Evaluating the effect of orthognathic treatment on facial attractiveness and estimated age by means of artificial intelligenece

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Evaluating the Effect of Orthognathic Treatment on Facial Attractiveness and Estimated Age by Means of Artificial Intelligence

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This thesis is dedicated to my beloved husband and parents

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List of Abbreviations

AOB	Anterior Open Bite
asym.	asymmetry
CI	Confidence Interval
Class II	Angle's classification of malocclusion Type II
Class III	Angle's classification of malocclusion Type III
CNNs	Convolutional Neural Networks
diff.	difference
dpi	dots per inch
et al.	and others
fMRI	functional Magnetic Resonance Imaging
IMDb	Internet Movie Database
JPEG	Joint Photographic Experts Group
n	number
OFC	Orbitofrontal Cortex
OR	Odds Ratio
OSA	Obstructive Sleep Apnea
SD	Standard Deviation
SSRO	Sagittal Split Ramus Osteotomy
WSR	Wilcoxon Signed-Rank
X^2	Pearson's chi-squared
y	year

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Abstract

AIM: Improvement of facial appearance is one of the two principal reasons why patients seek orthognathic treatment. Ordinarily, facial beauty is assessed as part of treatment outcome by lay people or professionals. The use of artificial intelligence permits scoring facial attractiveness objectively and reproducibly by characterizing attractiveness of particular facial traits. The aim of this study was to apply a trained algorithm on orthognathic patients, and to assess the impact of orthognathic therapy on facial attractiveness and apparent age.

SUBJECTS AND METHODS: Pre- and post-treatment photographs (n=2164) of 146 consecutive orthognathic patients (females: 77 [52.7%]; males: 69 [47.3%]; mean age before treatment: 23.2 years) were collected for this longitudinal retrospective single-center evaluation. For every case, gender, type of malocclusion and performed surgery were recorded. For every photograph, facial attractiveness and apparent age were established with a computational algorithm comprising a face detector, convolutional neural networks (CNNs) for the extraction of deep features, and support vector regression for apparent age and facial attractiveness (score: 0 - 100). The computational algorithm was trained on >13’000 face images with more than 17 million ratings for attractiveness, and on >0.5 million images for age estimation. Results for pre- and post-treatment photographs were averaged for every patient separately, and compared to real age. In order to analyze the impact of gender, type of malocclusion and surgery, Pearson's chi-squared (x^2) tests were computed, odd ratios (OR) established and Wilcoxon signed-rank tests applied to the differences of mean attractiveness. To determine significant differences between real age and apparent age, before and after therapy, a Mann-Whitney-U-test was conducted.

RESULTS: Overall, facial attractiveness did not significantly improve in females (42.41 to 40.92, p=0.341) or males (46.98 to 48.42; p=0.255). The odds of increased attractiveness were higher for Class II patients than for non-Class II patients (OR: 3.3), and after conducted mandibular (OR: 2.8) or chin osteotomy (OR: 2.2). Before therapy, patients appeared older than their real age, with a mean difference between apparent age and real age of 1.19 years for females (p= 0.016) and 1.74 years for males (p<0.001). After treatment, the discrepancy between apparent age and real age was reduced mainly in females, with a residual mean difference of 0.22 years (p=0.476). In males, most of the dissimilarity remained with a mean difference of 1.59 years (p=0.002).

CONCLUSIONS: Orthognathic therapy changes facial features and, especially in females, makes the face appear younger. Facial attractiveness, as assessed with artificial intelligence, however, seems to remain unaffected. Potential patients for orthognathic therapy should be made aware of this fact.

1 Introduction

Being attractive is advantageous and a desirable asset. Social interest in improving attractiveness is enormous, and societal pressure to appear attractive clearly dictates many decisions and behaviourisms.

Several studies have illustrated that attractive individuals obtain higher appraisal regarding their competence, intelligence, smartness, success, health, as well as sexual responsiveness and elicit more empathy compared to people perceived as unattractive [1-4]. The "beautiful is good" [1] attitude is instilled and adopted already in childhood, where in movies the ugly witch is associated with the forces of evil and beautiful protagonists are equated with kindness [5]. Facial attractiveness is particularly important, as it has been documented that natural favoritism is shown to attractive faces irrespective of race, gender and age: Babies, when simultaneously presented with two pictures of an attractive and unattractive face, tend to direct their look to the former [6-8]. According to evolutionary psychologists, facial qualities are used as clues to detect people with disadvantageous genes and diseases, independent of cultural influences. The judgement based on facial preferences is greatly influenced by attractiveness and a youthful appearance, both signs for fitness and health. While youthfulness relates to a positive impression, signs of aging are perceived as unhealthy and unattractive [2, 9].

Neuroanatomical studies on brain systems have demonstrated, based on functional magnetic resonance imaging (fMRI), that pictures of extremely attractive, unattractive, or anomalous faces lead to more activation in the right amygdala, the area responsible for unconscious induction of emotions [10]. Moreover, highly attractive faces induce neural activations in the medial orbitofrontal cortex (OFC), an area usually activated by pleasant touch, as well as neural activations in the reward system, such as the nucleus accumbens. Conversely, unattractive and anomalous faces caused neural activation in the lateral prefrontal cortex. Lastly, a smiling facial expression enhances neural activation in the medial OFC, signifying that the attractiveness of a face is easily positively modulated with a smile [2, 11, 12].

Patients with severe dentofacial deformities suffer not only from functional problems with chewing, speaking or biting, but are also impeded in their social interactions and are often discriminated against, which might lead to an introverted lifestyle, compromised self-confidence, or other personality changes [13, 14]. In fact, the two main motives for patients to undergo orthognathic treatment are improvement of facial aesthetics and alleviation of functional problems [15-17]. In Europe, female orthognathic patients seem to attach more importance to the improvement in facial aesthetics than males [17].

1.1 **Orthognathic surgery**

The possibilities in orthodontic treatments for adults are mostly limited to tooth movements within the given boundaries of the alveolar bone. For patients with severe malocclusions, absence of residual growth usually implies that a satisfactory result can only been achieved through combined surgical and orthodontic efforts. The decision to carry out a combined procedure must be made before treatment begins, as an “orthodontic-only” approach will aim to camouflage the basal jaw discrepancy with compensatory dental positions. On the other hand, in the pre-surgical orthodontic phase, emphasis is put on dental de-compensation, and on a ideal relationship between teeth and the supporting alveolar bone. Thus, the pre-surgical phase often reveals the true jaw discrepancy on a dental level as well, but at the same time enables correcting surgically the skeletal and its corresponding dental malocclusion together [18-20].

With the osteotomy techniques available in this day and age, dentofacial anomalies of all types can be addressed. In particular, it is possible to reposition the upper and / or lower jaw, move the chin, or even dentoalveolar segments independently. This versatility together with important advances in surgery, such as the introduction of semi-rigid intermaxillary fixation, has transformed orthognathic surgery to one of the most valuable solutions for complex dentofacial malocclusions [18, 20].

1.1.1 ***Different surgical approaches***

For adjustments of the mandibula, the sagittal split ramus osteotomy (SSRO) was introduced more than half a century ago [21]. It is commonly preferred due to several advantages: Primarily because it allows rotational and translational repositioning of the anterior segment, while at the same time protecting the inferior alveolar nerve, and offers greater amenability to rigid fixation compared to other mandibular bodily procedures and ramus osteotomy techniques [22].

In addition to a SSRO, an inferior anterior osteotomy of the mandible is performed in approximately one third of all cases in order to reposition the chin in all three planes of space relative to the mandibular body [18]. Not only a vertical reduction by moving the chin backward or upward (with superior results achieved by removing some bone) or increase by moving the chin forward or downward (with superior results achieved by using bone grafts) are possible, but also the correction of an asymmetry by moving the chin sideways [20].

SSRO is sometimes preceded by distraction osteogenesis, which offers the possibility of larger movements and bony callus apposition, both especially required in patients with hemifacial microsomia or hemimandibular hypoplasia. However, perfect occlusal relationships are hardly ever attained with distraction osteogenesis, and combined orthodontic-orthognathic surgery is frequently required in a second step. Hence, distraction osteogenesis is routinely limited to and mainly used for early age interventions [18].

Orthognathic correction of the maxilla is generally performed with the Le Fort I osteotomy, which allows for a correction in all three spatial planes. Le Fort I osteotomy is mostly indicated for the correction of Class II and III malocclusion, dentofacial asymmetry, obstructive sleep apnea (OSA), maxillary atrophy or excess, and is very often executed in combination with mandibular SSRO. Due to a low rate of complications, a predictable long-term stability and its low technical difficulty, the Le Fort I osteotomy is, apart from the SSRO, one of the core procedures in orthognatic surgery [23]. For the correction of the entire mid-face, Le Fort I remains however insufficient, and more comprehensive approaches need to be applied, such as Le Fort II or Le Fort III osteotomies. Similar to mandibular distraction osteogenesis, severe maxillary deficiency can also be treated with distraction osteogenesis instead of a Le Fort III osteotomy, thus circumventing the need of extensive bone grafts [18].

For a satisfactory outcome, an orthodontic pre-treatment and a solid pre-surgical planning considering the limits of each possible method are indispensable. Moreover, orthodontists and surgeons need to be aware of the possibilities and limitations of each osteotomy, and need to ensure that the desired outcome together with all eventualities are adequately portrayed when the patient's informed consent is sought [23].

1.1.2 *Evaluating the aesthetic outcome*

Much research has been conducted on how to accurately evaluate the outcome of orthognathic surgery. Functional and aesthetic improvements have been studied based on subjective assessments of patients, together with changes in self-confidence and social adjustment [24, 25]. Other approaches encompass orthodontics and maxillofacial surgeons evaluating the changes in dental occlusion, cephalometric measurements, soft tissue proportions and facial aesthetics before and after treatment [26].

Yet, all historical approaches fall short to adequately address the assessment of *social* attractiveness. Professional appraisal of attractiveness, as performed by orthodontists, surgeons or general dentists, relies on taught rules of beauty dictated by “ideal” facial features, golden ratios and other established proportions [26]. These classic rules of facial harmony will however not reflect the attractiveness as perceived by peers [27, 28].

The assessment of attractiveness performed by a limited number of lay people is equally inconclusive. The subjectivity involved is too important to be ignored and may corrupt the evaluation altogether [29].

1.2 **Artificial intelligence**

Recent advances in artificial intelligence could help to overcome the above-mentioned drawbacks. The term artificial intelligence is applied to applications when a computer, robot or machine is trained to mimic "cognitive" functions that humans associate with a cognitive act performed by a human mind. Although optical letter / character recognition or optical facial recognition is a rudimentary cognitive function, it is usually excluded from artificial intelligence, owing to the fact that the cognitive aspects are very limited. On the other hand, the *interpretation* or *analysis* of a recognized face (concerning for example its attractiveness or apparent age) enters unquestionably the realms of artificial intelligence. A research group at the ETH Zurich Vision Lab has recently developed algorithms that enable the evaluation of facial attractiveness and the estimation of apparent age [30, 31]. Based on more than 13'000 profile images from dating websites and rated for attractiveness by over 17 million of heterosexual members (18-37 years), the computer program learned to predict social attractiveness. With over 500’000 facial images with annotated age (16-77 years) extracted from the Internet Movie Database (IMDb) and Wikipedia, an algorithm was established to predict the apparent age. The amount of training data strongly affects the accuracy of the trained models [31]. Thus, the large data set lead to robust performances whilst considering particularities, distribution and bias [30, 31], to efficiently overcome the above-mentioned problems associated with subjectivity of single raters. In short, the use of artificial intelligence enables scoring facial attractiveness objectively, reproducibly, based on an algorithm that reflects relevant opinion.

Artificial intelligence has never been applied to assess both improvements in social attractiveness and changes of apparent age in orthognathic patients. With the algorithms established by Timofte and co-workers from the ETH Zurich, a new robust diagnostic tool could be introduced to evaluate treatment outcome, in order to overcome the prevalent drawbacks.

1.3 **Aims**

The aims of the present study were therefore (a) to evaluate the impact of orthognathic therapy on facial attractiveness and apparent age estimation, by applying the newly developed and validated algorithm on pre-and post-treatment photographs, and (b) to assess the possible influences of gender, underlying malocclusion and chosen osteotomy on the obtained results.

2 Materials and Methods

2.1 Setting

The present investigation's design is a retrospective longitudinal cohort study of consecutive patients who underwent orthognathic treatment (i.e. a combined orthodontic-maxillofacial surgery therapy). All patients' records were collected from the archives of the Clinic of Orthodontics and Paediatric Dentistry at the University of Zurich.

2.2 Inclusion criteria for patients

Records of all archived patients who had undergone orthognathic therapy were considered. Patients with craniofacial syndromes, cleft lip and palate, previous maxillofacial surgery and reported facial traumas, as well as patients with incomplete records, were excluded. The records included (at least frontal and profile) photographs before and after therapy, and several variables collected from the patients' records (sex; age at beginning and end of therapy; age at surgery; age at follow-up; type of malocclusion and type of surgery). Exclusion criteria were unfinished treatment or missing data. Over all, 146 patients were included in the data analysis.

The forms of pre-treatment malocclusions were categorized as

- **Class II:** Retrognathia of the lower jaw or/and prognathia of the upper jaw
- **Class III:** Prognathia of the lower jaw or/and regtrognathia of the upper jaw
- **Anterior Open Bite (AOB):** Anterior skeletal open bite
- **Asymmetry:** Asymmetry of the lower face

The different types of surgery were labelled as

- **Le Fort I:** Le Fort I osteotomy in the upper jaw
- **SSRO:** Sagittal Split Ramus Osteotomy of the lower jaw
- **Chin:** Chin osteotomy
- **Additional:** Other maxillofacial osteotomies

2.3 Ethics

Written informed consent for secondary use of the patients' data including their facial photographs was obtained from all patients (and their legal guardians) prior to treatment, according to the directives set by the National Federal Council [32]. Ethical guidelines [33] were strictly followed and irreversible anonymization was performed in accordance with State and Federal Law [34, 35]. Judicial and ethical conformity of this study were attested and confirmed by the local ethics committee (KEK 2016-00990).

2.4 Photographic images

2.4.1 *Digitalization*

Recent photographic images of patients were taken digitally and archived electronically (FR-win®, CE 0124, Computer konkret, DentalSoftwarePower) and could thus be used in their present format. Older patient images were only available as reversal film slides (36 mm × 24 mm) or developed photos, and had to be scanned for further use. The slides and mounted slides were digitalized with a slide scanner (Optic Film dia scan, 8200i SE, plustek) using a dedicated software (SilverFast® 8, 8.8.Or5, Laser Soft Imaging AG LSI) at an image resolution of 2400 dots per inch (dpi), then exported and stored in JPEG format. The photographic images were scanned with a photo scanner (Epson Perfection Easy Photo Fix, V750 PRO, Epson) using a dedicated software (Epson Scan, 3.83 DE, Epson) at an image resolution of 600 dpi, then exported and stored in JPEG format. All photographic images were of adequate quality. Digital image enhancement was performed to improve image quality, only altering contrast and brightness.

2.4.2 *Image selection and labeling*

Both the initial records and the records at the end of treatment consisted of several standardized images of the patient's face, using a single-lens reflex camera, a monochrome blue background and a dedicated flash reflector. The different types of facial images taken are listed in Table 1.

Table 1 *Different image types taken as routine records during and after orthodontic treatment.*

Image Type	Viewing Angel	Characteristic
1	Frontal	Resting posture
2	Frontal	Smile
3	Frontal	Habitual occlusion
4	Profile	Resting posture
5	Profile	Habitual occlusion
6	45°	Habitual occlusion
7	45°	Smile

The seven possible image types were not always available for all patients. However, only patients with at least one frontal and one profile picture (pre- and post-treatment) were considered. Two examples of the used photographic material series are shown in Figure 1 (Retgrognathia) and Figure 2 (Prognathia) respectively. Alltogether, 2164 annotated facial images were digitally archived, processed, evaluated and used for the statistical analysis.

Figure 1 *Representative case of used photographical material of a retrognathia patient before (top row) and after (bottom row) treatment.*

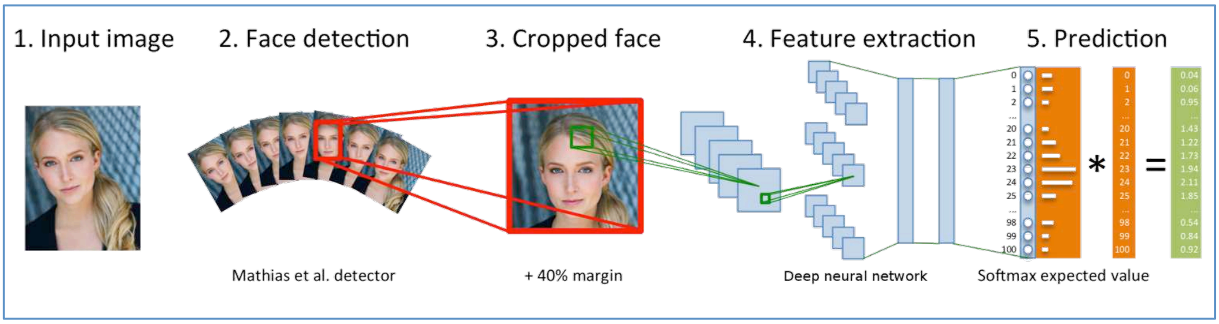
Figure 2 *Representative case of used photographical material of a prognathia patient before (top row) and after (bottom row) treatment.*

2.5 Assessment of apparent age and facial attractiveness

For every single photograph (n=2164), apparent age and facial attractiveness were established with a computational algorithm comprising a face detector, convolutional neural networks for the extraction of deep features, and support vector regression for apparent age and facial attractiveness. The computational algorithm was trained on >13'000 face images with more than 17 million ratings for attractiveness, and on >0.5 million images for age estimation [30].

Single image values of apparent age and facial attractiveness were averaged for every patient based on two series (before treatment; after treatment). As such, four values were used as primary outcome for every patient: apparent age (a) before and (b) after treatment, and attractiveness (c) before and (d) after treatment.

Figure 3 *Processing pipeline: the face is detected in the input image and fed through a deep convolutional neural network for features extraction and to further predict the attractiveness and the age. Figure taken from reference [31].*



2.6 Statistics

All statistical analyses of the data were done with the SPSS software (IBM SPSS version 21, Armonk, NY, USA). All variables were descriptively reviewed and checked for normality using a Kolmogorov-Smirnov test. Facial attractiveness and apparent age were regarded as primary outcome, and patient's gender, type of malocclusion and type of performed surgery were used as potentially influencing variables. In order to analyze the impact of the influencing variables on facial attractiveness, Pearson's chi-squared (X^2) tests were computed, and odd ratios (OR) with corresponding confidence interval (CI) included. Differences of mean attractiveness values before and after treatment were assessed with a Wilcoxon signed-rank (WSR) test. To determine significant differences between real age and apparent age before and after therapy, a Mann-Whitney-U-test was conducted. Differences were considered significant at $p < 0.05$ and highly significant at $p < 0.01$.

3 Results

3.1 Description of patients and performed surgery

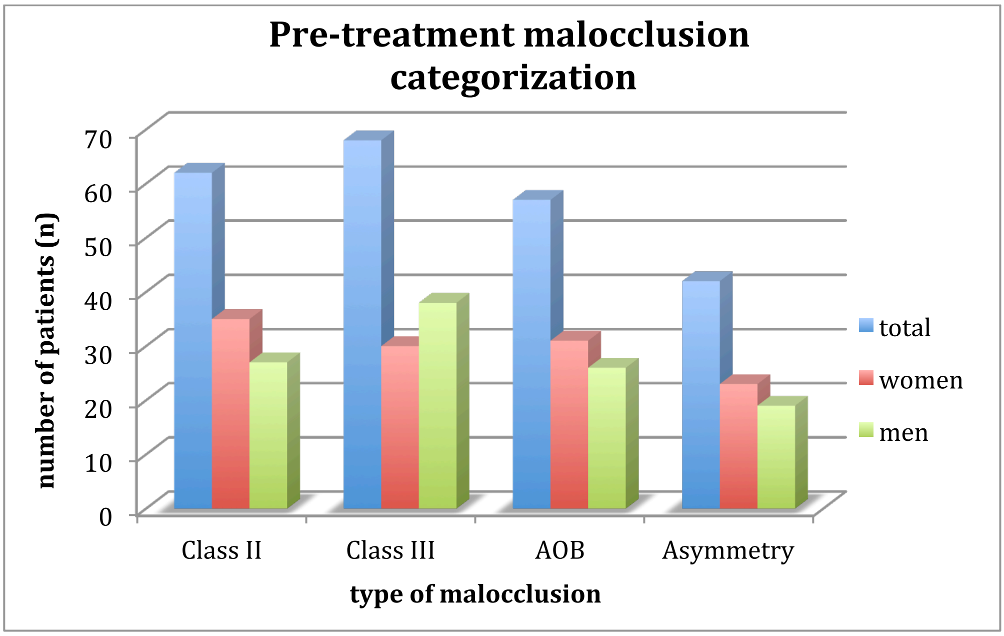
The mean age of the 146 orthognathic patients (females: 77 [52.7%]; males: 69 [47.3%]) at the beginning of treatment was 23.2 years (standard deviation (SD): 8.6 years). At the time of surgery, the mean age of the patients was 25.4 years (SD: 8.5 years), the youngest patient being 16.6 years and the oldest 59.8 years old. At conclusion of the combined treatment, the mean age of the patients was 26.3 years (SD: 8.6 years). On average, the orthodontic-surgical treatment period of the included patients lasted 3.1 years.

The pre-treatment malocclusion categorization of the patients is summarized in Table 2 and shown in Figure 4.

Table 2 *Pre-treatment malocclusion categorization in numbers and percentages of patients.*

Gender	All types	Class II	Class III	AOB	Asymmetry
Total	146 (100%)	62 (42.5%)	68 (46.6%)	57 (39.0%)	42 (28.8%)
Females	77 (100%)	35 (45.5%)	30 (39.0%)	31 (40.3%)	23 (29.9%)
Males	69 (100%)	27 (39.1%)	38 (55.1%)	26 (37.7%)	19 (27.5%)

Figure 4 *Comparison of the pre-treatment malocclusion categorization of the patients.*

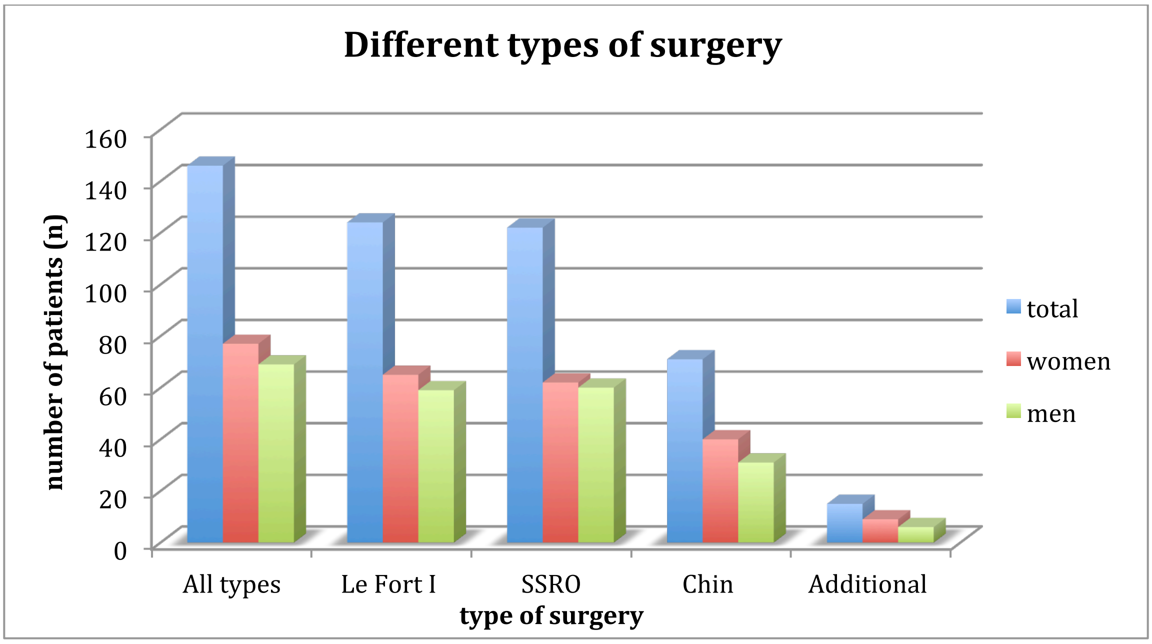


The different types of approaches used for orthognathic surgery are given in Table 3 and Figure 5, respectively. During data analysis, it became apparent that the orthognathic planning documents were at times incomplete or incorrect, since pre-treatment decisions regarding the surgical procedures were sometimes reconsidered in the operating theater. Hence, post-operative radiographs were consulted to ascertain the surgical procedures.

Table 3 *Number of patients undergoing certain types of surgery.*

Gender	All types	Le Fort I	SSRO	Chin	Additional
total	146 (100%)	124 (84.9%)	122 (83.6%)	71 (48.6%)	15 (10.3%)
women	77 (100%)	65 (84.4%)	62 (80.5%)	40 (51.9%)	9 (11.7%)
men	69 (100%)	59 (85.5%)	60 (87.0%)	31 (44.9%)	6 (8.7%)

Figure 5 *Comparison of the number of patients undergoing different types of surgery to correct bone position.*



3.2 Apparent age and attractiveness

The mean score for attractiveness is given on a scale from 0% to 100% (0: extremely unattractive; 100% extremely attractive). The attractiveness-score before treatment was 44.6% (SD: 11.4%), and remained similar at the end of treatment with a score of 44.5% (SD: 10.8%).

Mean apparent age before treatment was 24.6 years (SD: 8.8 years), thus patients appeared on average 1.4 years older than their actual age (23.2 years, SD: 8.6 years). At the end of the combined treatment, the mean apparent age of the patients was 27.2 years (SD: 9.2 years), and patients appeared on average only 0.9 years older than their actual age (26.3 years; SD: 8.6 years).

3.2.1 *Determinants of changes in attractiveness*

To disclose variables influencing the change in attractiveness, the computed information consisted of a X^2 test, and OR for the subgroup's improvement in nominal attractiveness compared to the other group. Mean values for attractiveness before and after treatment were calculated with the percentage difference. Due to absence of normal distribution of the mean attractiveness before and after treatment, a nonparametric WSR test was used to calculate the significance of the differences of the mean attractiveness values before and after treatment.

Table 4 lists information on the effect of gender on attractiveness, Table 5 investigates the influence of the initial type of malocclusion before treatment, and in Table 6 the type of surgery used for orthognathic therapy was analyzed as determinant of attractiveness changes.

Table 4 *Impact of gender on the reported attractiveness changes: Left: results of Pearson's chi-squared test: p-values and OR values with the 95% CI are given. OR refers to male vs. female with female being used as reference. Right: results of Wilcoxon-test for differences in attractiveness before and after treatment.*

Gender					**Mean Attractiveness**			
		Subjects with improved attractiveness	**X^2**	**OR (95% CI)**	**Before**	**After**	**Difference**	**Wilcoxon-test**
	(n)	(%)	p-Value		(%)	(%)	(%)	p-Value
Females	77	45.4	0.324	1.4 (0.7-2.6)	42.4	40.9	-1.48	0.341
Males	69	53.6	0.324	1.4 (0.7-2.6)	47.0	48.4	1.43	0.255

Table 5 *Impact of initial malocclusion on the reported attractiveness changes: Left: results of Pearson's chi-squared test: p-values and OR values with the 95% CI are given. OR refers to the specific malocclusion type, with all other types being used as reference. Right: results of Wilcoxon-test for differences in attractiveness before and after treatment.*

Malocclusion					**Mean Attractiveness**			
		Subjects with improved attractiveness	**X^2**	**OR (95% CI)**	**Before**	**After**	**Difference**	**Wilcoxon-test**
	(n)	(%)	p-Value		(%)	(%)	(%)	p-Value
Class II	62	66.1	<0.001**	3.3 (1.7-6.6)	41.9	44.4	2.47	0.028*
Class III	68	35.3	0.020*	0.3 (0.2-0.7)	47.0	44.7	-2.26	0.153
AOB	57	43.9	0.291	0.7 (0.4-1.4)	45.2	44.9	-0.30	0.688
Asym.	42	47.6	0.794	0.9 (0.4-1.8)	46.1	44.0	-2.09	0.457

** Significant at the 0.05 level*

*** Highly significant at the 0.01 level*

Table 6 *Impact of conducted surgery on the reported attractiveness changes: Left: results of Pearson's chi-squared test: p-values and OR values with the 95% CI are given. OR refers to the specific surgery type, with all other types being used as reference. Right: results of Wilcoxon-test for differences in attractiveness before and after treatment.*

Surgery					**Mean Attractiveness**			
		Subjects with improved attractiveness	**X^2**	**OR (95% CI)**	**Before**	**After**	**Difference**	**Wilcoxon-test**
	(n)	(%)	p-Value		(%)	(%)	(%)	p-Value
Le Fort	124	45.2	0.017*	0.3 (0.1-0.8)	45.1	44.2	-0.91	0.499
SSRO	122	53.3	0.031*	2.8 (1.1-7.2)	44.5	44.9	0.41	0.450
Chin	71	59.2	0.021*	2.2 (1.1-4.2)	42.7	45	2.28	0.101

** Significant at the 0.05 level*

Neither gender, nor most of the initial malocclusions, except Class II had an impact on attractiveness changes. The correction of a Class II resulted in a significant increase in attractiveness, and the odds of improved attractiveness were three times higher than compared to non-Class II patients, with 66.1% of the Class II patients being more attractive after treatment. It is noteworthy that all other types of malocclusion influenced the attractiveness negatively, and a Class III correction resulted in significantly more patients with lower attractiveness values.

Analysis of the performed surgery on attractiveness demonstrated that although facial attractiveness remained on average unaffected (p<0.499), the amount of patients with improved attractiveness differed markedly between the surgical procedures. The odds of improved attractiveness were higher after SSRO (OR: 2.8) and chin osteotomy (OR: 2.2), but lower after Le-Fort I osteotomy (OR: 0.3).

3.2.2 *Determinants of changes in apparent age*

Apparent age was calculated for all images before and after therapy. This computed age is only informative when compared to the real chronological age. Based on the assumption that a young apparent age is desirable, success of treatment is determined by a lower apparent age in relation to real age or a reduction of an older appearance. To analyze the variables potentially influencing the changes in apparent age, the computed apparent age was compared against the real age (i.e., chronological age). Real and apparent age before and after treatment failed to be normally distributed and a nonparametric Mann-Whitney-U-Test was used to calculate the significance (p-value) of the differences.

Table 7 illustrates the effect of gender on the apparent age compared to the real age, the influence of different types of malocclusions the patient had before treatment is given in Table 8, and Table 9 shows the impact of different types of surgery on the apparent age.

Table 7 *Influence of gender on computed apparent age. Means (± 1 SD) of real (i.e., chronological) age and apparent age are given for before (left) and after (right) treatment, respectively, together with the difference and its statistical significance.*

Gender		**Before Treatment**				**After Treatment**			
		Real age	**Apparent age**	**Diff.**	**Mann-Whitney U-test**	**Real age**	**Apparent age**	**Diff.**	**Mann-Whitney U-test**
	(n)	(y)	(y)	(y)	p-Value	(y)	(y)	(y)	p-Value
Females	77	22.85	24.03	+1.19	0.016*	25.97	26.19	+0.22	0.476
		±8.02	±7.90			±7.85	±8.19		
Males	69	23.56	25.30	+1.74	<0.001**	26.73	28.31	+1.59	0.002**
		±9.25	±9.70			±9.52	±10.23		

** Significant at the 0.05 level*

*** Highly significant at the 0.01 level*

Table 8 *Influence of type of malocclusion on computed apparent age. Means (± 1 SD) of real (i.e., chronological) age and apparent age are given for before (left) and after (right) treatment, respectively, together with the difference and its statistical significance.*

Malocclusion		**Before Treatment**				**After Treatment**			
		Real age	**Apparent age**	**Diff.**	**Mann-Whitney U-test**	**Real age**	**Apparent age**	**Diff.**	**Mann-Whitney U-test**
	(n)	(y)	(y)	(y)	p-Value	(y)	(y)	(y)	p-Value
Class II	62	22.62	24.11	+1.49	0.004**	25.97	26.59	+0.62	0.249
		±8.18	±8.97			±8.10	±8.56		
Class III	68	23.16	25.06	+1.90	<0.001**	26.31	27.63	+1.32	0.009**
		±8.99	±9.13			±9.28	±9.75		
AOB	57	21.89	23.39	+1.50	0.001**	25.01	25.73	+0.72	0.084
		±8.14	±8.41			±8.17	±8.98		
Asym.	42	23.07	24.46	+1.39	0.015*	26.20	27.71	+1.51	0.035*
		±8.35	±7.92			±8.14	±9.67		

** Significant at the 0.05 level*

*** Highly significant at the 0.01 level*

Table 9 *Influence of type of surgery on computed apparent age. Means (± 1 SD) of real (i.e., chronological) age and apparent age are given for before (left) and after (right) treatment, respectively, together with the difference and its statistical significance.*

Surgery		**Before Treatment**				**After Treatment**			
		Real age	**Apparent age**	**Diff.**	**Mann-Whitney U-test**	**Real age**	**Apparent age**	**Diff.**	**Mann-Whitney U-test**
	(n)	(y)	(y)	(y)	p-Value	(y)	(y)	(y)	p-Value
Le Fort	124	23.14	24.58	+1.54	<0.001**	26.39	27.41	+1.03	0.006**
		±8.76	±8.86			±8.80	±9.49		
SSRO	122	23.37	24.89	+1.52	<0.001**	26.53	27.71	+1.18	0.003**
		±8.80	±8.77			±8.91	±9.26		
Chin	71	23.45	25.19	+1.74	<0.001**	26.60	27.56	+0.96	0.070
		±9.27	±9.45			±9.51	±9.96		

** Significant at a 0.05 level*

*** Highly significant at a 0.01 level*

Before treatment, the computed apparent age was generally higher than the real age, irrespective of gender or malocclusion. Table 7 demonstrates that before treatment, both males and females appeared significantly older than their real age. After treatment, the differences between apparent age and real age were smaller than before, with especially favorable results displayed by female patients. Their apparent age was similar and did not statistically differ from their real age, whereas male patients still appeared older and their apparent age still differed significantly from their real age, even after treatment.

In Table 8, the influence of the underlying initial malocclusion is reported. Patients with a Class II or an AOB malocclusion benefited most from the therapy regarding their apparent age. Before therapy, Class II patients appeared 1.49 years older than they really were, and after treatment real age and apparent age showed no significant difference anymore. Likewise, in the AOB group, the initial significant mean difference between apparent age and real age of 1.5 years was reduced to a non-significant difference of 0.72 years after therapy. In Class III patients, only a non-substantial decrease was observed, and asymmetric faces seemed to be hardly affected by treatment.

The analysis of the impact of the type of surgery on apparent age is summarized in Table 9. The most beneficial type of surgery is the chin osteotomy, as it helped to reduce the highly significant mean difference between apparent age and real age before therapy of 1.74 years to a non-significant mean difference of 0.96 years after therapy. Le Fort I and SSRO surgery caused a reduction of the discrepancy between apparent age and real age as well, but to a smaller degree. Thus, the mean differences between apparent age and real age remained significant after therapy.

4 Discussion

4.1 Facial attractiveness

As outlined in the introduction, improvement of facial attractiveness is a crucial aspect when evaluating the success of orthognathic treatment. However, scoring facial attractiveness is inherently problematic, as both lay people's and professional's assessments suffer from serious bias. Apart from the fact that different ground truth might exist, depending on the rater group, a study carried out by Ng *et al.* demonstrated another additional bias: the very fact that the raters are aware of an executed therapy leads to more favorable attractiveness outcome scores [36]. The aim of this present investigation was to overcome the subjectivity common in all traditional rating protocols by means of artificial intelligence. By applying a dedicated and validated algorithm, a novel approach was used to estimate facial attractiveness and apparent age.

4.1.1 *The sample*

The sample size of 146 patients represented with over 2100 images can clearly be considered sufficient for the analysis performed. Both the types of malocclusions and the types of surgery were adequately represented and evenly distributed over the genders. The mean ages, both at start and at the end of the therapy, as well as the duration of 3.1 years for the treatment, are representative for a typical cohort of orthognathic patients.

4.1.2 *Changes in attractiveness*

The computational algorithm analysis showed no significant improvement of facial attractiveness after the orthodontic-surgical treatment neither for females (42.41 to 40.92; p-value: 0.341), nor for males (46.98 to 48.42; p-value: 0.255). This unexpected result is surprising and stands in stark contrast to subjective evaluation, as previous studies have illustrated that 92% of patients were satisfied with the treatment results and saw their expectations fulfilled [16, 37].

The following might explain why facial attractiveness was not significantly improved. Orthognathic therapy stretches over several years (for our examined group well over 3 years), and by far exceeds the reported mean durations of 1.9 years for routine orthodontic treatment [38], and it is well known that attractiveness diminishes with age [39]. This tendency is also noticeable in the algorithm used, which has a clear bias for younger faces. Thus, obtaining similar results in facial attractiveness after therapy could be interpreted as having successfully wound back the biological clock by three years (or more).

This may sound like a small improvement, but causing a 22-year-old girl to remain as attractive and "keeping her from aging" into a 25-year-old woman is no small achievement.

To gain a better understanding of the influence of age on perceived attractiveness, corrections addressing this bias could be performed. Normalization of the present data according to age was, however, not performed due to the greater amount of facial images required for this computational procedure and the lack of Gaussian distribution of the data. Further investigations evaluating the impact of ageing on attractiveness in orthodontic or orthognathic cohorts would definitely be a welcome addition to the pertinent scientific literature.

4.1.3 *Influence of malocclusion and surgery on facial attractiveness*

When evaluating the underlying malocclusion, computed facial attractiveness was not affected except for Class II malocclusions, for which a significant improvement could be observed. Indeed, patients with a corrected Class II malocclusion showed highly significantly more often an improvement in computed facial attractiveness compared to the other patients, and the odds for improved facial appearance were three times higher than for patients without prior Class II malocclusion.

Conversely, facial attractiveness of patients with previous Class III malocclusion was mostly negatively affected by the correction of the prognathic mandible. This finding stands in agreement with other studies that analyzed malocclusions and demonstrated that prognathic mandibles in Class III malocclusion subjects were perceived as a less severe aesthetic impairment compared to a retrognathic mandibles common in Class II malocclusions [40-42]. The above-mentioned result is clinically relevant, as it highlights the need to differentiate between Class II and Class III patients. Patients with a Class II malocclusion whose main motivation for surgery is facial aesthetics might probably be more easily satisfied than Class III patients with equal motivation.

In scientific literature, gender-related differences in the assessment of the anteroposterior position of the mandible are described, with a positive bias toward prognathism in males, but not in females [43]. The present results do not corroborate the gender-associated favoritism.

The statistical analysis showed a significant influence of the chosen osteotomy on nominal attractiveness improvement. Lower jaw and chin surgeries improved attractiveness significantly more compared to patients without these surgeries. The odds to have higher facial attractiveness scores after SSRO or chin osteotomy were more than twice as high than without these surgeries. Previous reports have shown the importance of correct chin positioning and a relevant influence of chin retrusion or protrusion on perceived attractiveness [27].

The present results demonstrate that mandibular corrections in general, and chin osteotomies in particular, are adequate surgical means to noticeably correct chin imbalances.

4.2 Apparent age estimation

By applying artificial intelligence to assess facial attractiveness, a novel approach is being introduced that can be compared and interpreted against the backdrop of pre-existing scaling methods. In contrast to facial attractiveness, it seems that no attempt has ever been made to assess apparent age of orthognathic patients using artificial intelligence. The present results constitute hence the first attempt to investigate the influence of an orthognathic-surgical treatment on age appearance. In order to interpret the changes in apparent age, it was decided to compare the computed apparent age to the real chronological age.

4.2.1 *Changes in apparent age*

The computational age estimation illustrated that in general people with severe malocclusions appeared older than their real age. Gender had an impact on age appearance, with females being significantly more likely than males to have a younger facial appearance after orthognathic-surgical therapy. Before treatment, females had a significant mean difference between apparent age and real age of 1.2 years, whereas after treatment their appearance corresponded to their real age. Although males also appeared younger after therapy, the changes were minor and the differences between apparent and real age remained significant. The finding that orthognathic surgery may alter age appearance is anything but elementary. Plastic surgery is at times aimed at changing the apparent age, but orthognathic surgery focuses on achieving balanced facial harmony. The observation that relocation of the chin or other parts of the lower face may influence age appearance is novel and important.

4.2.2 *Influence of malocclusion and surgery on apparent age*

Considering the various malocclusions before treatment, a significant benefit in terms of reduction of apparent age (in comparison to real age) could be achieved in patients who underwent surgery for correction of skeletal Class II or AOB malocclusions. For these two groups the mean difference between apparent age and real age was significant before the treatment, but not after therapy. Class II patients therefore not only had the greatest improvement in facial attractiveness but also profited from a rejuvenating effect of the orthognathic-surgical treatment.

Patients with skeletal Class III malocclusions also showed a decrease of discrepancy between apparent and real age before and after treatment, gaining a younger appearance. In contrast, the results indicated that patients with asymmetry did not benefit from a rejuvenating effect. It is noteworthy that improvement of facial attractiveness and reduction of age appearance do not always correspond with each other and might differ in patients with identical underlying malocclusions or surgical procedures. Orthodontists should be cognizant of these differences and address the multifaceted motivations of orthognathic patients accordingly, respecting the type of malocclusion to be corrected and the type of envisaged surgery. Addressing the motivating factors appropriately is fundamental, both before and after surgery. Facial aesthetics has been recognized as crucial key-factor: patients attributing great importance to facial aesthetic improvements are more likely to be satisfied with treatment outcome than patients focusing on improvement of oral function [15]. As such, orthodontists and maxillofacial surgeons are well-advised to present the possibilities and limitations of orthognathic surgery, according to type of malocclusion and type of surgery, and compare the surgical possibilities with the patients' motivations.

4.3 **Limitation**

Utilizing a novel approach based on artificial intelligence is indeed a promising venture that enables to overcome several major pertinent drawbacks. At the same time, the introduction of a novel and unique algorithm must be evaluated with caution. First, the algorithm has been used in connection to social media, but never against the backdrop of medical interventions. Orthognathic subjects might identify certain features as important and worth changing, while some of these features might be underrepresented in the algorithm. This obviously is not a methodological shortcoming, but rather a general observation that discrepancies between the subjective patient's view and the computed score might persist. Or, to put it more simply: Having mastered a system to objectively assess treatment outcome does not necessarily mean that patients themselves will think accordingly.

Second, the algorithm analyzed not only the lower part of the face, i.e., the region of interest, but was influenced by other features of the face as well, which were outside the area treated orthognathically. Therefore, ageing, hairstyle, glasses, or even make-up might have affected the results. Conversely, the very fact that orthognathic surgery cannot exercise more influence on attractiveness than hairstyle or type of glasses is an important information, which should be communicated to potential patients who wish to undergo orthognathic surgery.

Lastly, although the amount of patients and images was sufficient to perform simple statistical analyses, the sample size remained too small for exhaustive statistical examinations.

4.4 Unanswered questions

Artificial intelligence enables scoring facial attractiveness objectively and reproducibly, whilst being based on an algorithm that mirrors relevant opinion. Yet the interpretation of the obtained scores is uncertain. What does a statistically significant increase or decrease mean in terms of relevance? Are changes in attractiveness score linearly correlated to relevance? These and more questiones remain unanswered and should be subject of future investigations.

Artificial intelligence is a tool that can be applied to more than just facial attractiveness and apparent age, when considering an assessment of treatment outcome. As for the present, the ETH Zurich Vision Lab algorithms include another feature focusing on gender prediction. Being able to detect if a certain face belongs to a masculine or to a feminine subject might not be as relevant in orthognathic cases, but can without a doubt be advantageous in other plastic surgeries of the face. Further research with a computational algorithm could examine different surgical techniques and whether they render females' appearance more feminine and males' appearance more masculine.

4.5 **Conclusions**

The present study is the first investigation to use artificial intelligence to analyze facial attractiveness and apparent age before and after an orthodontic-surgical treatment (orthognathic therapy). The applied algorithms permitted to score facial attractiveness and apparent age objectively and reproducibly. The validity of the algorithm, being based on millions of ratings, by far surpasses the validity of any subjective assessments.

Overall, facial attractiveness was not much altered and remained, after therapy, similar to the pre-surgical score. Of all individuals assessed, patients with a Class II before surgery, or patients who were subject to SSRO or chin osteotomy had the highest odds to benefit from the surgery in terms of facial attractiveness.

In pre-surgical patients, apparent age was on average around one and a half years higher than their real age. Apparent age could be positively influenced by orthognathics, and especially females appeared younger after surgery.

When assessed with artificial intelligence, the impact of orthognathic surgery seems limited on facial attractiveness and apparent age. Since many patients seek orthognathic surgery for aesthetic reasons, the insignificance of the benefits – as seen through the lens of social-media trained algorithms – should be made clear to potential patients.

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6 Erklärung

Dissertation

Ich bestätige, die vorliegende Arbeit mit dem Titel

Evaluating the Effect of Orthognathic Treatment on Facial Attractiveness and Estimated Age by Means of Artificial Intelligence

selbstständig und ohne weitere Hilfen, ausser den unten explizit aufgeführten, durchgeführt und verfasst zu haben. Ich bestätige überdies, dass die Arbeit als Ganzes oder in Teilen weder bereits einmal zur Abgeltung anderer Studienleistungen an der Universität Zürich oder an einer anderen Universität oder Ausbildungseinrichtung eingereicht worden ist.

Fremdbeiträge

Die computergestützte Berechnung der Attraktivität und des geschätzten Alters wurden an der ETH Zürich im Computer Vision Laboratory von Eirikur Agustsson unter Leitung von Dr. Radu Timofte durchgeführt.

Verwendung von Quellen

Ich erkläre ausdrücklich, dass ich sämtliche in der oben genannten Arbeit enthaltenen Bezüge auf fremde Quellen (einschliesslich Tabellen, Grafiken u. Ä.) als solche kenntlich gemacht habe. Insbesondere bestätige ich, dass ich ausnahmslos und nach bestem Wissen sowohl bei wörtlich übernommenen Aussagen (Zitaten) als auch bei in eigenen Worten wiedergegebenen Aussagen anderer Autorinnen oder Autoren (Paraphrasen) die Urheberschaft angegeben habe.

Ich bestätige mit meiner Unterschrift die Richtigkeit dieser Angaben.

Datum:

Name: Bernini Vorname: Domino

Unterschrift:…………………………………………..

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