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Three-dimensional soft tissue effects of mandibular midline distraction and surgically assisted rapid maxillary expansion: an automatic stereophotogrammetry landmarking analysis

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Abstract. Studies on mandibular midline distraction (MMD) are mostly performed using conventional research methods. Concerning surgically assisted rapid maxillary expansion (SARME), more research is conducted using three-dimensional (3D) techniques. Research on bimaxillary expansion, the combination of MMD and SARME, is reported sparsely. The main objective of this study was to provide a 3D evaluation of soft tissue effects following SARME and/or MMD. Patients who underwent SARME and/or MMD between 2008 and 2013 were included. Stereophotogrammetry was undertaken at the following time points: preoperative (T1), immediately post-distraction (T2), 1 year postoperative (T3). An automatic 3D facial landmarking algorithm using two-dimensional Gabor wavelets was applied for the analysis. Twenty patients who had undergone SARME were included, 12 of whom had undergone bimaxillary expansion. Age at the time of surgery ranged from 16 to 47 years. There was a significant downward displacement of soft tissue pogonion. Furthermore, there was a significant mean increase of 2.20 mm in inter-alar width and a non-significant mean increase of 1.77 mm in inter-alar curvature point width. In conclusion, automatic stereophotogrammetry landmarking analysis of soft tissue effects showed downward displacement of soft tissue pogonion following bimaxillary expansion and transverse widening of the

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inter-alar width and a tendency towards an increase in inter-alar curvature point width after SARME.

Key words: mandibular midline distraction osteogenesis; mandibular symphyseal distraction osteogenesis; SARME; soft tissue; 3D; automatic landmarking.

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Transverse mandibular and maxillary deficiencies manifest in anterior and posterior crowding and/or in uni- or bilateral crossbite. Historically, these discrepancies were treated with orthodontic and/or dental extraction therapy. New treatment options became possible following the introduction of distraction for the facial skeleton in the early 1990s[1,2].

Mandibular midline distraction (MMD) is an effective technique to widen the mandible in order to solve transverse mandibular deficiencies[2–4]. For transverse maxillary deficiencies, surgically assisted rapid maxillary expansion (SARME) is an accepted technique and well reported in the literature[5–9]. In some specific cases, a combination of MMD and SARME is indicated, which is termed bimaxillary expansion[10,11]. Research on MMD is mostly performed using conventional research methods including dental cast models and posterior–anterior cephalograms[4], whereas for SARME, three-dimensional (3D) imaging analysis techniques are available to assess study outcomes[9]. However, to date, research on bimaxillary expansion has been reported sparsely in the literature[12,13], and it appears that only one paper has reported soft tissue effects following bimaxillary expansion using 3D imaging analysis techniques[11].

Since 3D imaging techniques make it possible to analyse bony and overlying soft tissue structures more accurately compared with conventional two-dimensional (2D) radiographs, it is possible to obtain highly realistic skeletal and facial information. In addition, it is possible to acquire volumetric changes of bony and overlying soft tissue structures using 3D landmarking. This makes it possible to calculate a prediction of facial changes following MMD and/or SARME.

Soft tissue effects can be evaluated by 3D facial surface scans or stereo photographs, which are obtained using stereophotogrammetry. The resulting data consist of a cloud of triangulated 3D points that form a 3D model on which the full colour texture of the face can be mapped. 3D surface scans have been used in landmark-based clinical research with manually placed 3D landmarks[14,15]. Recently, a new method was created at the Erasmus MC, University Medical Center Rotterdam, the Netherlands that can automatically place landmarks on facial surface data[16,17].

The main objective of this study was to provide a 3D evaluation of the soft tissue effects following MMD and/or SARME. These potential soft tissue effects could be taken into account by clinicians during orthognathic surgery planning and could be used to inform patients.

Materials and methods

A retrospective observational study was conducted after approval had been obtained from the Medical Ethics Committee of Erasmus MC, University Medical Center Rotterdam, the Netherlands.

Patients

Patients who had undergone MMD and/or SARME at the Department of Oral and Maxillofacial Surgery, Erasmus MC, University Medical Center Rotterdam, the Netherlands between 2008 and 2013 were included in this study.

The inclusion criteria were a mandibular discrepancy (mandibular anterior and/ or posterior crowding, uni- or bilateral crossbite) treated with MMD and a maxillary discrepancy (maxillary anterior and/ or posterior crowding and/or uni- or bilateral crossbite) treated with SARME. The patients had to be at least 16 years old.

The exclusion criteria were the presence of a congenital (craniofacial) deformity, additional orthognathic surgery following MMD (bilateral sagittal split osteotomy) or SARME (Le Fort I) before 1 year postoperative, mental retardation, history of radiation therapy or head injuries leading to fractures and/or soft tissue scars in the facial area of interest, missing stereophotogrammetry record at T1 and/or T3, and insufficient stereophotogrammetry record quality as a result of artefacts or hair obstructing the facial area of interest.

For MMD, the surgical technique was similar to that described by Mommaerts[18], and only bone-borne distractors were used[10]. For SARME, the surgical technique applied was that described by Koudstaal et al.[7], and only tooth-borne distractors (Hyrax) were used. For both MMD and SARME, the surgical intervention was performed under general anaesthesia. Stereophotogrammetry records were obtained at fixed time points: preoperative (T1), immediately post-distraction (T2), and 1 year postoperative (T3).

Stereophotogrammetry analysis

A 3D stereophotogrammetry setup with four cameras (EOS 1000D; Canon Inc.) and integrated software (DI3Dcapture, version 6.8.16.4255; Dimensional Imaging Ltd, Glasgow, UK) were used to capture 3D photographs of the face. All photographs were taken in natural head position and with relaxed facial musculature.

The stereophotogrammetry analyses were performed with an automatic 3D facial landmarking algorithm combining template with shape-based methods, as described previously elsewhere[16,17]. In short, the automatic landmarking algorithm aligns the 3D surface scans, projects to 2D, and extracts 2D features that serve as input for multiple base 2D landmarking algorithms. These base algorithms are then combined using ensemble learning. After the landmarks are located, they are reverted back to 3D. Additionally, correlations between landmark coordinates in the training sample are used in a principal components (PCs) guided search. Twenty-six landmarks were automatically placed. Additionally, all landmark positions were checked manually by three observers (AG, JPG, and MAJ) and repositioned if necessary on the 3D (Fig. 1) and flat (Fig. 2) views.

The stereophotogrammetry analysis was divided into two regions. For MMD, the soft tissue regions were condylion, gonion, pogonion, sublabiale, labiale inferius, cheilion, and stomion. For SARME, the soft tissue regions were pronasale, alare, alar curvature point, nostril base point, subnasale, subspinale, crista philtri, and labiale superius.

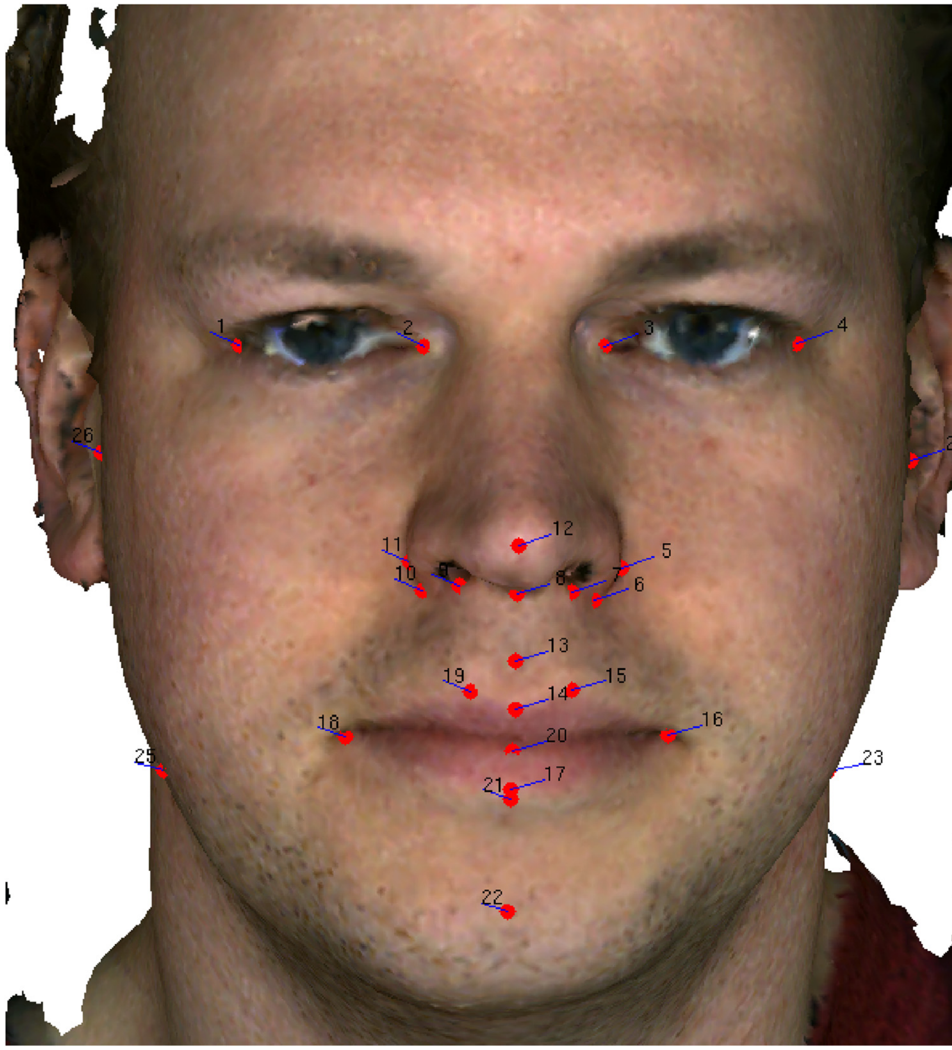

Fig. 1. Overview of the 26 automatically placed facial landmarks in 3D view.

To assess the effect of MMD on the soft tissue structures, the following relevant point-to-point landmark distances were measured digitally: 25–23, 25–22, 23–22, 21–23, 21–25, 17–22, 17–21, 14–12, 22–1, 22–4, 18–16, 17–20, 17–16, 17–18, 26–24, 1–25, and 4–23. For the effect of SARME on the soft tissue structures, the following relevant point-to-point landmark distances were measured digitally: 26–24, 11–5, 10–6, 9–7, 15–19, 16–18, 14–20, 8–12, 1–12, 4–12, 8–5, 8–10, 1–13, 4–13, 1–14, 4–14, 1–19, and 4–15. The landmark distances between the left and right exocanthion (4–1) and left and right endocanthion (3–2) were used as control measurements. (See Supplementary Material Table S1 for a list of the landmark definitions.)

Because of incomplete records for T2, the stereophotogrammetry analysis was only performed for T1 and T3.

Statistical analysis

The two-sided paired-samples *t*-test was used to assess differences between T1 and T3. A Bonferroni correction was applied to adjust *P*-values for the MMD outcome (adjusted significance level $P < 0.0026$) and for the SARME outcome (adjusted significance level $P < 0.0025$), separately.

Results

Patients

Twenty patients fulfilled the inclusion criteria. All 20 patients had undergone SARME. Twelve of these patients had undergone bimaxillary expansion. The age of the patients at the time of surgery ranged from 16 to 47 years. See Table 1 for the patient characteristics.

All patients completed the treatment, and the transverse expansion required to correct the transverse discrepancy was obtained. Eleven of the 20 patients underwent additional orthognathic surgery after the 1-year follow-up. During MMD, the bone-borne distractor caused a dehiscence in the buccal mucosa underneath the lower lip in one patient only. This was transient and healed within 2 weeks with the use of frequent flushing.

Stereophotogrammetry analysis

The complete results of the stereophotogrammetry analysis for MMD are described in Table 2. For the distance between landmarks 22 and 1, there was a significant difference between the values at T1 (mean 119.17 mm, standard deviation (SD) 8.20 mm) and those at T3 (mean 122.36 mm, SD 7.54 mm) ($P = 0.000873$). Even after applying the Bonferroni correction, this significance still held. For the dis-

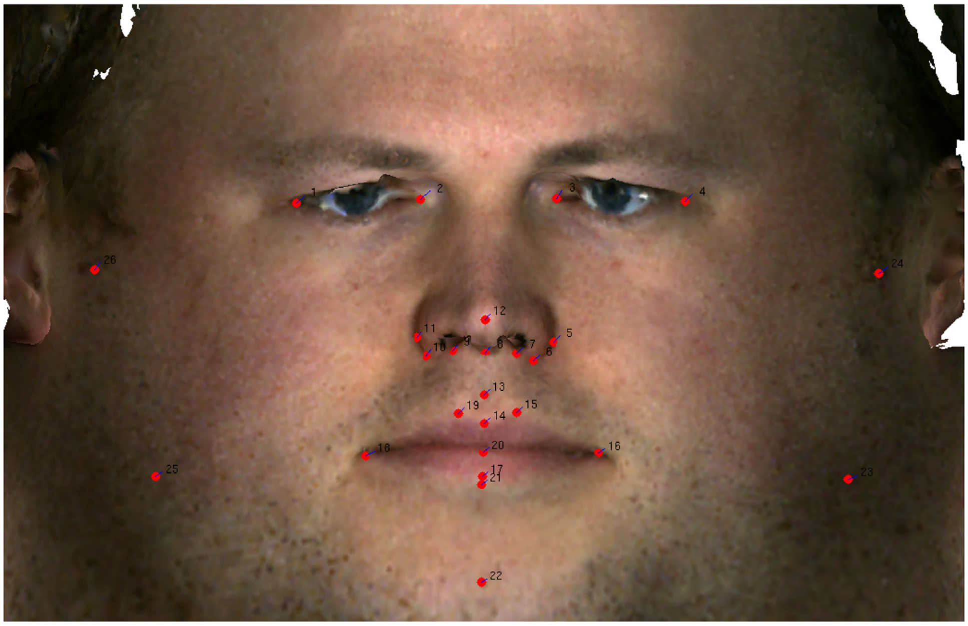

Fig. 2. Overview of the 26 automatically placed facial landmarks in flat view.

tance between landmarks 22 and 4, there was a significant difference between the values at T1 (mean 119.29 mm, SD 7.93 mm) and those at T3 (mean 122.41 mm, SD 7.35 mm) ($P = 0.001444$); this was also significant after Bonferroni correction. These outcomes indicate a downward displacement of the soft tissue pogonion.

Regarding the inter-soft tissue gonion distance (25–23), there was an non-significant difference between the values at T1 (mean 110.71 mm, SD 11.63 mm) and at T3 (mean 114.44 mm, SD 13.78 mm) ($P = 0.112611$). This outcome indicates a tendency towards an increase in the inter-soft tissue gonion distance, although not significant.

The complete results of the stereophotogrammetry analysis for SARME are described in Table 3. For the distance between landmarks 11 and 5, there was a significant difference between the values at T1 (mean 34.93 mm, SD 2.99 mm) and those at T3 (mean 37.13 mm, SD 3.32 mm) ($P = 0.000011$). Even after applying the Bonferroni correction, this significance held. This outcome indicates a transverse widening of the inter-alar width. For the distance between landmarks 10 and 6, there was a significant difference between the values at T1 (mean 24.82 mm, SD 2.13 mm) and at T3 (mean 26.59 mm, SD 2.92 mm) ($P = 0.003641$). However, after applying the Bonferroni correction, this significance disappeared. This outcome indicates a tendency towards an increase in the inter-alar curvature point width.

Discussion

This retrospective observational study was performed to assess the 3D evaluation of soft tissue effects following MMD and/or SARME. Stereophotogrammetry records at T1 and T3 were analysed with an automatic 3D facial landmarking algorithm using 2D Gabor wavelets, as described by de Jong et al.[16,17]. The results showed a downward displacement of the soft tissue pogonion with a tendency towards an increase in the inter-soft tissue gonion distance. Furthermore, a transverse widening of the inter-alar width and a tendency towards an increase in the inter-alar curvature point width were observed.

Regarding MMD, these results are similar to those described by Bianchi et al.[11]. In their study, a forward and downward displacement of the chin was observed, with a forward projection of the lower lip[11]. It should be noted that simultaneous SARME was performed in that study and in the present study. Regarding the downward displacement of the soft tissue pogonion in the present study, it is thought that this is the effect of the maxillary downward displacement following SARME. This theory is strongly supported by Xi et al.[19], as they observed a skeletal downward displacement of the maxilla with a clockwise rotation of the mandible and inferior chin displacement after only SARME[19]. Therefore, in the present study, this should be interpreted as a result of bimaxillary expansion rather than of the MMD.

Furthermore, no significant displacement of the lower lip region was observed in the present study. However, it should be noted that differences in lip projection could be the result of dental movements due to orthodontic treatment and not a solitary effect of MMD. This makes comparison and analysis difficult.

There was a tendency towards an increase in the inter-soft tissue gonion distance when looking at the soft tissue structures in this region. This outcome is in concordance with de Gijt et al.[4], as they observed a slight increase in the skeletal ramal angle at T3. In their study, a bone-borne distractor was applied as well, and this increase was not significant, with no difference in the skeletal ramal angle in the long-term follow-up (6.5 years)[4]. However, this outcome could be strongly

Table 1. Baseline patient characteristics.

T1–T3	Bimaxillary expansion	SARME (without MMD)
Number of patients	12	8
Mean age (range), years	29 (16–45)	31 (18–47)
Female to male ratio	8F:4M	5F:3M

F, female; M, male; MMD, mandibular midline distraction; SARME, surgically assisted rapid maxillary expansion.

Table 2. Stereophotogrammetry analysis for MMD; values are reported in millimetres.

Landmark numbers		T1		T3		Difference		*P*-value
		Mean	SD	Mean	SD	Mean	SD	
1	4	90.23	3.30	90.75	3.70	0.52	1.52	0.264951
2	3	35.67	2.36	36.03	2.42	0.36	1.27	0.347393
25	23	110.71	11.63	114.44	13.78	3.73	7.50	0.112611
25	22	88.66	9.37	89.99	9.47	1.33	5.50	0.420623
23	22	89.79	11.03	93.43	11.88	3.64	6.85	0.092566
21	23	90.80	10.27	94.08	11.73	3.28	6.78	0.122151
21	25	89.35	8.68	90.38	8.96	1.03	5.79	0.551859
17	22	34.18	5.54	35.12	4.69	0.95	5.05	0.529495
17	21	22.17	4.90	22.02	4.96	−0.15	3.62	0.890993
14	12	34.17	4.38	34.85	3.56	0.68	2.16	0.298288
22	1	119.17	8.20	122.36	7.54	3.19	2.44	0.000873*
22	4	119.29	7.93	122.41	7.35	3.11	2.56	0.001444*
18	16	49.28	3.10	50.44	3.80	1.16	3.17	0.231442
17	20	10.57	1.72	10.99	2.07	0.42	2.45	0.568333
17	16	30.61	2.52	30.38	2.30	−0.24	2.07	0.698722
17	18	30.39	2.22	30.13	3.51	−0.26	2.68	0.738356
26	24	138.36	11.32	139.28	11.17	0.92	2.82	0.284216
1	25	98.59	7.78	95.42	9.06	−3.17	6.48	0.118876
4	23	99.00	8.34	95.40	8.75	−3.60	6.51	0.081861

MMD, mandibular midline distraction; SD, standard deviation; T1, preoperative; T3, 1 year postoperative.
Note: The Bonferroni correction adjusts the *P*-value from 0.05 to 0.0026316.
* *P*-value significant after Bonferroni correction.

related to the type of distractor used. Tooth-borne distractors apply their force at the dentoalveolar level and will theoretically create more posterolateral widening compared to bone-borne distractors, which apply their force anteriorly at the basal bone level only. Related to this, the soft tissue effects in the gonion region might be different depending on the type of distractor used. It appears that no study comparing the soft tissue effects of the two distractor types following MMD has been conducted.

Table 3. Stereophotogrammetry analysis for SARME; values are reported in millimetres.

Landmark numbers		T1		T3		Difference		*P*-value
		Mean	SD	Mean	SD	Mean	SD	
1	4	91.83	4.12	91.99	4.51	0.15	1.65	0.684464
2	3	36.61	3.16	37.04	3.30	0.43	1.40	0.185323
26	24	138.49	10.52	138.74	10.35	0.25	3.22	0.734357
11	5	34.93	2.99	37.13	3.32	2.20	1.76	0.000011*
10	6	24.82	2.13	26.59	2.92	1.77	2.63	0.003641
9	7	18.40	2.64	19.14	2.44	0.74	2.58	0.107022
15	19	13.43	2.41	13.46	2.15	0.02	1.87	0.953980
16	18	49.25	3.80	50.12	4.03	0.87	3.67	0.303071
14	20	8.34	1.73	8.40	2.59	0.06	2.00	0.890028
8	12	19.80	2.34	19.72	2.34	−0.08	2.84	0.897302
1	12	71.18	4.00	71.22	4.41	0.03	1.98	0.939200
4	12	71.47	4.26	71.18	4.38	−0.28	2.08	0.548059
8	5	22.70	1.53	23.56	2.71	0.86	2.72	0.174075
8	10	15.52	1.71	16.13	1.99	0.61	1.66	0.114247
1	13	73.43	4.27	73.47	4.20	0.04	1.39	0.906020
4	13	74.13	4.25	74.02	4.40	−0.11	2.17	0.824239
1	14	81.34	4.30	81.96	4.48	0.62	1.81	0.142973
4	14	82.00	4.20	82.53	4.26	0.54	1.76	0.187736
1	19	75.91	4.17	76.52	4.11	0.61	1.96	0.182647
4	15	76.54	4.04	77.11	4.06	0.56	1.74	0.165240

SARME, surgically assisted rapid maxillary expansion; SD, standard deviation; T1, preoperative; T3, 1 year postoperative.
Note: The Bonferroni correction adjusts the *P*-value from 0.05 to 0.0025.
* *P*-value significant after Bonferroni correction.

Regarding SARME, similar soft tissue effects were observed by Nada et al.[20]. In their study, an increase in the nasal volume and inter-alar width was observed at 22 months post-SARME[20]. This outcome is an aesthetic effect of SARME for clinicians, which has to be taken into account when planning the orthognathic surgery. In the present study, there was a mean increase of 2.20 mm in the inter-alar width and a mean increase of 1.77 mm in the inter-alar curvature point width. Although these increases are minimal, it is difficult to predict how the patient will experience these soft tissue effects from the aesthetic viewpoint.

A limitation of this study is the sample size (maximum $n = 20$ per group or smaller), which might have led to bias in the *P*-values of the two-sided paired-samples *t*-test. However, the groups were also compared with the non-parametric two-sided Wilcoxon signed-rank test, with the same significant differences found. A second limitation is that the T2 stereophotogrammetry records were not complete for all of the patients included. This made it impossible to analyse the soft tissue effects of MMD and/or SARME during the treatment at the end of distraction. Since aesthetic aspects are becoming of greater importance in orthognathic surgery, it is essential to provide the patient with a prediction of the soft tissue effects during the treatment as well.

There was a downward displacement of the soft tissue pogonion after bimaxillary expansion. However, this outcome does not provide a prediction of soft tissue effects for patients scheduled to undergo MMD without simultaneous SARME. Bimaxillary expansion appears to be beneficial for patients with a short lower third of the face. On the other hand, bimaxillary expansion could lead to undesirable soft tissue effects for patients with a pre-existing gummy smile and long face. The transverse widening of the inter-alar width after SARME could also be undesirable for patients. Clinicians should communicate these possible soft tissue effects with the patient carefully during orthognathic surgery planning. The soft tissue effects of MMD without simultaneous SARME have not yet been clarified. Furthermore, there is still a lack of knowledge about the differences in soft tissue effects resulting from the use of the different types of distractors following MMD.

In conclusion, automatic stereophotogrammetry landmarking analysis of soft tissue effects showed a downward displacement of the soft tissue pogonion following bimaxillary expansion and a transverse widening of the inter-alar width and a tendency towards an increase in the inter-alar curvature point width after SARME. Clinicians should communicate these possible soft tissue effects to the patient carefully during the planning of the orthognathic surgery.

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Competing interests

None.

Ethical approval

Ethical approval was given by the Medical Ethics Committee of Erasmus MC, University Medical Center Rotterdam, the Netherlands (approval number: MEC-2013-367).

Patient consent

Not required.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.ijom.2018.10.016.

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