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Tariq Z. Issa

Yunsoo Lee

Emily Berthiaume

Mark J. Lambrechts

Caroline Zaworski

See next page for additional authors

Authors
Tariq Z. Issa; Yunsoo Lee; Emily Berthiaume; Mark J. Lambrechts; Caroline Zaworski; Qudratallah S. Qadiri; Henley Spracklen; Richard Padovano; Jackson Weber; John J. Mangan; Jose A, Canseco; Barrett I. Woods; I. David Kaye; Alan S. Hilibrand; Christopher K. Kepler; Alexander R. Vaccaro; Gregory D. Schroeder; and Joseph K. Lee

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Utility of Seated Lateral Radiographs in the Diagnosis and Classification of Lumbar Degenerative Spondylolisthesis

Tariq Z. Issa, Yunsoo Lee, Emily Berthiaume, Mark J. Lambrechts, Caroline Zaworski, Qudratallah S. Qadiri, Henley Spracklen, Richard Padovano, Jackson Weber, John J. Mangan, Jose A. Canseco, Barrett I. Woods, I. David Kaye, Alan S. Hilibrand, Christopher K. Kepler, Alexander R. Vaccaro, Gregory D. Schroeder, Joseph K. Lee

Department of Orthopaedic Surgery, Rothman Institute, Thomas Jefferson University, Philadelphia, PA, USA

Study Design: Retrospective cohort study.

Purpose: Our goal was to determine which radiographic images are most essential for degenerative spondylolisthesis (DS) classification and instability detection.

Overview of Literature: The heterogeneity in DS requires multiple imaging views to evaluate vertebral translation, disc space, slip angle, and instability. However, there are several restrictions on frequently used imaging perspectives such as flexion-extension and upright radiography.

Methods: We assessed baseline neutral upright, standing flexion, seated lateral radiographs, and magnetic resonance imaging (MRI) for patients identified with spondylolisthesis from January 2021 to May 2022 by a single spine surgeon. DS was classified by Meyerding and Clinical and Radiographic Degenerative Spondylolisthesis classifications. A difference of >10° or >8% between views, respectively, was used to characterize angular and translational instability. Analysis of variance and paired chi-square tests were utilized to compare modalities.

Results: A total of 136 patients were included. Seated lateral and standing flexion radiographs showed the greatest slip percentage (16.0% and 16.7%), while MRI revealed the lowest (12.2%, $p<0.001$). Standing flexion and lateral radiographs when seated produced more kyphosis (4.66° and 4.97°, respectively) than neutral upright and MRI (7.19° and 7.20°, $p<0.001$). Seated lateral performed similarly to standing flexion in detecting all measurement parameters and categorizing DS (all $p>0.05$). Translational instability was shown to be more prevalent when associated with seated lateral or standing flexion than when combined with neutral upright (31.5% vs. 20.2%, $p=0.041$; and 28.1% vs. 14.6%, $p=0.014$, respectively). There were no differences between seated lateral or standing flexion in the detection of instability (all $p>0.20$).

Conclusions: Seated lateral radiographs are appropriate alternatives for standing flexion radiographs. Films taken when standing up straight do not offer any more information for DS detection. Rather than standing flexion-extension radiographs, instability can be detected using an MRI, which is often performed preoperatively, paired with a single seated lateral radiograph.

Keywords: Lumbar spine; Spondylolisthesis; Radiography; Seated lateral; Flexion-extension

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Corresponding Author: Yunsoo Lee
Rothman Orthopaedic Institute at Thomas Jefferson University, 925 Chestnut St, 5th Floor, Philadelphia, PA 19107, USA
Tel: +1-267-339-3737, Fax: +1-267-479-1321, E-mail: yunsoo.lee@rothmanortho.com

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Introduction

The diagnosis of lumbar degenerative spondylolisthesis (DS) broadly encompasses several variations in translation, ventral or angular instability, and intervertebral disc collapse [1]. While no definitive clinical recommendations exist for the treatment of DS, providers generally provide conservative therapy before turning to surgical management for those patients' refractory to nonoperative treatment. The existence of instability, however, aids in directing clinical decision-making toward arthrodesis rather than only decompression for the subset of DS patients who are diagnosed with an unstable spondylolisthesis [2,3].

Unstable spondylolisthesis, which often clinically presents as axial back pain with the loading of the lumbar spine, is radiographically visualized as the anterior-posterior translation of the affected vertebral segment on dynamic imaging. While several authors consider the translation of >3 mm to signify dynamic instability [4,5], others define this as the degree of slip, with instability requiring a difference in slip translation of >6%–8%, depending on the diseased level [6-8]. There is currently no standardized positioning for the diagnosis of instability, although upright radiographs are the most popular method for diagnosing lumbar DS, and dynamic flexion-extension radiographs are often used in addition to determining instability. Recent study has questioned the diagnostic value and dependability of flexion-extension radiographs in DS. First of all, dynamic flexion-extension radiographs are subject to significant measurement error and may not show the full motion that the affected spinal motion segment undergoes throughout the arc of motion [5]. Furthermore, due to the patient's potential substantial motion limitations brought on by the underlying spinal pathology's subjective discomfort, these radiographic views are vulnerable to significant bias. Because of pain-limited rigidity, investigators have demonstrated that the diagnosis rate of unstable DS increased by over 600% after the administration of analgesia [9]. To address these drawbacks, authors have proposed several alternative mechanisms for diagnosing instability including radiographs in the lateral decubitus position, supine magnetic resonance imaging (MRI), and seated lateral radiographs [7,8,10,11]. While Zhou et al. [7] suggested that sitting lateral radiographs perform better than dynamic flexion-extension radiographs when paired with supine MRI, these findings have not yet been confirmed by additional researchers. Hence, the main goal of our study was to further determine whether seated lateral radiographs can adequately be used in the replacement of dynamic flexion radiographs in diagnosing both angular and translational instability. Secondarily, we aimed to ascertain whether either view would change the DS classification as determined by the Meyerding or Clinical and Radiographic Degenerative Spondylolisthesis (CARDS) classification systems.

Materials and Methods

1. Study design and setting

This study was approved by the Institutional Review Board at Thomas Jefferson University Hospital (IRB #19D.508). Due to its retrospective nature and low risk to subjects, the requirement of informed consent was waived. After institutional review board approval, a retrospective assessment was conducted of consecutive patients of at least 18 years of age who received radiographic assessment and were diagnosed with degenerative lumbar spondylolisthesis as noted by the International Classification of Diseases-10 M43.16 at a single surgeon's practice from January 2021 to May 2022. In addition to the usual standing neutral upright and standing flexion radiographs, it is standard of care in this surgeon's practice for all patients with suspected degenerative lumbar spondylolisthesis to obtain a seated lateral radiograph. Standing extension radiographs are not obtained in this practice as prior studies have showed the poor utility of these images and increased patient pain [8,9]. A power analysis was performed using prior study data from Zhou et al. [7] which found that a total of 132 patients with seated lateral and standing flexion radiographs were required to obtain statistical power at the accepted level of 0.80.

2. Radiographic assessment

Each patient received routine standing flexion and neutral upright radiographs along with seated lateral radiographs conducted by trained radiology technicians utilizing the same machine. For seated lateral radiographs, patients are advised to sit upright with their backs against the chair. The chair is standard among all patients with a back support to mid-back with arm rests. Patients are told to

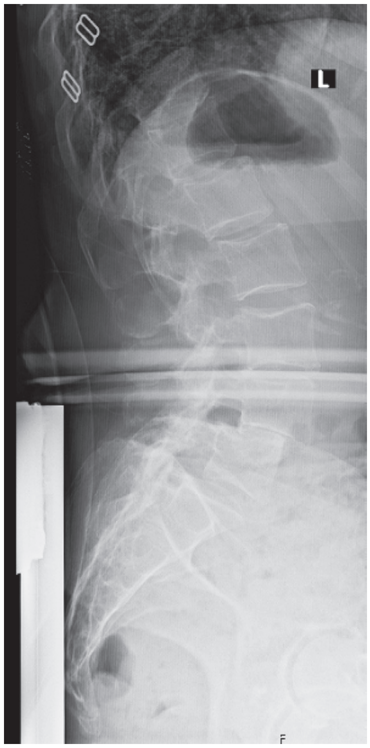

Fig. 1. Example seated lateral radiograph exposing an L4–L5 degenerative spondylolisthesis in a patient instructed to sit upright.

rest their arms on whatever part of their body feels most comfortable, usually on their legs. However, they are told to keep their arms off the armrests to prevent blocking the radiography image (Fig. 1). All radiographs were then uploaded to our center's radiographic imaging processing software, Picture Archiving and Communication System (PACS; Sectra AB, Linköping, Sweden), for standardization. Radiographs were analyzed by two examiners who measured radiographic parameters including slip amount, slip percentage, and slip angle, and identified the presence of kyphosis or bony apposition. To obtain precise measurements using the PACS image processing software, both raters enlarge all images by a factor of 200%. Patients were excluded from the study if the arm of the chair blocked the level of the slip and measurements could not be obtained.

3. Spondylolisthesis classification

Patients with a diagnosis of DS were categorized using two confirmed spondylolisthesis grading systems, the Meyerding and the CARDS classifications [12,13]. By evaluating patients according to the degree of vertebral body translation through evaluation of the slip %, the Meyerding classification is determined. Grade I is defined as 0%–25% slip, Grade II is 25%–50%, Grade III is 50%–75%, Grade IV is 75%–100%, and Grade V is greater than 100% [13]. The CARDS classification accounts for other radiographic morphology. The definitions of CARDS B and C are slip 5 mm and >5 mm, respectively, with lordosis and a partially maintained disc space. Any spondylolisthesis with kyphotic angulation is categorized as D by CARDS. CARDS D categorizes any spondylolisthesis with kyphotic angulation [12].

4. Statistical analysis

Descriptive statistics were reported as mean and standard deviation for continuous variables and mean and percent for categorical variables. Analysis of variance (ANOVA) testing between imaging methods was used to do univariate comparisons and then paired *t*-tests were used to look for statistically significant measurement differences. A paired chi-square test (McNemar test) was used to assess categorical data. All statistical tests were performed using Stata SE ver. 17.0 (Stata Corp., College Station, TX, USA). All *p*-values less than 0.05 were considered significant.

Results

One hundred thirty-six patients with spondylolisthesis were identified with complete seated lateral, standing upright, and dynamic flexion radiographs. Eighty-eight of these had an available supine MRI. Patients had an average body mass index of 29.5 kg/m^2 and were 65.8 years old on average. L4–L5 had the highest rate of spondylolisthesis (78.7%), followed by L5–S1 (11.8%) and L3–L4 (9.6%) (Table 1).

Seated lateral and standing flexion radiographs showed a similar degree of slip percentage (16.0% versus 16.7%, p=0.176) and slip angulation (4.66° versus 4.97°, p=0.446). Both views also detected a similar degree of kyphotic angulation (16.9% versus 12.5%, p=0.387) and disc space collapse (23.5% versus 21.3%, p=0.663). ANOVA showed a significant difference in slip angle and slip percentage among the included imaging parameters, which were lowest on MRI (p<0.001). Seated lateral radiographs and standing flexion radiographs exposed a more kyphotic angulation than either neutral upright radiographs (p=0.001) or supine MRI (p=0.002), which performed similarly (7.19 versus 7.20, p=0.9791) (Table 2). Additionally, there

Table 1. Cohort demographics (N=136)

Characteristic	Value
Age (yr)	65.8±9.3
Sex	
Male	91 (66.9)
Female	45 (33.1)
Body mass index (kg/m²)	29.5±6.5
Osteoporosis	16 (11.8)
Smoking status	
Current	8 (6.0)
Former	14 (10.5)
Never	111 (83.5)
Spondylolisthesis level	
L3–L4	13 (9.56)
L4–L5	107 (78.7)
L5–S1	16 (11.8)

Values are presented as mean±standard deviation or number of patients (%).

Table 2. Effects of radiograph selection on slip parameters

Variable	Slip %	*p*-value	Slip angle (°)	*p*-value
Seated lateral	16.0±7.4	0.176	4.66±5.0	0.446
Standing flexion	16.7±7.1		4.97±5.6	
Neutral upright	14.7±7.7	<0.001*	7.19±4.7	0.979
Supine MRI	12.2±6.7		7.20±5.0	
p-value	<0.001*		<0.001*	

Values are presented as mean±standard deviation.
MRI, magnetic resonance imaging.
*$p<0.05$ (statistically significant).

Table 3. Spondylolisthesis classification based on primary imaging assessment

Variable	Seated lateral (N=136)	Standing flexion (N=136)	*p*-value
CARDS[a]			0.771
CARDS A	19 (17.8)	19 (17.8)	
CARDS B	26 (24.3)	22 (20.6)	
CARDS C	44 (41.1)	51 (47.8)	
CARDS D	18 (16.8)	15 (14.0)	
Meyerding			0.856
Class I	119 (87.5)	118 (86.8)	
Class II	17 (12.5)	18 (13.2)	

Values are presented as number (%).
CARDS, Clinical and Radiographic Degenerative Spondylolisthesis.
[a]CARDS was only utilized for comparison of L4–L5 spondylolisthesis (N=107).

Table 4. Effects of imaging selection on assessment of spondylolisthesis ROM

Variable	Translational ROM (%)	Angular ROM (°)
SL-NU	1.32 (6.51)	2.53 (4.50)
Flex-NU	1.95 (5.31)	2.21 (5.02)
SL-MRI	4.52 (6.42)	2.76 (4.73)
Flex-MRI	4.62 (5.81)	2.48 (4.02)
p-value	<0.001*	0.884

ROM, range of motion; SL, seated lateral; NU, standing neutral upright; Flex, standing flexion; MRI, supine magnetic resonance imaging.
*$p<0.05$ (statistically significant).

were no variations in Meyerding's categorization between standing flexion radiographs and seated lateral radiographs ($p=0.856$). Although a comparison of seated lateral radiographs and standing flexion radiographs did not significantly change the CARDS classification for L4–L5 spondylolisthesis, seated lateral radiographs did result in marginally more kyphotic angulation but with less vertebral body translation, yielding non-significantly different CARDS classifications (CARDS A [17.8% versus 17.8%], CARDS B [24.3% versus 20.6%], CARDS C [41.1% versus 47.8%], and CARDS D [16.8% versus 14.0%] spondylolisthesis [$p=0.771$]) (Table 3).

To determine DS stability, seated lateral and standing flexion images were compared against each patient's respective neutral upright images and supine MRI, when available since both pairs showed the greatest difference in mean slip percentage and angulation. Significant differences in the amount of translational range of motion identified between imaging procedures were shown by ANOVA testing. The combination of seated lateral-MRI and standing flexion-MRI showed a greater translational range of motion than either seated lateral or flexion radiographs when compared with standing neutral upright radiographs (4.52%±6.4% and 4.62%±5.8% versus 1.32%±6.5% and 1.95%±5.3%, $p<0.001$). Standing and seated lateral flexion both performed similarly when measured against an upright lateral radiograph ($p=0.8170$) or an MRI ($p=0.2011$). No imaging modalities were found to vary from one another in terms of the amount of angular range of motion ($p=0.884$) (Table 4).

Patients were significantly more likely to be identified with translational instability when comparing their seated lateral radiographs (31.5% versus 20.2%, $p=0.0412$) or standing flexion radiographs (28.1% versus 14.6%, $p=0.0143$) to supine MRI than to standing neutral upright

Table 5. Ability of imaging technique in identifying spondylolisthesis instability

Comparison	Translational instability		Angular instability	
	Unstable	*p*-value	Unstable	*p*-value
SL-NU vs. Flex-NU (N=136)		0.2393		0.2059
SL-NU	26 (14.0)		19 (14.0)	
Flex-NU	20 (14.7)		15 (11.0)	
SL-MRI vs. Flex-MRI (N=89)		0.4669		1.000
SL-MRI	28 (31.5)		16 (18.0)	
Flex-MRI	25 (28.1)		16 (18.0)	
SL-NU vs. SL-MRI (N=89)		0.0412*		0.4795
SL-NU	18 (20.2)		14 (15.7)	
SL-MRI	28 (31.5)		16 (18.0)	
Flex-NU vs. Flex-MRI (N=89)		0.0143*		0.05881
Flex-NU	13 (14.6)		11 (12.4)	
Flex-MRI	25 (28.1)		16 (18.0)	

Values are presented as number (%). Translational instability defined as greater than 6% slip difference at L5–S1 and greater than 8% at all other levels. Angular instability is defined as more than 1° difference at L5–S1 and a greater than 10° difference at all other levels.
SL, seated lateral; NU, standing neutral upright; Flex, standing flexion; MRI, supine magnetic resonance imaging
*$p<0.05$ (statistically significant).

films. When paired with MRI to identify instability, there was no statistically significant difference between the seated lateral or standing neutral upright radiographs (31.5% versus 28.1%, p=0.4669). Patients with seated lateral or standing flexion films showed similar rates of angular instability around the sagittal axis regardless of whether these views were paired with standing neutral upright images or MRI (Table 5).

Discussion

The evaluation of the range of motion of the spinal motion segment continues to generate controversy, particularly when diagnosing unstable spondylolistheses [14]. Currently, segmental spondylolisthesis is diagnosed through postural radiography tests, including classic flexion and extension radiographs [15-17]. However, because most daily tasks are performed while seated, these imaging techniques may result in incorrect alignment correction as opposed to a seated lateral radiograph, which may more precisely mimic physiologic movement and stress [18,19]. Prior range of motion analyses have revealed that when patients with spinal deformity move from standing to a seated position, lumbar lordosis may be decreased by almost 50% [17]. In this study, we examine the effectiveness of seated lateral radiographs in comparison to other traditional radiographs and advanced imaging for identifying the severity of degenerative lumbar spondylolisthesis and the presence of instability. Overall, we discovered that seated lateral radiographs can accurately detect both translational and angular instability and provide similar diagnostic utility to standing flexion radiographs. We also determined that the standing neutral upright radiograph offers no additional clinical value in the classification of spondylolisthesis and that either a sitting lateral or standing flexion radiograph can be combined with MRI for diagnostic reliability in a surgical algorithm. Despite the lack of statistical significance, seated lateral radiographs revealed more kyphosis, increasing CARDS type D patients, while standing flexion radiographs showed a greater slip in patients, increasing CARDS type C classification. Furthermore, for surgeons who use the CARDS classification system, utilization of both seated lateral and standing flexion radiographs may help detect maximal translation and kyphotic angulation. When taken as a whole, seated lateral radiographs seem to have the best chance of finding DS while also yielding the most useful information.

Despite its widespread utilization, standing flexion-extension radiographs have been detected as poor imaging modalities for reliable spondylolisthesis diagnosis [7,11]. A recent analysis of 240 DS patients discovered that out of 225 patients classified as stable on standing flexion-extension radiographs, 84 (37.3%) were reclassified as unstable following preoperative computed tomography or intraoperative lateral radiographs [20]. Due to these different imaging techniques, spinal fusion was recommended for a considerable number of patients rather than spinal decompression [20]. Chan et al. [21] discovered that standing neutral upright radiographs with supine MRI identified instability, which they defined as a difference >3 mm in translation, in 61.7% of spondylolistheses compared to only 21.4% using flexion-extension radiographs. This observation was reinforced by Liu et al. [11], who demonstrated that the use of supine MRI in conjunction with neutral upright radiographs revealed higher translational mobility and more frequently identified instability than flexion-extension radiographs. When attempting to diagnose instability, the goal of forward bending is to increase flexion to expose the greatest degree of kyphotic angulation of ventral translation. However, the theoretical comparison of maximal forward bending and backward extension on "dynamic" flexion extension is significantly underestimated on static radiographs when compared to *in vivo* continuous kinematic analysis [5].

Due to the discomfort experienced during the examination and changes in muscular tone, standing flexion-extension radiographs can also severely underestimate the range of motion. In a population of lumbar DS patients with moderate to severe axial back pain, Chou et al. [9] compared radiographic examinations before and after the administration of 30 mg of intramuscular ketorolac. Thirty minutes after analgesia, patients reported reduced visual analog scale pain by over 52%, and flexion-extension radiographs showed a significantly greater dynamic slip, segmental angle, lumbar lordosis, and slip percentage, increasing the overall incidence of DS instability from 6% to 38% [9]. Patients with dynamic instability may also have a greater amount of pain when standing rather than sitting [21]. Patients will have antalgic contractions and increased muscle tone as a result of their pain, which results in paraspinal muscle rigidity [22]. Surface electromyography data of lumbar muscles has shown more asymmetric and disorganized muscular contractions in patients with low back pain compared to a healthy population [23]. The listhesis is stabilized and the instability that can result in severe discomfort is prevented by the enhanced paraspinal muscular tone. Recumbent or lateral decubitus films may address this by relieving muscle contraction and allowing for a greater range of motion [24].

In our research, we also question the effectiveness of neutral upright radiographs in the diagnosis of spondylolisthesis, as comparing standing flexion or seated lateral radiographs with MRI performed better than comparing neutral upright radiographs. The neutral upright radiograph may not provide any new diagnostic information because MRI is required for surgical therapy strategies for lumbar DS. Several studies have reported that MRI is a great modality to be combined with flexion radiographs [3,7,11,21,22], and one study identified that the combination of seated lateral and supine MRI was significantly superior to neutral upright and supine MRI [7]. In addition, a different study concluded that standing radiographs were not clinically useful and advised recumbent radiographs to detect more spinal hypermobility [22].

As the data continues to reveal no conclusive evidence as to which imaging modality is most effective, clinicians may keep some superiority over one view over another. While adding little to no new knowledge to the patient's treatment plan, doing studies that are only marginally useful in assisting with diagnosis increases the amount of time and money spent on the patient and the whole healthcare system. Furthermore, limiting extraneous radiographs can considerably lower patient radiation exposure, which is particularly pertinent as lumbar radiographs emit significantly greater doses of radiation than other comparable imaging studies. While lateral lumbar radiographs produce effective radiation doses as high as 1.50 mSv, lateral cervical and chest radiographs release radiation doses of 0.02 mSv and 0.25 mSv, respectively [25]. We propose that neutral upright films may not be clinically effective for spondylolisthesis imaging and routine repeat upright films should be removed to reduce patient radiation exposure and health system costs. Our study, which indicates sitting lateral radiographs as appropriate alternatives, is contextualized by the aforementioned concerns about the value of flexion-extension radiographs due to their poor diagnostic capabilities, patient discomfort during the examination, and radiation exposure. However, more study is required to contribute to the body of knowledge and directly compare various imaging modalities to determine whether sitting lateral radiographs are a preferable option to other radiographic views and to further validate whether they are a feasible alternative. The results of this study should be interpreted in the context of our study's limitations, including those inherent to any radiographic study. Because our clinic population only represents the practice of a single surgeon, patients with different characteristics may benefit from various imaging modalities based on inherent anatomic variations [11]. However, because all patients were given posture instructions from the same technician using the same X-ray machine in a single clinic setting, we think that this setting helps to improve radiographic homogeneity. Another limitation is the absence of standing extension films, limiting our ability to conclude the poor reliability of extension films. However, we do not achieve these additional radiographs to limit patient radiations and facilitate higher-value care without charging payers for the additional costs of tests with limited utility [3,11].

Conclusions

Seated lateral radiographs should be given strong consideration in the diagnosis and management of lumbar DS. We discovered seated lateral radiographs to be comparable to standing flexion films in revealing kyphotic angulation and vertebral translation, although the combination of the two may help in determining the most accurate CARDS classification. The combination of seated lateral radiographs and supine MRI was equivalent to the use of standing flexion radiographs in diagnosing translational and angular instability with the advantage that obtaining seated lateral radiographs may be logistically easier and more patient-friendly than dynamic standing radiographs. Diagnostic efforts can be concentrated on these imaging investigations, removing the need for extra testing that might increase radiation exposure and lower the quality of care.

Conflict of Interest

No potential conflict of interest relevant to this article was reported.

ORCID

Tariq Issa: https://orcid.org/0000-0002-0978-5225
Yunsoo Lee: https://orcid.org/0000-0002-6039-5142
Mark Lambrechts: https://orcid.org/0000-0002-9106-2228
Jose Canseco: https://orcid.org/0000-0002-2152-5725
Alexander Vaccaro: https://orcid.org/0000-0002-8073-0796

Author Contributions

Conception: TZI, YL, MJL, JKL, GDS; methodology: TZI, YL, MJL. JKL; data collection: CZ, QSQ, HS, JW, RP; data analysis: TZI, GDS, CKK, CZ, JW; writing–original draft: TZI, YL, EB, QSQ, HS, RP; writing–review and editing: JW, MJL, JM, JAC, ASH, CKK, ARV, GDS; project administration: MJL, GDS, CKK; study supervision: YL, MJL, JAC, ASH, CKK, ARV, GDS; and approval of final manuscript: TZI, YL, EB, MJL, CZ, QSQ, HS, JW, JM, JAC, BIW, IDK, ASH, CKK, ARV, GDS, JKL.

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