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The precise location of "Midshaft" clavicle fractures: Scrimmaging from the 42 yard-line

Kofi D Agyeman[1], Joseph A Abboud[2], Steven P Kalandiak[1], Jonathan C Levy[3], Anand M Murthi[4], Grant Jamgochian[5], Mohamad Y Fares[2], and Peter M Govey[5]

Abstract

Background: The realities of midshaft clavicle fracture distribution have not been described accurately. Consequently, a topographical depiction of midshaft clavicle fractures may help design implants that are more anatomically concordant with the fractured clavicle, leading to better outcomes and fewer complications.
Methods: This is a retrospective cohort study. One-hundred sixty-six surgically treated midshaft clavicle fractures of four fellowship-trained shoulder surgeons were evaluated to determine the precise "location" of the fracture on standard radiographs. This location was determined by noting the lateral, central, and medial endpoint of each fracture, expressed as a percentage (0%–100%) of the distance from the lateral to the medial end of the clavicle.
Results: Fractures on average began at the 36% line (SD = 6%), were centered at the 42% line (SD = 6%), and ended at the 48% line (SD = 7%). Ninety percent of fractures were centered lateral to the midpoint, and 64% were completely lateral to the midpoint. Thirty-two percent of midshaft fractures extended into the lateral third of the clavicle, but no fractures extended into the medial third.
Conclusion: Midshaft clavicle fractures in skeletally mature individuals appear to occur predominantly within the lateral metadiaphyseal half of the clavicle, and rarely extend into the medial third. Industry professionals and surgeons alike should consider this when designing and selecting implants. To note, our study relied on two-dimensional radiographs, and future studies should work on fully capturing the complex three-dimensional anatomy of the clavicle.
Level of evidence: IV.

Keywords

Clavicle fracture, clavicle measurements, fracture fixation, clavicle plate placement

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Introduction

The clavicle is a sigmoid long bone of the pectoral girdle, with a convex shape on its medial border when assessed from the Cephalad view.[1] It connects the appendicular and axial skeleton in smooth harmony with other adjacent bony structures like the scapula.[1] Fractures to the clavicle shaft are very common and are increasingly treated with surgery.[2] As the frequency of clavicle fracture surgery and the popularity of pre-contoured plates have grown, numerous clavicle-specific plates have been introduced. Although several fracture classification schemes exist for these fractures,[2–6] little information is available on the geographic distribution of fractures within specific fracture groups, yet such information might prove useful in guiding implant design, contour, and positioning.

Traditional classification schemes have focused on fracture location along the longitudinal axis of the clavicle, with Allman describing segments of thirds and Robinson's

[1]University of Miami, Miller School of Medicine, FL, USA
[2]Rothman Orthopedic Institute/Thomas Jefferson Medical Center, Philadelphia, PA, USA
[3]Holy Cross Orthopedic Institute, Fort Lauderdale, FL, USA
[4]MedStar Union Memorial Hospital, Baltimore, MD, USA
[5]Musculoskeletal Education and Research Center (MERC), A Division of Globus Medical, Inc., Audubon, PA, USA

Corresponding author:
Joseph A Abboud, Rothman Orthopaedic Institute, Thomas Jefferson University, 925 Chestnut Street, 5th Floor, Philadelphia, PA 19107, USA.
Email: abboudj@gmail.com

fifths.[3,6] Neer's classification further delineates types of lateral-end fractures, while Craig's subdivides both the medial and lateral ends.[4,5] Fractures in the midshaft are by far the most common. Using the Allman classification, Postacchini et al. evaluated 535 clavicle fractures and noted that 81% were in the midshaft.[3,7] While intuitively, a "mid"-shaft fracture would be centered on the clavicle, no study has confirmed this. The challenges of poorly fitted implants for midshaft clavicular fractures have been documented in the literature.[8] The complex anatomy of these fractures renders the accuracy of implant design of utmost importance, as a small deviation from anatomic integrity may significantly impact patient outcomes.[1,8] We believe that knowledge of the true location of midshaft clavicle fractures can have direct relevance to implant design, surgical approach, and implant selection. As such, the purpose of this study is to describe the position where midshaft fractures are centered on the clavicle and to describe the zone in which these fractures occur. The hypothesis is that the location of the centerpoint of these fractures is at the lateral metadiaphyseal region of the clavicle rather than at the true midpoint.

Materials and methods

This study was derived from a previous project that is Institutional Review Board-exempt due to the fact that in the former, only de-identified radiographs were reviewed by the attending physician. Accordingly, a consecutive series of midshaft clavicle fractures from the practices of four fellowship-trained shoulder and elbow surgeons were retrospectively reviewed. Inclusion criteria included skeletally mature patients who underwent operative treatment of their midshaft clavicle fractures (approximately restored to length). Clavicle fractures that occurred in skeletally immature patients or did not undergo operative management were excluded from our study. Initial postoperative anteroposterior (AP) radiographs, either with or without cephalad tilt, were reviewed by surgeons using ImageJ software (National Institutes of Health, Bethesda, MD, USA) to select five points on the clavicle: (1) the lateral end of the clavicle at the center of the bone (acromion side), (2) the medial end of the clavicle at the center of the bone (sternal side), (3) the lateral extent of the fracture, (4) the medial extent of the fracture, and (5) the conoid tubercle (Figure 1). Surgeons exported sets of Cartesian *x*- and *y*-coordinates for each subject for analysis in Excel software (Microsoft Corporation, Redmond, Washington, USA).

The overall clavicle straight-line length, projected in the plane of the radiograph, was calculated as $L_{1\to2} = \sqrt{((x_2 - x_1)^2 + (y_2 - y_1)^2)}$, and the negative reciprocal slope of the line between points (1) and (2) was applied to define perpendicular lines passing through landmark points (3), (4), and (5) (Figure 1). The intersection of these perpendicular lines with the line of length $L_{1\to2}$ yielded points (3′), (4′), and (5′). The distances between $L_{1\to3'}$, $L_{1\to4'}$, and $L_{1\to5'}$ were calculated to represent straight-line distances projected in the plane of the radiograph originating from the clavicle's lateral end and following a direction parallel to the lateral-to-medial bone length $L_{1\to2}$. Because these lengths share a common direction, normalized lateral-to-medial distances were calculated to the beginning of the fracture zone as $(L_{1\to3'})/(L_{1\to2})$, end of the fracture zone as $(L_{1\to4'})/(L_{1\to2})$, and conoid tubercle as $(L_{1\to5'})/(L_{1\to2})$. To orient positions on the clavicle, the lateral end is assigned 0% and the medial end as 100%. The length of the fracture zone as a percentage of overall clavicle length was calculated as $[(L_{1\to4'})-(L_{1\to3'})]/(L_{1\to2})$. The centerpoint of the fracture was defined as the midpoint between the medial and lateral extents of the fracture. Since a fracture that extends from the midshaft to a point lateral to the conoid tubercle might not be considered classically midshaft, these fractures were excluded from the analysis if $(L_{1\to5'})>(L_{1\to3'})$—in other words, if *any* part of the fracture extended laterally to the center of the conoid tubercle. For illustrative purposes, the position of the average fracture zone in terms of true distance along a representative clavicle of average length, 15.2 cm, was utilized.[9]

All data are presented as mean values with standard deviation. Statistical analyses were performed with Excel and Prism 7 software (GraphPad, La Jolla, CA, USA). A post-hoc power calculation was conducted to make sure the population size provided adequate power to identify a statistically significant shift. After observing that midshaft fracture zone centerpoints were approximately normally distributed, a 1-sample *t*-test was utilized with the null hypothesis to ensure there was no difference between the true mean fracture zone centerpoint and the true midshaft at 50%. The alternative hypothesis was that the true mean fracture zone centerpoint is located lateral to the true midshaft.

Results

One-hundred-ninety-four de-identified immediate postoperative radiographs were initially evaluated. Twenty-eight radiographs were excluded because the fracture zone extended lateral to the conoid tubercle, consistent with Orthopaedic Trauma Association (OTA) classification as distal (lateral) end segment fractures.[10] Describing the location as lines 0%–100% from the lateral to medial ends of the entire clavicle, the average conoid tubercle was located at the 26% line (SD = 3%), although exclusion for lateral fracture location was evaluated individually for each conoid tubercle position. This resulted in 166 radiographs included for analysis as midshaft fractures. A post-hoc power calculation demonstrated that a sample size of 166 samples would have 97% power to identify a statistically significant shift of as little as 3% away from

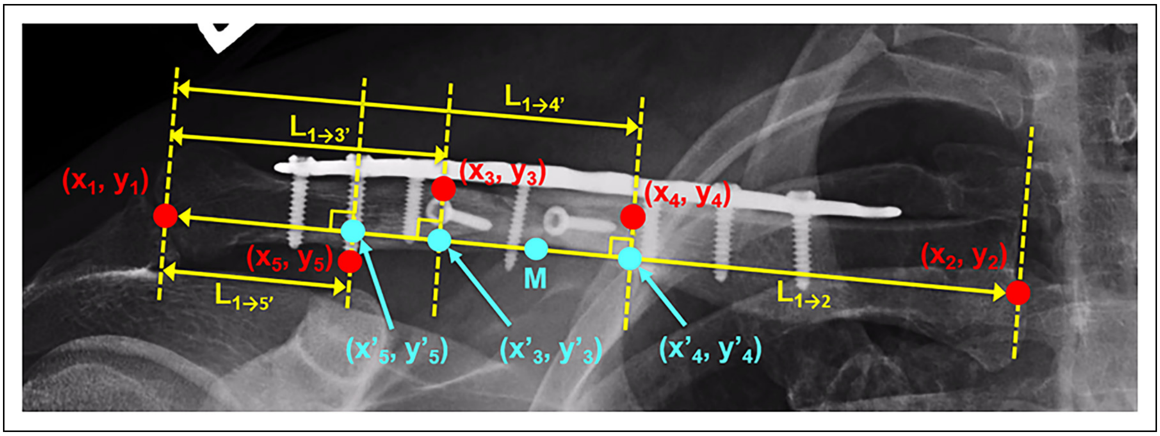

Figure 1. Representative selection and analysis of clavicle fracture zone position. Initial landmarks (shown in red) were identified by surgeons, and *x*- and *y*-coordinates were analyzed to provide lengths between each landmark (yellow lines) along a common lateral-to-medial trajectory.

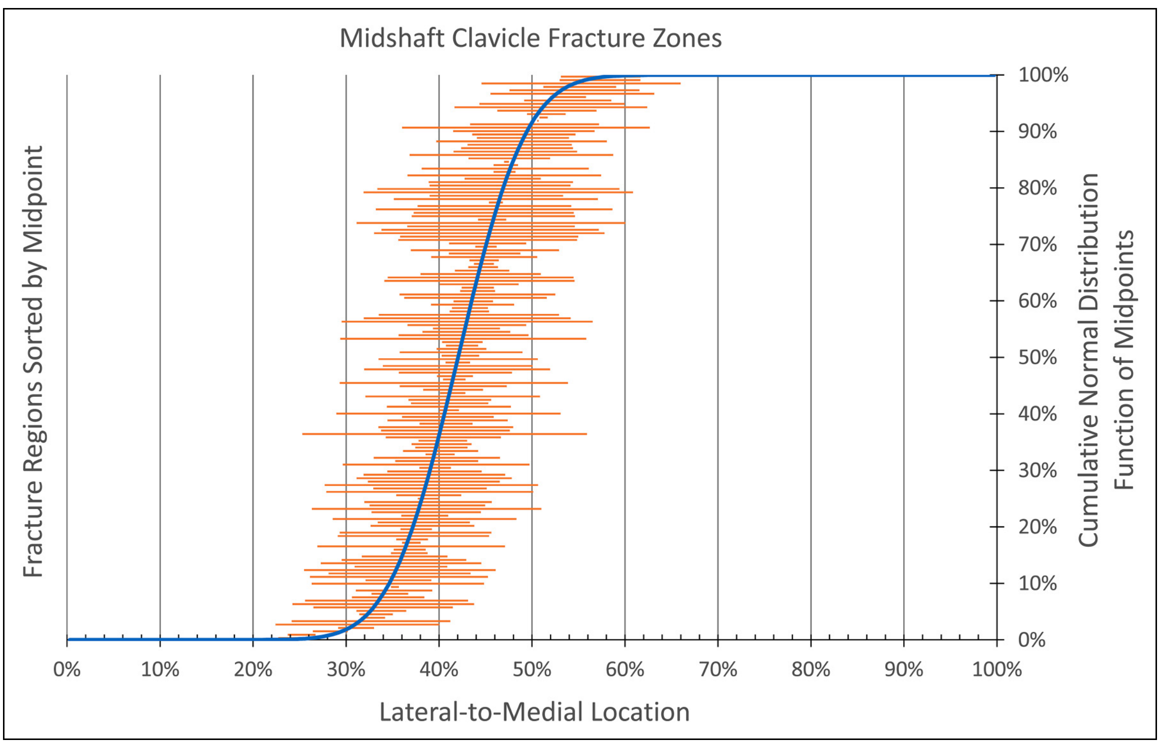

Figure 2. Midshaft clavicle fracture zones are represented by orange bars and ranked by lateral-to-medial position, where 111 of 166 fractures spanned the average clavicle fracture zone center at the 42.4% mark. The blue line represents the expected normal distribution of fracture zone centers about a mean of 42.4 ± 5.8%.

the precisely 50% midshaft fracture location given, a 10% standard deviation of position among the population and alpha = 0.05 false positivity rate. For these 166 midshaft clavicle fractures, there were 101 male and 48 female patients, with 17 not reported. The average age was 36 years (SD = 14; range 13–72 years). Around 41% of the fractures occurred on the right clavicle, while 59% occurred on the left clavicle. All radiographs were analyzed, and there were no losses to follow-up.

Fracture zone centerpoints were normally distributed around an average centerpoint localized at the 42% line (Figure 2). The frequency with which any given position along the clavicle's length was spanned by a midshaft fracture zone also approximated a normal distribution

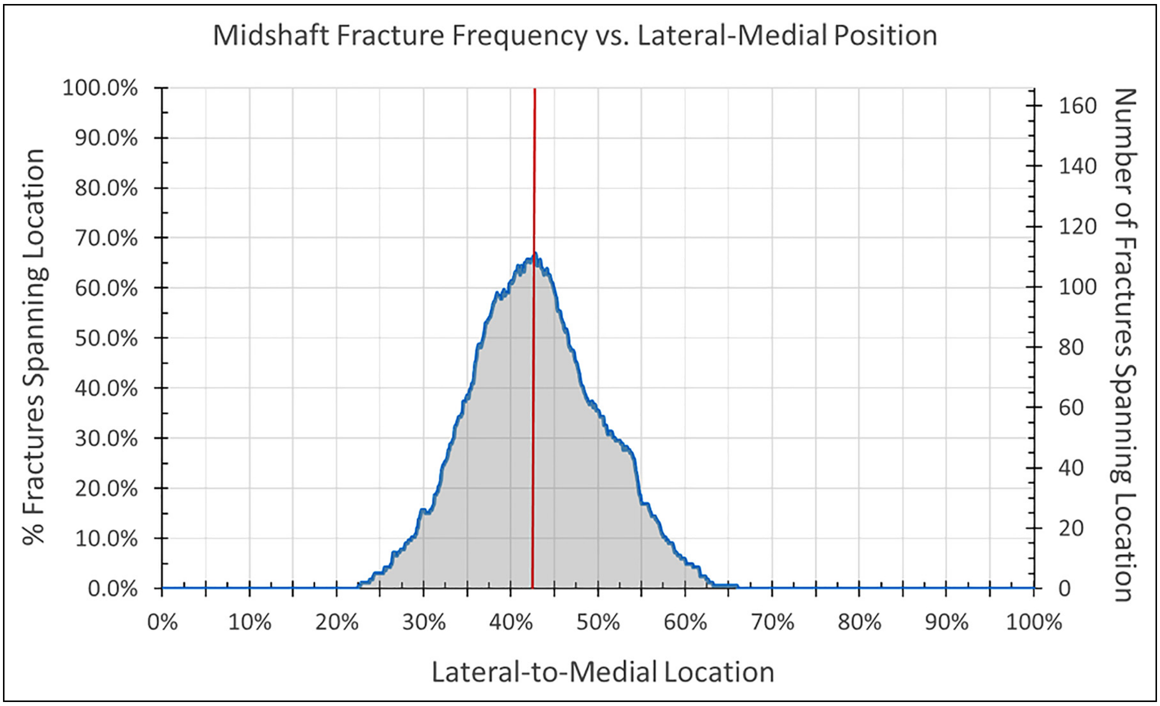

Figure 3. Midshaft fracture frequency versus lateral-medial position. The red line represents 249 the average clavicle fracture zone at 42.4%.

(Figure 3). The average fracture zone occupied 12% of the total clavicular length (SD = 7%; range 0.12% to 31%). On average, fractures began at the 36% line (SD = 6%), were centered at the 42% line (SD = 6%), and ended at the 48% line (SD = 7%). These measurements confirm the authors' hypothesis that the average fracture zone center-point is lateral to the true midpoint ($P < 0.0001$).

Over 90% of fractures (151 of 166) were centered lateral to the midpoint at the 50% line. Only 36% of midshaft fracture zones (65 of 166 fractures) reached the midpoint of the clavicle at all, while the remaining 64% of fracture zones (101 fractures) fell entirely lateral to the midpoint of the clavicle. It should be noted that 32% of midshaft fractures (53 of 166) extended into the lateral third of the clavicle, but none extended into the medial third.

Discussion

Midshaft clavicle fractures are common fractures frequently discussed in the literature.[2,11,12] As the frequency of surgical treatment of these fractures has increased, multiple pre-contoured implants have been designed to better manage these fractures.[2,9,13,14] However, while multiple classifications have been written to describe these fractures, no study has focused on the true geographic distribution of midshaft clavicle fractures. The purpose of this study was to accurately identify the topographical location of midshaft clavicle fractures, and our hypothesis was that the exact location is not concordant with that of pre-contoured implants. Our results indeed suggested that midshaft clavicle fractures are not centered on the midpoint of the clavicle. Rather, midshaft fractures are centered lateral to the midline, on average at a point approximately 42% of the distance from the lateral to the medial end of the clavicle. Furthermore, the average midshaft fracture zone, which runs from 36% to 48% of the distance from lateral to medial, does not include the midpoint. In fact, 64% of all fractures examined did not cross the midpoint of the clavicle at all. Several reasons may explain this finding. The shift in bone structure around the inflection point of the clavicle, as well as the nature of the injuries that impact the clavicle, may cause a stress riser around the 42% line, leading to fractures that are noticeably lateral to the midpoint. In addition, the insertion of various muscles, and the consequent unbalanced stress exerted by them can cause increased vulnerability lateral to the midpoint of the clavicle. The deltoid, in specific, has a higher volume and greater involvement in clavicular biomechanics when compared to other muscles like the trapezius, scalene, or sternocleidomastoid.[15] This unbalanced tension plays a role in governing the location of the rising fracture following injury.

This lateral metadiaphyseal distribution of nominally midshaft fractures may help to better explain why even pre-contoured plates developed specifically for clavicle fractures have been reported to fit poorly.[8] A lateral shift of

8% straight-line distance from the true midshaft might seem small—this would be equivalent to only a 12 mm lateral shift on a clavicle of an average 152 mm total length. However, the region of the bone near the 42% mark is variable in curvature, and it is near this location that the sigmoid-shaped clavicle antecurve transitions to a retrocurve. For this reason, slight shifts in this region of transitional curvature can profoundly change the plate contour required for anatomical fixation.

The biomechanics of fracture fixation dictate the choice of an implant that stabilizes the fracture while resisting deforming forces.[4,8,14,16–18] It follows that pre-contoured plates failing to adequately fit a fracture's morphology may subject patients to undue risks of implant failure, hardware soft tissue irritations, and possibly fracture nonunion.[12] Several studies have recognized plate-related complications after plate fixation of midshaft clavicle fractures and high rates of soft tissue irritation, often necessitating plate removal, which has since been associated with worse long-term clinical outcomes.[5,9,11,16–21] While some studies have employed tactics to predict appropriate plate and screw positioning, simulated fracture patterns evaluated are typically placed in idealized, midpoint ("50% line") positions.[8,12,22–25]

Therefore, it stands to reason that implant designs that better fit the actual fracture morphology seen in the mid-lateral metadiaphyseal fracture region may reduce the incidence of preventable reoperations or the morbidity associated with incorrect plate position, shape, or length.

Data from this study highlights that midshaft fractures occur predominantly within the lateral half of the clavicle. The authors' data show that 90% of fractures are centered within the lateral metadiaphyseal half, and nearly 2/3 have fracture zones that do not even reach the midpoint of the clavicle. While it is fairly common for midshaft fractures to extend slightly past the conoid tubercle into the lateral portion of the clavicle, rarely do these fractures extend into the medial third of the clavicle. In this series, the average centerpoint of midshaft clavicle fractures was found to be 42% of the total clavicular length from lateral to medial. This information is useful for surgical planning, as it allows the surgeon to have a preoperative idea of the anatomical topography of the fractured clavicle prior to surgery. It also has immense implications related to implant design and plate positioning. Certainly, other morphological factors such as the variability of curvature, and bend and rotation of the clavicle play important roles in implant design.[8] However, knowledge of the location of these fractures may help facilitate the production of implant designs that are more anatomically concordant with the presenting patient, and can thus, help achieve better outcomes. Further investigation with plate fit analysis would help clarify whether current implant designs are suited to match typical fracture zones of midshaft clavicle fractures.

The location of fractures in other anatomical sites of the body has been adequately explored in the literature. These include studies on the location of distal radius fractures and proximal humerus fractures.[26–30] Nevertheless, and to our knowledge, this is the first study to explore the location of midshaft clavicle fractures. This study is not without limitations. The researchers' data set includes solely operative fractures; hence, an inherent selection bias exists, as nonoperative fracture patterns may be distributed differently. Given the complex anatomy of clavicle shaft fractures, measuring lengths from three-dimensional (3D) computerized tomography (CT) imaging would likely be more accurate than two-dimensional (2D) radiographic measurements, as the 2D radiographs may not be able to appropriately assess the curvature of the clavicle. That being said, postoperative CT data were rarely available. The patients in this study were all skeletally mature; thus, these data may not be extrapolated to pediatric clavicle fractures. In addition, given the presence of anatomic variations within the population, using the contralateral uninjured clavicle as a control may have been beneficial for assessing pre-injury length. However, due to the retrospective nature of the data review, radiographs of uninjured clavicles were not readily obtained for the studied population. The retrospective nature of the study also subjected the findings to inherent selection bias and all of the other limitations associated with retrospective studies. Finally, the authors' findings would likely benefit from further analysis of clinical or radiographic outcomes dependent on the exact location of the fracture along the midshaft.

Conclusion

The actual topographic distribution of clavicle fractures is not accurately described in the literature and does not fall precisely in accordance with the general classification. Our study showed that midshaft fractures appear to predominantly occur within the lateral half of the clavicle, and rarely involve extension into the medial third. These fractures, on average, began at the 36% line, were centered at the 42% line, and ended at the 48% line, with the vast majority being found to be centered lateral to the midpoint. The actual locations and topographic patterns of midshaft fractures have direct application on the design and manufacturing of precontoured implants used for fracture fixation, and as such, industry professionals and surgeons alike should consider this when designing and selecting implants for patients. Designing the proper implant allows for better fracture healing and union, and consequently, better patient outcomes. This study was limited by the use of 2D radiographs for assessment of clavicle anatomy, and future studies should consider the use of CT scans for a 3D evaluation of clavicle fractures, taking into account the curvature, bending and rotation of the complex morphology of the clavicle.

Authors contributions

All authors contributed to the study's conception and design. JAA, SPK, JCL, and AMM were responsible for data collection, while PMG contributed to data analysis. The first draft of the manuscript was written by GJ and KDA, and subsequently revised by MYF. All authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Declaration of conflicting interests

The author(s) declared the following potential conflicts of interest with respect to the research, authorship, and/or publication of this article: Authors JAA, SPK, JCL, and AMM are paid consultants of Globus Medical, Inc. (GMI). Authors PMG and GCJ are salaried employees with stock options of GMI. Authors KDA and MYF report nothing to disclose.

Ethical approval

This manuscript was derived from a study that is Institutional Review Board-exempt due to the fact that in the study, only de-identified radiographs were reviewed by the attending physician.

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Consent to publish

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ORCID iDs

Joseph A Abboud https://orcid.org/0000-0002-3845-7220
Mohamad Y Fares https://orcid.org/0000-0001-8228-3953

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