafe swallow and an efficient vs. inefficient
235 swallow was not equally balanced.

236 Future studies may expand the analysis of the mechanisms affecting swallowing safety and
237 efficiency to other types of OPHL. An assessment of swallowing with high-resolution impedance
238 manometry may provide a better understanding of these mechanisms. Interventional studies should
239 be performed to verify the efficacy of rehabilitative and surgical strategies targeting the identified
240 mechanisms on swallowing safety and efficiency in patients with an OPHL type IIa +ARY.

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243 4. Materials and Methods

244 The cross-sectional study was carried out according to the Declaration of Helsinki. All subjects
245 enrolled in the study gave their written informed consent; all data were collected prospectively.

246

247 4.1. Patients

248 Patients were recruited at the Otorhinolaryngology Service of the Martini Hospital (Turin, Italy)
249 during their follow-up assessment, over a 5 months period. Selection criteria were: OPHL type IIa
250 +ARY, subjective swallowing complaints, no evident disease at the last follow-up, preservation of
251 respiration and speech, absence of a tracheostomy, no salvage total laryngectomy performed and at
252 least 3 months follow-up. For the homogeneity of the sample, only male patients who underwent an
253 OPHL type IIa +ARY were included. Nineteen patients were recruited. Median age was 66 (range 51-
254 82), median time from surgery to last follow-up was 23 months (range 5-54). Tumors' stage was T2N0
255 tumor in 12 patients, T3N0 in 6 patients, and T4N0 in 1 patient. Only one patient underwent
256 radiotherapy after surgery.

257

258 4.2. Videofluoroscopic study of swallowing

259 Patients underwent a standardized videofluoroscopic assessment of swallowing with the Digital
260 Subtraction Angiography Unit (Advantix LC Plus, General Electric) at 25 frames/second. Patients
261 were seated in lateral viewing plane. Videofluoroscopic studies were digitally recorded,
262 downloaded, and de-identified for subsequent data analyses. A liquid 10ml barium bolus, a semisolid
263 10 ml barium bolus, and half biscuit were administered.

264

265 4.3. Dynamic imaging grade of swallowing toxicity (DIGEST)

266 The DIGEST is a validated five-point ordinal scale that provides an overall rating of pharyngeal
267 swallowing function assessed through videofluoroscopy [11]. The DIGEST includes a total score and
268 two subscores: (i) the safety profile, derived by assigning the maximum Penetration-Aspiration scale
269 [39] score across the different swallowing trials, (ii) the efficiency profile, derived by estimating the
270 maximum percentage of the pharyngeal post-swallow residue. Both the total DIGEST score and the
271 subscores range from 0 to 4 (0 = no pharyngeal dysphagia, 1 = mild, 2 = moderate, 3 = severe, 4 = life
272 threatening).

273

274 4.4. Videofluoroscopic measures

275 Videofluoroscopic recordings were assessed by a blinded speech and language pathologist using
276 the Carestream software (Carestream Health, Inc.). Overall, 10 parameters were selected from the
277 literature for the videofluoroscopic analysis [9, 26, 40, 41]. They included 4 spatial measures, 2
278 temporal measures and 4 ordinal variables. Definitions used to rate the 10 parameter are reported in
279 Tables 3 and 4. Spatial measurements were made after calibration of the digitized image to the size
280 of a standard coin taped to the submandibular region of the patients during the swallowing study.
281 For temporal parameters, the number of frames was counted and then transformed into seconds
282 (number of frames : 25).

283

284 **Table 3.** Temporal and spatial videofluoroscopic measures

Measure	Abbreviation	Unit of measurement	Definition
Total pharyngeal transit time	TPT	s	Time from when bolus head first passes posterior nasal spine to time when bolus tail exits PES

PES opening duration	POD	s	Time from when PES first opens for bolus entry to when it first closes behind the bolus
PES opening (lateral)	POL	mm	Distance at the narrowest point of opening between C3 and C6 (upper esophageal sphincter) on lateral fluoroscopic view
Hyoidomandibular distance during swallowing	HMS	mm	Distance between the upper margin of the hyoid bone and lower margin of the mandible during swallowing
Hyoidomandibular distance at rest	HMR	mm	Distance between the upper margin of the hyoid bone and lower margin of the mandible at the standing point immediately prior to swallowing
Hyoidovertebral distance during swallowing	HVS	mm	Distance between the anterior border of vertebral spine and hyoid bone during swallowing

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Table 4. Ordinal videofluoroscopic variables

Ordinal variable	Abbreviation	Operational definitions
Laryngeal closure	LC	Ability to close the laryngeal vestibule during swallowing, assessed based on the presence or absence of air in the vestibule. Ratings: 1. Complete and protective 2. Complete and not protective 3. Incomplete and protective 4. Incomplete and not protective.
Epiglottic movement	EM	Tilting of the epiglottis during swallowing, assessed based on the contact between the epiglottis and the CAU. Ratings: 1. Complete inversion 2. Incomplete inversion
Initiation of pharyngeal swallowing	IPS	Site of onset of the swallowing reflex. Ratings: 0. Bolus head at posterior angle of the ramus 1. Bolus head at valleculae 2. Bolus head at posterior laryngeal surface epiglottis 3. Bolus head at pyriform sinuses 4. No appreciable initiation of swallowing at any location
Tongue base retraction	TBR	Backward movement of the tongue based during swallowing, assessed based on the contact between the tongue base and the posterior pharyngeal wall. Ratings: 1. Complete retraction 2. Incomplete retraction

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288 4.5. Statistical analysis

289 Considered the small sample size, results are reported as median and interquartile (IQ) range
290 and non parametric statistics were conducted. Statistical analysis was performed with the IBM SPSS
291 Statistics 25.0® package for Windows (SPSS Inc, Chicago, IL). Swallowing was judged as unsafe if
292 the patient scored ≥ 2 on the DIGEST safety profile and as inefficient if the patient scored ≥ 2 on the
293 DIGEST efficiency profile. The age, the time from surgery to follow-up, and videofluoroscopic
294 measures were compared in: (i) patients with safe swallowing vs. patients with unsafe swallowing;
295 (ii) patients with efficient swallowing vs. patients with inefficient swallowing. The statistical
296 significance was set at $p < 0.05$.
297

298 5. Conclusions

299 The mechanisms underlying swallowing impaired safety and efficiency have been analyzed in
300 a group of patients who underwent an OPHL Ila +ARY. An incomplete laryngeal closure affects
301 swallowing safety leading to laryngeal penetration and aspiration. An increased total pharyngeal
302 transit time and hyoidomandibular distance during swallowing, a reduced UES lateral opening, and
303 an incomplete tongue base retraction cause post-swallow pharyngeal residue, thus, reducing the
304 swallowing efficiency. A swallowing evaluation after an OPHL type Ila +ARY should focus on the
305 assessment of these mechanisms, in addition to the identification of signs of dysphagia. Rehabilitative
306 and surgical approaches targeting these mechanisms may improve swallowing function in this
307 population.
308

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