

A Simple Methodology to Better Appreciate Structures in Mandibular Angle Fractures Using 3-Dimensional Reconstruction Software

ARJUNAN KUMARAN¹, WEN CHAO CHEW², CHOR HOONG HING³, WINSTON TAN⁴, THIAM CHYE TAN⁵

ABSTRACT

Introduction: In Singapore, fractures of the mandible are common and of which, 32% occur at its angle. Current Two-Dimensional (2D) imaging methods are lacking in accuracy, leading to increased surgical morbidity.

Aim: To determine the Length (L), Diameter (D), Width (W) and Height (H) measurements in fractured and non-fractured mandibles by using Three-Dimensional (3D) Computed Tomography (CT).

Materials and Methods: A single centre retrospective CT based study of 23 subjects (46 mandibular angles and M3s) was conducted and subjects below 16 years, conservatively managed fractures, mandibles without M3s and cases with inadequate CT scan data were excluded. Intraosseous M3 L

and D and mandibular H and W were measured and ratios L/H and D/W were calculated.

Results: Average mean (Standard Deviation, SD) L, D, H and W was 8.58 (2.089), 11.63 (2.156), 29.17 (4.830) and 16.94 (1.967) mm respectively. Average mean L/H and D/W were 0.30 (0.070) and 0.69 (0.126) respectively. There was a trend towards greater osseous volume occupied horizontally in fractured mandibles. Measurements demonstrated good reliability (CA 0.999-1.000) and good intra and inter-observer variability (ICC 0.998-1.000, $p < 0.001$).

Conclusion: A 3D reconstruction with OsiriX offers greater insight at little additional cost. However, this can be further streamlined and automated.

Keywords: Computer aided surgery, Facial plastics, Maxillofacial trauma, Radiology

INTRODUCTION

Due to complex nature of Mandibular Angle Fractures (MAF), fixation surgery carries a significant risk of morbidity [1] and common post-operative complications include alveolar osteitis and pathologies of the periodontal region and temporomandibular joint [2,3]. In particular, close proximity of the third molar (M3) to the mandibular canal in which the Inferior Alveolar Nerve (IAN) runs, poses a high risk of iatrogenic injury, which can result in mental paraesthesia or anaesthesia. This is further complicated by variations in M3 morphology and its Three-Dimensional (3D) spatial relation to the canal. Incidence rates vary but a review by Tuzi A et al., reported a 0.2-0.9% risk of permanent and 3.3-13% risk of reversible IAN injuries respectively [4]. Good pre-operative imaging and surgical planning can reduce this and individualised risk profiles will allow better patient counselling.

Existing M3 imaging modalities include (standard intraoral, panoramic and extraoral) plain radiography, (standard, cone beam and tuned aperture) Computed Tomography (CT) and Magnetic Resonance Imaging (MRI) [5]. Current clinical practice involves panoramic radiography for routine cases and research and CT for complicated ones [6]. However, these are not without shortcomings. Panoramic radiography inaccurately describes M3 root morphology as it lies outside the center of rotation of the detector leading to distortion and magnification differences [7]. 3D interpretation is also impossible as buccolingual information is lacking [4]. Though CT offers better geometric accuracy and resolution of bony structures [8], it is still two-dimensional (2D).

To overcome this, 3D models can be constructed from 2D CT scan DICOM (Digital Imaging and Communications in Medicine) data to visualise previously hidden surfaces and allow greater interactivity through user-controlled rotation in any direction [9,10]. In addition, digital isolation of interfaces is possible, making it easier to delineate bone from soft tissue.

OsiriX version 7.5 (Pixmeo., Switzerland) is an open-source user friendly DICOM image processing software that can convert 2D CT scan images into a 3D model from volume acquisitions in a Virtual Operating Room (VOR) developed by Rosset A et al., at the University of Geneva for the Mac OS X operating system [11,12]. The software can also provide thick-slab Maximum Intensity Projections (MIP), orthogonal and oblique multiplanar reformatting (MPR), and 3D surface and volume rendering images. The 3D volume rendering and MPR images are most useful for pre-operative evaluation surgical planning and 3D coordinates can be plotted for anatomic and kinematic analyses [13].

As the DICOM server is included within the software, a Picture Archiving and Communication System (PACS) can be built, allowing navigation through large sets of multi-dimensional data on personal computers with minimal processing from its central processing unit. This obviates the need for expensive dedicated workstations, making it highly affordable and portable. With these potential advantages in mind, our study attempts to apply OsiriX to M3 evaluation in the context of MAF repair.

MATERIALS AND METHODS

A retrospective analysis of the Computed Tomography (CT) scans and demographic data of 23 subjects with 25 MAFs (2 subjects had bilateral MAFs) from an existing local database was performed. These subjects were managed by surgeons from the Plastic, Reconstructive and Aesthetic Surgery department of a single centre (National University Hospital, NUH, Singapore) between January 2001 and December 2010.

Inclusion and Exclusion Criteria

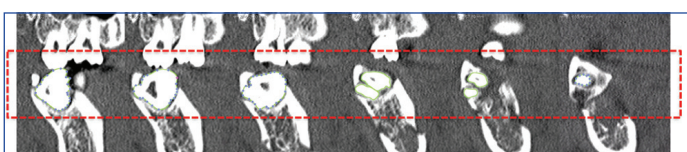
Open reduction and internal fixation with M3 retention was performed in all cases and all subjects were discharged well. They were subsequently followed-up as outpatients at one and six months postoperatively. Those who were below 16 years of age

and was managed conservatively were excluded. Subjects with complete follow-up and adequate CT scan imaging were analysed. Fine cut (1 mm slice interval) CT scans of the mandible, facial skeleton and head were used, as long as the mandibular angle was well visualised. If more than 1 scan was available, the one with the better resolution was selected. Subjects with bilateral MAF were logged as separate entries.

CT MEASUREMENTS

OsiriX was used to measure the intraosseous M3 length (L) and diameter (D) and the mandibular height (H) and width (W). As a surrogate measure of osseous volume occupied by the M3 vertically and horizontally, the ratio of the mean intraosseous M3 length to mean mandibular height (L/H) and mean intraosseous M3 diameter to mean mandibular width (D/W) were calculated respectively.

To isolate the M3, manual segmentation was done on each CT slice. Pixel density differences were used to identify boundaries and Region Of Interest (ROI) markers were placed along this edge. OsiriX then summated these ROIs into a 3D image of the M3. An example of this has been shown below in [Table/Fig-1a,b].



[Table/Fig-1a]: Example of manual segmentation of M3.

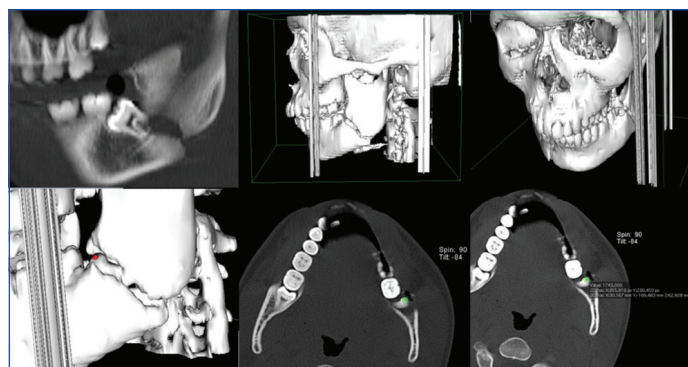


[Table/Fig-1b]: Resultant 3D model of M3.

To measure M3 variables, two points were placed on this model and their coordinates recorded. Lines were drawn between these points to ensure accurate placement of points. An example of image manipulation and point placement has been shown in [Table/Fig-2].

Intraosseous M3 Length and Mandibular Height

For intraosseous M3 length, the model was manipulated and one point each placed on the highest and lowest part of the M3 within the mandible. A line formed by these two points was approximately parallel to the ramus. For mandibular thickness, one point each was placed on the most superior and inferior point of the ramus. A



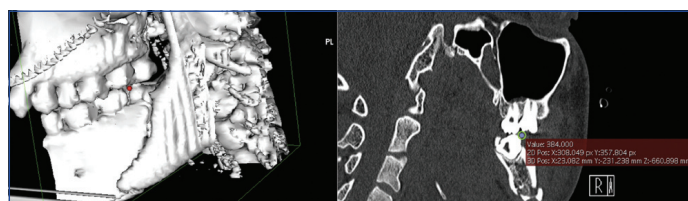
[Table/Fig-2]: Example of image manipulation and point placement.

line formed by these two points was approximately parallel to the ramus as well.

Intraosseous M3 Diameter and Mandibular Width

Similarly, for intraosseous M3 diameter, the model was manipulated and one point each placed on the medial and lateral aspect of the M3 within the mandible. A line formed between these two points was perpendicular to the ramus. For mandibular width, a point each was placed on the medial and lateral aspect of the mandible. A line formed by these two points was perpendicular to the ramus as well.

Accuracy checking was done by reconfirming point placement in the 2D-viewer. The coordinates in x, y, z format were input into Excel (Microsoft®, Washington) and distances automatically generated. An example of point placement and coordinate checking has been shown below in [Table/Fig-3].



[Table/Fig-3]: Example of point placement and coordinates checking.

Reliability Indices

All measurements were done by one of the authors and repeated by a second author to assess for repeatability. Inter and intra-observer variability was assessed for using Cronbach's Alpha (CA) and Interclass Coefficient Correlations (ICC).

STATISTICAL ANALYSIS

Statistical Package for Social Sciences (SPSS) version 23.0 (IBM Corp., Armonk, NY) was used for database construction and analysis. Parametric tests were performed and statistical significance set at $p < 0.05$.

RESULTS

A total of 23 subjects were included in this study (46 mandibular angles and M3s) and of these, 25 were MAFs (54.3%). The ratio of left:right mandibular angles was 11:14 and 10:11 in fractured and non-fractured sites respectively.

Measurements were performed thrice (twice by author AK and once by author CD) and averaged. The average mean (Standard Deviation, SD) intraosseous M3 length (L) and diameter (D) was 8.58 (2.089) and 11.63 (2.156) mm respectively. Average mean mandibular height (H) and width (W) was 29.17 (4.830) and 16.94 (1.967) mm respectively. Average mean ratio L/H and D/W were 0.30 (0.070) and 0.69 (0.126) respectively. Mean values for these variables across the three measurements and average have been summarised in [Table/Fig-4].

There was a trend towards fractured sites having greater osseous volume occupied by the M3 horizontally (larger D, smaller W, greater

	Measurement			Average
	1	2	3	
Intraosseous M3				
Length (L), mm	8.58 (2.105)	8.58 (2.100)	8.59 (2.064)	8.58 (2.089)
Diameter (D), mm	11.63 (2.154)	11.62 (2.158)	11.64 (2.157)	11.63 (2.156)
Mandibular				
Height (H), mm	29.18 (4.830)	29.15 (4.836)	29.18 (4.826)	29.17 (4.830)
Width (W), mm	16.94 (1.962)	16.93 (1.975)	16.94 (1.965)	16.94 (1.967)
Ratio				
L/H	-	-	-	0.30 (0.070)
D/W	-	-	-	0.69 (0.126)

[Table/Fig-4]: Mean intraosseous M3 and mandibular measurements.

D/W) but these values were not significantly different between fractured and non-fractured sites ($p=0.346-0.976$). These findings have been presented in [Table/Fig-5].

	Fractured (n=25)	Non-Fractured (n=21)	p-value
Intraosseous M3			
Length (L), mm	8.33	8.88	0.384
Diameter (D), mm	11.71	11.54	0.791
Mandibular			
Height (H), mm	29.28	29.04	0.865
Width (W), mm	16.93	16.95	0.976
Ratio			
L/H	0.29	0.31	0.346
D/W	0.70	0.68	0.576

[Table/Fig-5]: Comparison of mean measurements between fractured and non-fractured sites.

Measurements demonstrated both good reliability (CA 0.999-1.000) and good intra (ICC 0.999-1.000, $p<0.001$) and inter-user variability (ICC 0.998-1.000, $p<0.001$). These findings have been presented in [Table/Fig-6].

Measurement	Cronbach's alpha	Intraclass correlation (95% CI)			
		Intra-user	p-value	Inter-user	p-value
Intraosseous M3					
Length	0.999	1.000	<0.001	0.998	<0.001
Diameter	1.000	1.000	<0.001	1.000	<0.001
Mandibular					
Height	1.000	1.000	<0.001	1.000	<0.001
Width	1.000	1.000	<0.001	0.999	<0.001

[Table/Fig-6]: Reliability indices of measurements.

DISCUSSION

Presently, surgeons still mentally extrapolate 3D operative approaches from 2D preoperative investigations which is laborious but more importantly, highly dependent on a surgeon's level of experience and training [14]. Instead, using a digitally-reconstructed 3D model would minimise this inaccuracy by directly visualising patient specific anatomy [10] which can be appreciated independent of speciality (radiologists, clinicians and researchers) or seniority [2,13,15].

As such, the authors described a simple methodology to accurately quantitatively assess the M3 and mandible using OsiriX to create a 3D model for point placement. This produced highly reliable data with little intra and inter-user variability which was also seen by Kim G et al., in length measurement of 14 cadaveric porcine knees [13]. This method could be of particular use in cases with extensive comminution and displacement after trauma, where making accurate assessments and measurements on a 2D radiograph or CT scan is difficult.

OsiriX excels in time efficiency and imposes minimal computing requirements. Traditionally dedicated high-performance workstations with post-processing tools were required to visualise and process 3D, 4D and 5D data [11,16], but OsiriX runs on a regular laptop or desktop Mac OS X computer. It can generate a 3D model from DICOM data within 10-20 min compared with an hour taken by similar softwares, Advantage Workstation Volume Share 4 (AW), and CTRRY [13]. In addition, as its source code is available under the GNU General Public License open-source licensing agreement, individuals can create their own plug-ins to customise OsiriX for their own clinical, research or educational needs [14]. Already, OsiriX has been utilised in routine clinical use for craniomaxillofacial trauma [17], with ongoing trials for neurosurgery [18].

However OsiriX has its limitations as well. Firstly, measurements cannot be performed directly on the 3D model and the model itself cannot be altered once created [15]. Thus, to obtain the data, the authors had to place points on the 3D model in OsiriX, record their co-ordinates and then use a separate program to calculate distance between them. Though results were accurate and repeatable, they took a long time to obtain and the learning curve was steep. Secondly, manual segmentation using the ROI tool is tedious of a lower quality than the automatic volume-rendered models [12]. To optimise this, only fine cut (1 mm slice) CT scan DICOM data was used. Though ideal, thin-slice data can only be stored for a short period of time usually due to PACS storage capacity limitations [19]. Yakami M et al., have suggested ways to integrate OsiriX in the design of the data storage system to overcome this, but data storage still remains a problem at present [20].

The authors concede that despite the use of fine cut CT scan DICOM data, the resolution of 3D models generated in this study still was not high enough to view fine structures such as the IAN which runs in the mandibular canal, intimately related to the M3 root. This close relationship and shape, diameter and cortication status of the mandibular canal have been found to be risk factors for IAN injury during M3 surgery [21,22].

One way to optimise this further would be to utilise finer cut CT scans (0.5 mm slice interval) that focussed on the mandible specifically. On 2D imaging, 7 radiological signs suggest IAN proximity to the M3 and predict IAN injury: (1) darkening of the M3 root where it crosses the mandibular canal; (2) deflected or hooked roots around the canal; (3) narrowing of the root; (4) bifid root apex; (5) interruption or obliteration of either cortical line of the canal; (6) diversion of the canal in the region of the M3 root apices; (7) narrowing of the canal [23]. These, or their equivalents could be examined for on the 3D models.

Nonetheless, employment of OsiriX and other such programs is an exciting prospect for craniomaxillofacial surgery. Moving forward, there is particular interest in Computer-aided design and manufacturing (CAD/CAM) to take this one step further and produce exact replicas of the patient's anatomy and defects using 3D printing. This allows for even better surgical planning and customisation of surgical aids and prostheses [17,24,25]. Closer matching implants, reduced operating times and less invasive dissections are just some of the expected benefits [16,26-28].

LIMITATION

The limitation of this study would be relatively small sample size of 46. This likely accounted for the lack of significance of the trend towards fractured sites having greater osseous volume occupied by the M3 horizontally (larger D, smaller W, greater D/W) but not vertically (smaller L, larger H, lesser L/H). To overcome this, authors hope to conduct a second study with a larger sample size using 3D models with better resolution.

CONCLUSION

A 3D reconstruction from existing 2D imaging data offers surgeons greater insight at little additional cost. However, further work still needs to be done in streamlining and automating this process. Translation of this technology into aids and implants using 3D printing can offer individualised solutions to complex surgical pathologies.

REFERENCES

- [1] Ellis E. Treatment methods for fractures of the mandibular angle. *Int J Oral Maxillofac Surg.* 1999;28:243-52.
- [2] Bortoluzzi MC, Capella DL, Barbieri T, Pagilarini M, Cavalieri T, Manfro R. A single dose of amoxicillin and dexamethasone for prevention of postoperative complications in third molar surgery: A randomized, double-blind, Placebo Controlled Clinical Trial. *J Clin Med Res.* 2013;5(1): 26-33.
- [3] Pogrel MA. What are the risks of operative intervention. *J Oral Maxillofac Surg.* 2012;70(9):33-36.
- [4] Tuzi A, Di Bari R, Cicconetti A. 3D imaging reconstruction and impacted third molars: case reports. *Annali di Stomatologia.* 2012;III(3/4):123-31.
- [5] Flygare L, Öhman A. Preoperative imaging procedures for lower wisdom teeth removal. *Clin Oral Invest.* 2008;12:291-302.
- [6] Jun SH, Kim CH, Ahn JS, Padwa BL, Kwon JJ. Anatomical differences in lower third molars visualized by 2D and 3D X-ray imaging: Clinical outcomes after extraction. *Int J Oral Maxillofac Surg.* 2013;42:489-96.
- [7] Suomalainen A, Ventä I, Mattila M, Turtola L, Vehmas T, Peltola JS. Reliability of CBCT and other radiographic methods in preoperative evaluation of lower third molars. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod.* 2010;109:276-84.
- [8] de Melo Albert DG, Gomes AC, do Egito Vasconcelos BC, de Oliveira e Silva ED, Holanda GZ. Comparison of orthopantomographs and conventional tomography images for assessing the relationship between impacted lower third molars and the mandibular canal. *J Oral Maxillofac Surg.* 2006;64:1030-37.
- [9] Plooij JM, Naphausen MT, Maal TJ, Xi T, Rangel FA, Swennen FA, et al. 3D evaluation of the lingual fracture line after a bilateral sagittal split osteotomy of the mandible. *Int J Oral Maxillofac Surg.* 2009;38:1244-49.
- [10] De Paolis LT, Pulimeno M, Aloisio G. Visualization and interaction system for surgical planning. In: Luzar-Stiffler V, Jarec I, Bekic Z (Editors). *Proceedings of the 32nd International Conference on Information Technology Interfaces (ITI 2010), Cavtat/Dubrovnik, Croatia; 2010, June 21-24, 1st Ed. Zagreb, Croatia: University of Zagreb, University Computing Centre.* p269-274.
- [11] Rosset A, Spadola L, Ratib O. OsiriX: an open-source software for navigating in multidimensional DICOM images. *J Digit Imaging.* 2004;17(3):205-16.
- [12] Martin CM, Roach VA, Nguyen N, Rice CL, Wilson TD. Comparison of 3D reconstructive technologies used for morphometric research and the translation of knowledge using a decision matrix. *Anat Sci Educ.* 2013; <http://dx.doi.org/10.1002/ase.1367>.
- [13] Kim G, Jung HJ, Lee HJ, Lee JS, Koo S, Chang SH. Accuracy and reliability of length measurements on three-dimensional computed tomography using open-source OsiriX software. *J Digit Imaging.* 2012;25:486-91.
- [14] Mandel M, Amorim R, Paiva W, Prudente M, Teixeira MJ, Andrade AF. 3D preoperative planning in the ER with OsiriX®: When there is no time for neuronavigation. *Sensors* 2013;13:6477-6491
- [15] Matsumoto T, Kanzaki M, Amiki M, Shimizu T, Maeda H, Sakamoto K, et al. Comparison of three software programs for three-dimensional graphic imaging as contrasted with operative findings. *Eur J Cardiothorac Surg.* 2012;41(5):1098-1103.
- [16] Rengier F, Mehndiratta A, von Tengg-Kobligh H, Zechmann CM, Unterhinninghofen R, Kauczor HU, et al. 3D printing based on imaging data: Review of medical applications. *Int J Comput Assist Radiol Surg.* 2010;5(4):335-41.
- [17] Tepper OM, Sorice S, Hershman GN, Saadeh P, Levine JP, Hirsch D. Use of virtual 3-dimensional surgery in post-traumatic craniomaxillofacial reconstruction. *J Oral Maxillofac Surg.* 2011;69:733-41.
- [18] Thierfelder KM, Sommer WH, Baumann AB, Klotz E, Meinel FG, Strobl FF, et al. Whole-brain CT perfusion: reliability and reproducibility of volumetric perfusion deficit assessment in patients with acute ischemic stroke. *Neuroradiology.* 2013;<http://dx.doi.org/10.1007/s00234-013-1179-0>
- [19] Meenan C, Daly B, Toland C, Nagy P. Use of a thin-section archive and enterprise 3D software for long-term storage of thin-slice CT data sets. *J Digit Imaging.* 2006;19(1):84-88.
- [20] Yakami M, Ishizu K, Kubo T, Okada T, Togashi K. Development and evaluation of a low-cost and high-capacity DICOM image data storage system for research. *J Digit Imaging.* 2011;24(2):190-95.
- [21] Eyrich G, Seifert B, Matthews F, Matthiessen U, Heusser CK, Kruse AL, et al. 3-Dimensional imaging for lower third molars: is there an implication for surgical removal? *J Oral Maxillofac Surg.* 2011;69(7):1867-72.
- [22] Ueda M, Nakamori K, Shiratori K, Igarashi T, Sasaki T, Anbo N, et al. Clinical significance of computed tomography assessment and anatomic features of the inferior alveolar canal as risk factors for injury of the inferior alveolar nerve at third molar surgery. *J Oral Maxillofac Surg.* 2012;70(3):514-20.
- [23] Savi A, Manfredi M, Pizzi S, Vescovi P, Ferrari S. Inferior alveolar nerve injury related to surgery for an erupted third molar. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod.* 2007;103(2):7-9.
- [24] Mavili M, Canter H, Saglam-Aydinatay B, Kamaci S, Kocadereli I. Use of three-dimensional medical modeling methods for precise planning of orthognathic surgery. *J Craniofac Surg.* 2007;18:740-47.
- [25] Elgalal M, Kozakiewicz M, Olszycki M. Custom implant design and surgical pre-planning using rapid prototyping and anatomical models for the repair of orbital floor fractures. *Eur Radiol.* 2009;19(11):S397.
- [26] Wagner J, Baack B, Brown G, Kelly J. Rapid 3-dimensional prototyping for surgical repair of maxillofacial fractures: A technical note. *J Oral Maxillofac Surg* 2004;62:898-901.
- [27] D'Urso P, Earwaker W, Barker T, Redmond MJ, Thompson RG, Effeney DJ, et al. Custom cranioplasty using stereolithography and acrylic. *Br J Plast Surg.* 2000;53:200-04.
- [28] Hirsch DL, Garfein ES, Christensen AM, Weimer KA, Saddah PB, Levine JP. Use of computer-aided design and computer-aided manufacturing to produce orthognathically ideal surgical outcomes: A paradigm shift in head and neck reconstruction. *J Oral Maxillofac Surg.* 2009;67:2115-22.

PARTICULARS OF CONTRIBUTORS:

1. Medical Officer, Department of Plastics, Reconstructive and Aesthetics Surgery, National University Hospital, Singapore.
2. Medical Officer, Department of Plastics, Reconstructive and Aesthetics Surgery, National University Hospital, Singapore.
3. Research Co-ordinator, Department of Plastics, Reconstructive and Aesthetics Surgery, National University Hospital, Singapore.
4. Oral Maxillofacial Surgeon, Department of Plastics, Reconstructive and Aesthetics Surgery, National University Hospital, Singapore.
5. Plastic Surgeon, Department of Plastics, Reconstructive and Aesthetics Surgery, National University Hospital, Singapore.

NAME, ADDRESS, E-MAIL ID OF THE CORRESPONDING AUTHOR:

Dr. Arjunan Kumaran,
5 Lower Kent Ridge Road, Singapore.
E-mail: arjunankumaran@gmail.com

FINANCIAL OR OTHER COMPETING INTERESTS: None.

Date of Submission: **Dec 10, 2018**

Date of Peer Review: **Feb 28, 2019**

Date of Acceptance: **Apr 03, 2019**

Date of Publishing: **May 01, 2019**