Title
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Journal
Journal of Orthopaedics, 15(4)

ISSN
2589-9082

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Publication Date
2018-12-01

DOI
10.1016/j.jor.2018.08.044

Peer reviewed

Journal of Orthopaedics 15 (2018) 952–956

Contents lists available at ScienceDirect

Journal of Orthopaedics

journal homepage: www.elsevier.com/locate/jor

CT-measurement predicts shortening of stable intertrochanteric hip fractures

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ARTICLE INFO

Keywords:
Hip fracture
Computed tomography
Cephalomedullary nail
Sliding hip screw

ABSTRACT

Purpose: Intertrochanteric (IT) hip fractures can be treated with sliding hip screws (SHS) or cephalomedullary nails (CMN) based on the stability of the fracture. This stability is affected by the initial impaction of the fracture which can be difficult to assess. The aim of this paper is to develop specific pre-operative computed tomography (CT) measurements of IT fractures which are predictive of post-operative shortening.
Methods: A retrospective review was performed of 141 patients with AO/OTA 31A1 or 31A2 fracture patterns, who had pre-operative radiographs and CT scans, and who were treated with a SHS or a CMN. Pre-operative and post-operative imaging of IT fractures were analyzed for those fractures that shortened ≥15 mm post-fixation.
Results: 11 fractures shortened ≥15 mm with CMN being protective of shortening (6/36 SHS versus 5/105 CMN, $p = 0.0268$). A novel measurement made on the pre-operative CT scan called the cortical thin point (CTP) detected differences between patients with < 15 mm and ≥15 mm of post-operative shortening for the SHS group ($p = 0.0375$). CTP was found to be a reliable predictor for post-operative shortening of ≥15 mm when a cutoff threshold of 9 mm was used in the SHS group ($p = 0.0161$).
Conclusions: Measuring the CTP is predictive of post-operative shortening after fixation of an IT fracture with a SHS. CMN fixation may be protective of shortening. Patients with a CTP of ≤9 mm are at risk for fracture site shortening of more than 15 mm when treated with a SHS.

1. Introduction

Intertrochanteric (IT) hip fractures can be classified as stable or unstable based on the fracture pattern which affects implant selection.[1,2] Sliding hip screws (SHS) have been shown to have equivalent outcomes at lower cost compared to cephalomedullary nails (CMN) when used for stable fracture patterns.[1,3] Stable fracture patterns have a fracture line obliquity that allows compression at the fracture site under physiologic loading. For this to occur a buttress for the proximal fragment to settle against must be present on the distal fragment.[4,5] This buttress has been described as consisting of the posteromedial calcar and the lateral wall of distal fracture segment.[2,6]

More recently, patterns that affect the stability of the buttress – including coronal plane fractures of the proximal segment and fractures with thin but intact lateral walls on the distal fragment – have been identified as markers of unstable patterns that have higher all-cause failure rates when treated with a SHS.[7,8] These variants may occur as part of what has been thought of as stable AO/OTA 31A1 and 31A2 pattern fractures.[9] They can be difficult to detect on injury plain film x-rays taken in the emergency department, and therefore CT scans may be useful to better asses the fracture pattern.[10]

The ability to detect patterns predictive of fracture settling that causes substantial limb shortening after fixation of otherwise-stable fracture patterns remain poorly elucidated. SHS and CMN devices were designed to allow fracture sliding to improve union rates, and even substantial settling of the fracture may not be considered a mal-union.[11] However, too much settling may cause a diminished abductor level arm and a limb length discrepancy (LLD) which are associated with worse

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[1] Contributions: study concept, study design, literature review, data collection, data analysis, interpretation of results, direct writing contribution, editing and review

https://doi.org/10.1016/j.jor.2018.08.044
Received 11 June 2018; Accepted 25 August 2018
Available online 06 September 2018

functional outcomes, albeit no decrease in survival.[12,13] A symptomatic threshold of shortening has not been defined for the ambulatory hip fracture population, but LLDs have been extensively studied for the similarly-aged hip arthroplasty population. A post-operative LLD of greater than 10 mm has been shown to lead to lower Oxford Hip Scores and physical function three years after total hip arthroplasty.[14] Although controversial, an LLD of 1 cm or less is commonly used as an acceptable threshold that is well-tolerated after arthroplasty.[14,15]

One characteristic of a stable IT fractures that might predict substantial settling of a fracture is the impaction of the fracture present on the initial imaging. Fractures that have impaction of the lateral edge of the proximal segment against the lateral wall of the shaft will have a large void present after reduction. These impacted fracture patterns may be at risk for sliding back to the injury position if there is no implant, such as a CMN, to fill that void.[16] This impaction of the fracture site at injury cannot be reliably seen on plain film x-rays but is easily seen and measurable on CT scans. The purpose of this study was to determine if measuring impaction could be predictive of an IT fracture that is at risk of substantial shortening. Specifically, we hypothesized that: 1) impaction is easily and reliably measured on CT scans, and 2) the amount of impaction measured on the coronal reformats of the pre-operative CT scan will predict the risk of post-operative shortening for stable fracture patterns when a SHS is used but not when a CMN is used.

2. Methods

A retrospective chart review was performed of all patients with an IT fracture treated at an academic level-one trauma center from 1/2005 to 10/2016.825 patients were identified, and 141 (50 males, 91 females; age 77 ± 11 years) met our inclusion criteria: an AO/OTA 31A1 or 31A2 fracture pattern, pre-operative x-rays and CT scan that were available to review, operative treatment with a CMN (n = 105) or a SHS (n = 36), and at least 6 weeks of radiographic and clinical follow-up (Table 1).

All measurements were made on injury AP plain film x-rays and CT scans of the injured hip. The Lateral Wall Thickness (LWT) was measured on the injury plain film x-rays using previously described techniques (Fig. 1).[17] We developed two novel measurements that are done on the pre-operative CT scan to measure impaction. The Coronal Thin Point (CTP) was measured using coronal plane CT 2D reconstructions. We defined it as the narrowest distance the between the lateral wall of the distal fragment and the most distal extent of the lateral border of the proximal fragment (Fig. 2). The Axial Lateral Wall Average Thickness

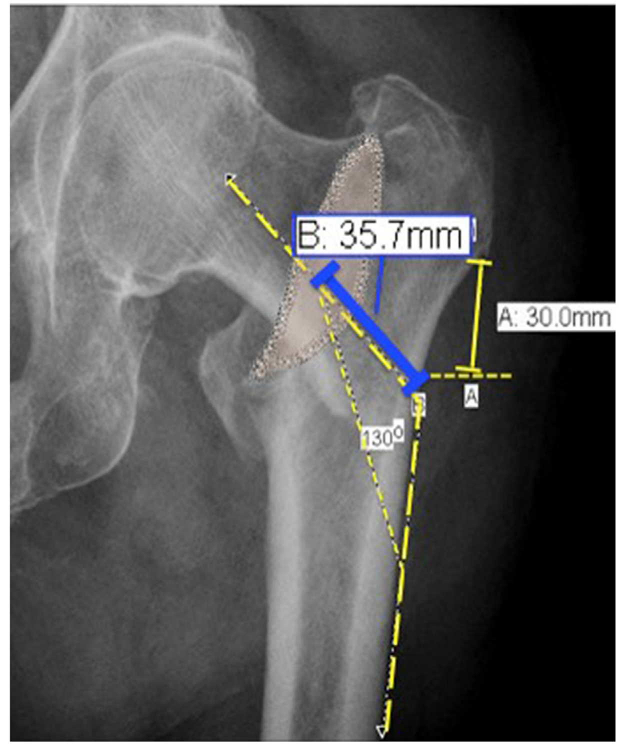

Fig. 1. Lateral wall thickness (LWT) is measured on an AP hip X-ray (blue line). It is the distance in mm from a reference point 3 cm (yellow line) below the innominate tubercle of the greater trochanter, angled at 130° upward to the fracture line (the midline between the two cortex lines).

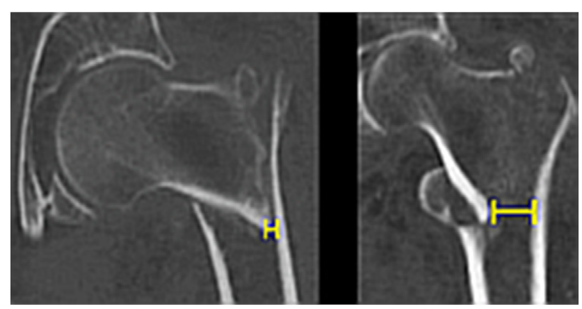

Fig. 2. The coronal thin point (CTP) is measured on coronal CT reformats of the intertrochanteric fracture. It is the distance between the lateral wall cortex and the most distal extent of the lateral aspect of the proximal fragment.

(ALWAT) was measured using the axial CT image cut at the level we predicted a lag screw to cross the fracture line if started 3 cm below the vastus ridge. Three parallel measurements centered on the midpoint of the lateral wall and 6 mm anterior and posterior to that midpoint were averaged to obtain the ALWAT (Fig. 3).

Post-operative fracture shortening was measured by comparing immediate post-operative x-rays to the last follow up x-rays that were available (Fig. 4). For SHS constructs, we measured the exposed length of the smooth portion of the lag screw from the proximal edge of the plate barrel to the first screw thread. For CMN constructs, we measured the exposed length of the lag screw or blade lateral to the body of the intramedullary nail. Magnification was corrected for by using the known implant diameter as a reference. We defined greater than or equal to (≥) 15 mm of shortening along the axis of the lag screw/blade as significant shortening. This corresponds to 10 mm of shortening of the limb, which been shown to be symptomatic after hip arthroplasty.[14] Patients were placed into two categories: the significant shortening group if they had ≥15 mm of shortening, or the insignificant

Table 1
Patient demographics and AO/OTA classification of patients treated with cephalomedullary nail and sliding hip screw.

	Cephalomedullary Nail[a]	Sliding Hip Screw[a]	*P*-Values[b]
Number of Patients	105	36	
Age (years)	77 ± 11 (52–106)	75 ± 12 (56–97)	0.3662
Female Gender	67 (64%)	24 (67%)	0.8414
AO/OTA Classification			0.0005[c]
31-A1.1	8 (8%)	12 (33%)	
31-A1.2	21 (20%)	12 (33%)	
31-A1.3	2 (2%)	1 (3%)	
31-A2.1	46 (44%)	7 (19%)	
31-A2.2	21 (20%)	3 (8%)	
31-A2.3	7 (7%)	1 (3%)	

[a] The values are presented as the number of patients with the percentage in parentheses, except for age which is given as the mean and standard deviation with minimum and maximum in parentheses.
[b] The p values were determined with the Fisher's Exact Test, except for age which was derived with the Wilcoxon Rank-Sum Test.
[c] Indicates statistical significance.

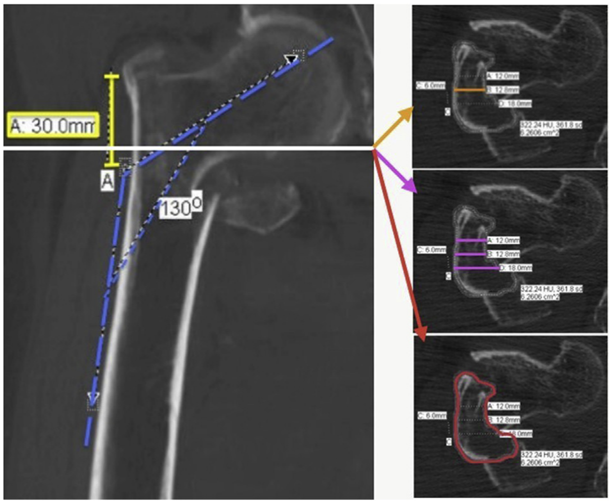

Fig. 3. Coronal image of a CT scan showing how to select the axial image at the level where the lag screw would cross the fracture line (white line). The Average Axial Lateral Wall Thickness (AALWT), defined as the average of three parallel measurements centered on the midpoint of the lateral wall and 6 mm anterior and posterior to that midpoint(magenta line).

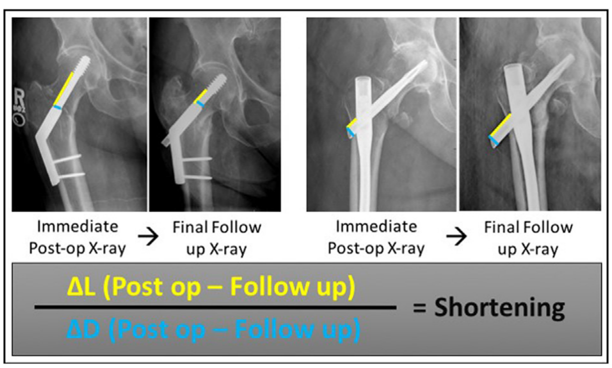

Fig. 4. Immediate post-operative x-rays and final follow up x-rays of a patient treated with a sliding hip screw and cephalomedullary nail constructs. Shortening along the axis of the femoral neck is measured for the sliding hip screw group by measuring the difference of the length of the exposed smooth portion of the lag screw. Shortening is measured for the cephalomedullary group by measuring the difference of the length of the lag screw or blade that is lateral to the nail. Magnification was corrected for by the known implant diameter.

shortening group if they had < 15 mm of shortening.

2.1. Statistical analysis

To determine the inter-observer reliability of the radiographic measurements, four surgeons measured the LWT, CTP, and ALWAT for fifteen randomly selected patients. A single factor analysis of variance (ANOVA) with repeated measures was used to calculate the intraclass correlation coefficient (ICC) for all measurements.

Continuous variables (e.g. CT measurements) were reported as mean ± standard deviation and range. Categorical variables (e.g. gender) were reported as the number of patients or the percentage of patients. A Fisher's exact test was used to determine the significance of any differences between categorical variables (e.g. AO Classification) for patients who shortened ≥15 mm versus those who shortened < 15 mm. A Wilcoxon Rank-Sum Test was used to determine the significance of differences in the X-ray and CT measurements between patients with and without significant shortening. For the variables that were significant (defined as $p < 0.05$), a Receiver Operating Characteristic (ROC) curve was used to determine a predictive model for risk of shortening ≥ 15 mm. A Fisher's Exact Test was used to validate the significance of the cutoff threshold for the shortening established by the ROC. Computations were performed using statistical software (JMP Pro, 13.0, http://www.jmp.com) and significance was set at $p < 0.05$.

3. Results

There were no differences in age or gender between the CMN and SHS groups. There was a difference in the distribution of AO/OTA fracture types between the two groups ($p = 0.0005$) (Table 1). 11/141 (8%) fractures shortened ≥ 15 mm: a higher proportion of SHS patients shortened ≥ 15 mm compared to the CMN group [6/36 (17%) for the SHS group vs. 5/105 (5%)] ($p = 0.0268$).

All measurements had a good or excellent inter-observer reliability based on the ICC. The LWT (Fig. 1) had the worst ICC (0.63); the CTP (Fig. 2) was the best (0.83), followed by the ALWAT (0.81) (Fig. 3).

3.1. SHS group

For the SHS group, there were 6 subjects that shortened ≥1.5 cm (1 AO/OTA 31A1.1, 3 AO/OTA 31A1.2, 1 AO/OTA 31A2.1, and 1 AO/OTA 31A2.2). The tip-to-apex distance for those who shortened ≥1.5 cm was 14.7 ± 1.8 mm which was not different from those who shortened < 1.5 cm at 17.9 ± 5.8 mm ($p = 0.0920$). The CTP was the only measurement that had statistical differences between the group that shortened ≥15 mm vs. those that did not (Table 2). The CTP was 7 mm thinner in the group that shortened ≥15 mm, [11 ± 8 mm versus 18 ± 8 mm ($p = 0.0375$)]. The LWT was 3 mm thinner in the group that shortened ≥15 mm (30 ± 8 mm) compared to those that did not at (33 ± 8 mm), but this difference did not reach statistical significance ($p = 0.4975$). The ALWAT measurement trended towards predicting shortening but did not meet statistical significance ($p = 0.1007$).

The ROC curve for the CTP of SHS group showed it was a reliable predictor for post-operative shortening ≥15 mm (AUC = 0.776) (Fig. 5). Using a cutoff threshold of 9 mm gave the best balance of sensitivity (67%) and specificity (90%) and there was a statistical difference in the likelihood of post-operative shortening ≥ 15 mm between patients with a CTP of more than or less than 9 mm ($p = 0.0161$).

3.2. CMN group

For the CMN group, there were 5 subjects that shortened ≥1.5 cm (1 AO/OTA 31A1.2, 3 AO/OTA 31A2.1, and 1 AO/OTA 31A2.2). The tip-to-apex distance for those who shortened ≥1.5 cm was 18.6 ± 3.0 mm which was not different from those who shortened < 1.5 cm at 17.1 ± 5.1 mm ($p = 0.3548$). There were no statistical

Table 2
Mean Measurements on X-ray and CT in the Sliding Hip Screw Group for Patients Who Shortened < 15 mm and Those Who Shortened ≥15 mm.

	Shortened < 15 mm[a] (N = 30)	Shortened ≥ 15 mm[a] (N = 6)	*P*-Values[b]
Lateral Wall Thickness (mm)	33 ± 8	30 ± 8	0.4975
Coronal Thin Point (mm)	18 ± 8	11 ± 8	0.0375[c]
Average Axial Lateral Wall Thickness (mm)	18 ± 5	15 ± 7	0.1007

[a] The values are presented as the mean ± standard deviation.
[b] The p-values were determined with the Wilcoxon Rank-Sum Test.
[c] Indicates statistical significance.

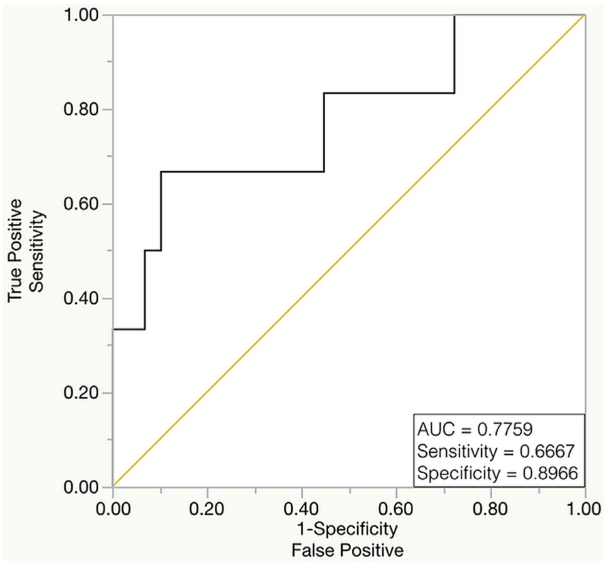

Fig. 5. Receiver operating characteristic (ROC) curve showing the true positive rate (sensitivity) against the false positive rate (1-specificity) for predicting fracture site shortening more than 15 mm based on the coronal thin point. The area under the curve was 0.7759 indicating fair predictive value of the ROC curve.

Table 3
Mean Measurements on X-ray and CT in the Cephalomedullary Nail Group for Patients Who Shortened < 15 mm and Those Who Shortened ≥15 mm.

	Shortened < 15 mm[a] (N = 100)	Shortened ≥ 15 mm[a] (N = 5)	*P*-Values[b]
Lateral Wall Thickness (mm)	27 ± 8	25 ± 3	0.6517
Coronal Thin Point (mm)	13 ± 7	17 ± 3	0.1248
Average Axial Lateral Wall Thickness (mm)	14 ± 4	15 ± 4	0.3280

[a] The values are presented as the mean ± standard deviation.
[b] The p-values were determined with the Wilcoxon Rank-Sum Test.

differences in any of the measurements between patients who shortened ≥15 mm vs. those that did not (Table 3).

4. Discussion

Our study is the first, to our knowledge, to find a radiographic measurement that is predictive of ≥15 mm of fracture site shortening or ≥1 cm of limb shortening for stable AO/OTA 31A1 and 31A2 type IT fractures treated with a SHS. The CTP measures impaction of the proximal femur into the lateral wall of the shaft and has an excellent inter-observer reliability (ICC = 0.83). Stable impacted IT fractures with a CTP of < 9 mm have a high risk of shortening ≥15 mm when treated with a SHS. The same was not true for stable impacted IT fractures treated with a CMN, perhaps because CMNs fill part of the void that is created after reduction.[16] The plain x-ray and axial cut CT measurements of lateral wall thickness we analyzed did not predict ≥15 mm of fracture site shortening in the SHS or CMN groups.

Our study is not without limitations. First, our study only evaluated radiologic outcomes, which cannot be directly correlated with functional outcomes. The clinical consequences of limb-shortening in the elderly hip fracture population remain unclear and difficult to interpret because these patients have diverse pre-injury functional capacities and there is no standardized threshold of acceptable shortening.[18] We chose a threshold of limb shortening that was clinically relevant based on the hip arthroplasty literature.[14,15] However, the geriatric hip fracture population may have different clinical symptoms with limb shortening than a similarly-aged hip arthroplasty population.[18]

Other limitations of this study include the retrospective study design and limited follow up. The follow-up period for inclusion was set only at 6 weeks in order to maintain as large a sample size as possible since majority of patients do not make their follow-up appointments. Although late shortening is rare in the setting of a fracture that heals, patients may continue to shorten at their fracture sites for up to 6 months.[19]

Our study uses novel CT measurements to predict post-operative fracture shortening in stable IT fractures. We designed these measurements to capture the amount of impaction of the proximal segment against the distal segment as well as the geometry of the intact portion of the lateral wall of the distal fracture fragment. Our CT measurements had excellent inter-observer reliability; markedly improved than the inter-observer reliability of the AO/OTA sub-classification of 31A fracture patterns when CT scans are used.[20,21] The CTP is easy to measure, reliable, and is a free piece of information when a CT is already ordered for other reasons as commonly performed at trauma centers.

Ideally, our measurement of impaction would be transferrable to a plain x-ray examination, which would be cheaper and involve less radiation. However, standardization of high-quality x-rays is difficult in the emergency room setting. Traction-internal rotation views of the proximal femur can help to obtain a better AP image of the hip, but in doing this maneuver, the fracture is being distracted as the distal fracture segment is being pulled and rotated away from the proximal femoral segment.[22] Furthermore, the subtle line of impacted cancellous bone that can be measured on CT scans cannot be seen on plain x-rays.

Before routine CT scans can be advocated for otherwise stable-appearing fractures, more work is needed to determine what clinical consequences of limb shortening do occur in geriatric hip fracture patients. A recent study found that the greater the shortening, the less likely the patient was able to return to premorbid walking levels at an average follow up of 14 months.[13] Another study looking at CMN fixation of IT fractures in the elderly demonstrated that a greater amount of lag screw sliding was correlated with worse functional outcomes on the SF-36 Survey and increased scores on the Visual Analog Scale.[12] While a clear threshold of symptomatic limb-shortening after hip fractures is still not known, ambulatory patients are more likely to be symptomatic when their fracture settles substantially.

Currently, there is a trend in the United States to use CMN implants for fixation of stable IT fractures in elderly hip fracture patients.[23] This trend is attributed to influences in training and surgeon preferences that have evolved with the introduction of newer short CMNs.[24] If postoperative fracture settling and limb shortening are to be used to compare implant choices and justify a more expensive implant, it is important to better understand which fractures are at a risk of healing with substantial limb shortening.[25] Impaction of IT fractures as measured by the CTP may be a helpful tool for future studies comparing implant selection when considering substantial limb shortening as an outcome.

5. Conclusion

This study introduces a novel CT-based measurement named the Coronal Thin Point. The CTP is a simple and reliable measure that quantifies impaction at the time of injury of IT fractures. Using a threshold of 9 mm, the CTP can identify which fractures are at risk of shortening ≥1.5 cm while healing. It remains unclear which patients will be symptomatically affected by this degree of shortening, but this study demonstrates that IT fractures otherwise considered stable with substantial impaction (CTP less than 9 mm) may benefit from use of a cephalomedullary nail implant to limit significant proximal femoral shortening. Further research analyzing this novel measurement and the clinical impact of shortening of healed IT fractures is warranted.

Acknowledgements

None.

Compliance with ethical standards

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or the comparable ethical standards.

For this type of study formal consent is not required.

The study was approved by our ethical committee.

Conflicts of interest

On behalf of all authors, the corresponding author states that there is no conflict of interest.

Funding

No funding sources to be declared.

Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.jor.2018.08.044.

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