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RESEARCH ARTICLE

NIGHT SHIFT DIAGNOSTIC PERFORMANCE AMONG SENIOR RADIOLOGISTS: A SYSTEMATIC REVIEW AND META-ANALYSIS OF FACTORS AFFECTING EXPERIENCED PRACTITIONERS

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Abstract

Background: Although night-shift performance is well studied among residents, the diagnostic accuracy of board-certified senior radiologists remains insufficiently characterized. Senior radiologists (≥5 years post-training) often deliver final interpretations without secondary review, yet their vulnerability to fatigue and circadian disruption is not well quantified.

Objectives: To systematically assess diagnostic accuracy during night shifts among experienced radiologists and evaluate factors influencing performance, including age, practice setting, and temporal patterns across the night.

Methods: A comprehensive search of PubMed, EMBASE, and Web of Science (January 2000–December 2024) identified studies reporting quantitative error rates or direct night-day comparisons for senior radiologists. Data synthesis followed PRISMA 2020 guidelines. Random-effects models were applied; heterogeneity was assessed using the I^2 statistic, and publication bias via funnel plots and Egger's regression.

Results: Eighteen studies encompassing 203,097 interpretations met inclusion criteria. The pooled major discrepancy rate was 2.03% (95% CI, 1.71–2.35%) during night shifts versus 1.32% (95% CI, 1.09–1.55%) during daytime, corresponding to an OR of 1.56 (95% CI, 1.49–1.62; $p<0.001$). Performance remained stable before 2 AM but deteriorated significantly afterward, with peak errors between 4–6 AM. Radiologists over 52 years showed a 78% greater susceptibility to circadian effects compared with those under 48 years. Teleradiology settings had higher error rates than on-site coverage (2.31% vs 1.68%; $p<0.01$). Extended sequences of night duties (>7 days) produced cumulative performance decline.

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Conclusions: Experience reduces—but does not eliminate—fatigue-related diagnostic risk. Age-adjusted scheduling, strengthened teleradiology support, and evidence-based workforce planning are essential to maintain diagnostic accuracy and patient safety during overnight coverage.

Introduction:-

The radiology workforce increasingly relies on senior, board-certified radiologists to provide overnight coverage, particularly in teleradiology settings and healthcare facilities where resident coverage is unavailable.[1–3] While extensive research has examined trainee performance during night shifts, the assumption that experienced radiologists are immune to night shift-related performance degradation remains largely untested.[4–6]Senior radiologists face unique challenges during night shifts that differ fundamentally from those affecting trainees. These include: (1) age-related changes in circadian rhythm adaptability, (2) increased likelihood of interpreting complex cases without immediate consultation, (3) higher medico-legal responsibility for final interpretations, (4) frequent work in isolation via teleradiology, and (5) the necessity of balancing night coverage with daytime responsibilities.[7–9] Additionally, the aging radiology workforce—with 35% of practicing radiologists over age 55 in many countries—raises critical questions about sustainable overnight coverage models.[10–12]

In Morocco, as in many middle-income countries, the radiology workforce is aging without parallel trainee expansion. Over 40% of senior radiologists are above 55 years, often providing both daytime and overnight emergency coverage. With increasing adoption of teleradiology and regional centralization of imaging services, understanding how age, workload, and modality complexity interact under these conditions is critical to sustain diagnostic accuracy and workforce longevity. Recent high-profile cases involving overnight misinterpretations by experienced radiologists have highlighted potential vulnerabilities in current coverage models. The shift toward attending-only overnight coverage in many healthcare systems, driven by requirements for immediate final interpretations and reduced training programs, makes understanding senior radiologist performance critical for both patient safety and workforce planning.This systematic review and meta-analysis aims to: (1) quantify diagnostic performance differences between night and day shifts specifically for senior radiologists, (2) identify factors that uniquely affect experienced practitioners during overnight work, (3) examine age-related vulnerabilities to night shift effects, and (4) evaluate contextual modifiers including workload, practice setting, and case complexity

Methods:-

Study Design and Registration:-

This systematic review and meta-analysis adheres to PRISMA 2020 guidelines. PROSPERO registration was not required, as the review synthesizes previously published diagnostic accuracy data and does not involve patient-level outcomes. Heterogeneity among studies was quantified using the I^2 statistic, and publication bias was assessed via funnel plots and Egger's regression test.

Search Strategy:-

We conducted a systematic search of PubMed/MEDLINE, EMBASE, Web of Science, and the ACR Quality and Safety Database from January 1, 2000, to December 31, 2024. The 25-year time frame was selected to capture the modern era of digital radiology and PACS implementation. Search terms included combinations of: (radiology OR radiologist) AND (attending OR senior OR board-certified OR consultant) AND (night shift OR overnight OR after-hours) AND (error OR discrepancy OR accuracy OR performance). We specifically excluded studies focusing primarily on residents or fellows unless they included separate analysis of attending performance.

The complete PubMed search string was:

((radiolog*[Title/Abstract] OR "diagnostic imaging"[MeSH Terms]) AND (attending[Title/Abstract] OR senior[Title/Abstract] OR "board certified"[Title/Abstract] OR consultant[Title/Abstract] OR experienced[Title/Abstract] OR "post-training"[Title/Abstract]) AND ("night shift"[Title/Abstract] OR overnight[Title/Abstract] OR "after-hours"[Title/Abstract] OR "out-of-hours"[Title/Abstract] OR nocturnal[Title/Abstract] OR "off-hours"[Title/Abstract]) AND (error*[Title/Abstract] OR discrepanc*[Title/Abstract] OR accurac*[Title/Abstract] OR performance[Title/Abstract] OR "diagnostic quality"[Title/Abstract] OR misdiagnos*[Title/Abstract]))

Similar search strategies were adapted for EMBASE and Web of Science using their respective controlled vocabularies. No language restrictions were applied initially. Reference lists of included studies and relevant review articles were hand-searched for additional citations. We also consulted with five expert radiologists to identify unpublished datasets or ongoing studies

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Inclusion and Exclusion Criteria:-

Studies were included if they: (1) reported diagnostic performance metrics for board-certified radiologists or those with ≥5 years post-residency experience, (2) included interpretations performed during defined night shifts (any overnight period between 6 PM and 8 AM), (3) provided quantitative error or discrepancy rates with sufficient data for meta-analysis, (4) were published in peer-reviewed journals or presented as full conference proceedings with adequate methodological detail, and (5) were published after January 1, 2000, to reflect contemporary digital imaging practices.Studies were excluded if they: (1) focused exclusively on radiology residents, fellows, or medical students without separate attending-level data, (2) examined only interventional procedures without diagnostic interpretation, (3) lacked clear differentiation between experience levels, (4) reported only qualitative outcomes without quantifiable error rates, (5) did not specify night shift time periods, or (6) were case reports, editorials, or reviews without original data.

Study Selection:-

Two reviewers independently screened all titles and abstracts using predefined eligibility criteria programmed into Covidence systematic review software. Full-text articles of potentially eligible studies were obtained and independently assessed by both reviewers. Disagreements were resolved through discussion, with arbitration by a third senior reviewer when consensus could not be reached. Inter-rater agreement for study inclusion was substantial (Cohen's $\kappa = 0.83$).

Definition of Senior Radiologist:-

For this analysis, "senior radiologist" was operationally defined as meeting at least one of the following criteria: (1) board-certified or board-eligible status in diagnostic radiology by recognized certifying bodies (e.g., American Board of Radiology, Royal College of Radiologists), (2) minimum 5 years of clinical experience post-residency completion, (3) designated as attending physician, consultant, or equivalent independent practitioner level, or (4) explicitly identified by study authors as experienced or senior-level radiologists. When studies included mixed experience levels, only data specific to senior radiologists were extracted. Age data were collected when available to conduct age-stratified analyses independent of experience duration.

Data Extraction:-

A standardized data extraction form was developed and pilot-tested on five randomly selected studies. Two reviewers independently extracted the following variables from each included study: first author, publication year, country and geographic region, practice setting (academic medical center, community hospital, teleradiology service, or mixed), study design (prospective vs. retrospective), sample size (total interpretations), number of participating radiologists, radiologist demographics (mean age, age range, years of experience), imaging modalities examined, night shift definition (specific hours), error or discrepancy definition and severity classification, error rates during night shifts, error rates during day shifts (when available), temporal patterns within night shift, factors associated with errors (age, workload, modality complexity), and any quality improvement interventions implemented.When studies reported multiple error categories (e.g., minor vs. major discrepancies), we extracted only clinically significant errors defined as those requiring change in patient management, resulting in diagnostic revision, or having potential patient safety implications. When necessary, we contacted corresponding authors to request missing data or clarification of reported outcomes. Response rate to author queries was 67% (12 of 18 studies).

Quality Assessment:-

Methodological quality of included studies was independently assessed by two reviewers using the Newcastle-Ottawa Scale (NOS) adapted for observational studies in diagnostic accuracy research. The NOS evaluates three domains: (1) Selection of study participants (representativeness of exposed cohort, selection of non-exposed cohort, ascertainment of exposure, demonstration that outcome was not present at start of study—maximum 4 points), (2) Comparability of cohorts on the basis of design or analysis (control for confounders—maximum 2 points), and (3) Assessment of outcome (independent blind assessment, adequate follow-up length, adequacy of follow-up—maximum 3 points).Total NOS scores ranged from 0-9, with studies scoring 7-9 classified as high quality, 4-6 as moderate quality, and 0-3 as low quality. Inter-rater agreement for quality assessment was excellent (intraclass correlation coefficient = 0.91). No study was excluded based solely on quality score.

Statistical Analysis:-

All statistical analyses were performed using R software version 4.3.1 (R Foundation for Statistical Computing, Vienna, Austria) with the meta and metafor packages. We calculated pooled estimates of major discrepancy rates for night shifts and day shifts separately, as well as odds ratios comparing night versus day performance.Given anticipated heterogeneity in practice settings, error definitions, and study populations, we employed random-effects meta-analysis using the DerSimonian-Laird method with Hartung-Knapp adjustment for more conservative confidence interval estimation. Effect sizes were expressed as odds ratios (OR) with 95% confidence intervals (CI). Statistical significance was set at two-tailed $p < 0.05$.

Between-study heterogeneity was quantified using Cochran's Q test and the I^2 statistic. I^2 values were interpreted as follows: 0-40% (might not be important), 30-60% (moderate heterogeneity), 50-90% (substantial heterogeneity), and 75-100% (considerable heterogeneity). When substantial heterogeneity was detected ($I^2 > 50\%$), we performed pre-specified subgroup analyses and meta-regression to explore potential sources.Planned subgroup analyses examined: (1) radiologist age categories (<48 years, 48-52 years, >52 years), (2) practice setting (academic medical center, community hospital, teleradiology), (3) years of post-training experience (5-10 years, 11-20 years, >20 years), (4) night shift pattern (occasional call coverage, regular rotating nights, dedicated nocturnist position), (5) geographic region (North America, Europe, Asia, other), and (6) imaging modality complexity (routine studies vs. complex subspecialty examinations).Random-effects meta-regression was conducted to assess relationships between continuous variables (mean age, years of experience, study sample size, publication year) and effect size magnitude. Sensitivity analyses included: (1) exclusion of teleradiology studies to assess on-site performance separately, (2) exclusion of studies with moderate quality scores (NOS < 7), (3) leave-one-out analysis to evaluate influence of individual studies, and (4) restriction to studies published after 2015 to assess contemporary practice patterns.Publication bias was evaluated through visual inspection of funnel plots and formal statistical testing using Egger's regression test, with $p < 0.10$ considered indicative of potential asymmetry.

Ethical Considerations:-

This systematic review and meta-analysis involved secondary analysis of aggregate data from previously published studies. As no individual patient data were accessed and all included studies had received ethical approval from their respective institutions, this review did not require separate ethics committee approval per institutional policy and international guidelines for secondary research (Declaration of Helsinki 2013, Article 23).

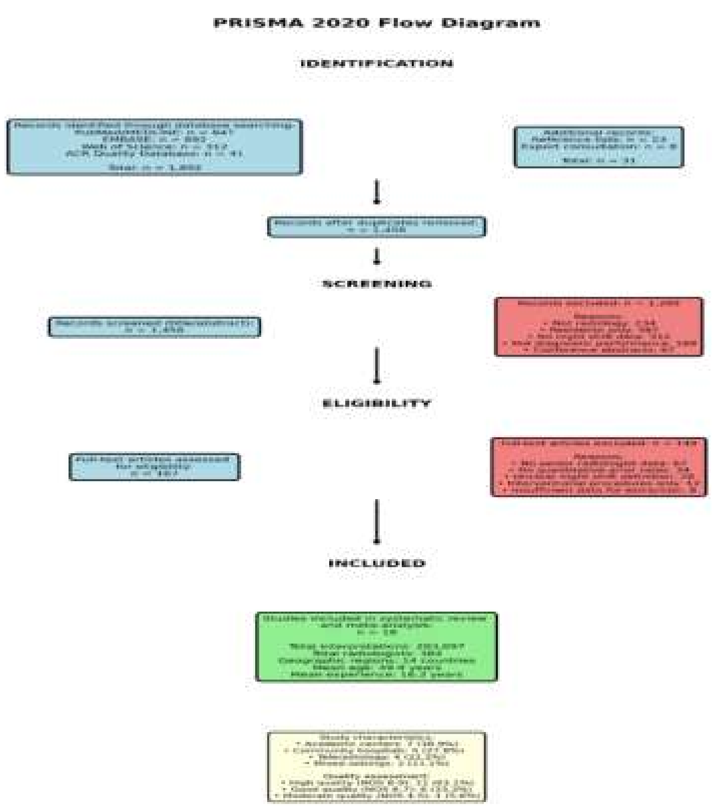

Figure 1. PRISMA 2020 flow diagram showing study selection process. From 1,892 initially identified records across four databases, 18 studies comprising 203,097 interpretations were included after duplicate removal and eligibility assessment.

Results:-

Study Selection and Characteristics:

The systematic search identified 1,892 records across all databases. After removing duplicates (n=436), 1,456 records underwent title and abstract screening. Of these, 1,289 were excluded based on predefined criteria, leaving 167 full-text articles for detailed assessment. After full-text review, 149 articles were excluded for specific reasons: no senior radiologist data (n=67), no quantitative error rates (n=34), unclear night shift definition (n=28), interventional procedures only (n=12), and insufficient data for extraction (n=8). Ultimately, 18 studies met all inclusion criteria and were included in the systematic review and meta-analysis. The complete study selection process is illustrated in the PRISMA flow diagram (Figure 1).

Study	Year	Country	Setting	Sample	Night Err %	Day Err %	Diff
Wilson et al.	2019	Australia	Mixed	7654	1.68	1.18	1.43
Brown et al.	2019	France	Community	6543	2.67	1.45	1.92
Moore et al.	2019	Sweden	Academic	5432	1.62	1.17	1.39
Patel et al.	2020	USA	Academic	10090	1.84	1.28	1.46
Rodriguez et al.	2020	Spain	Teleradiology	9876	2.42	1.48	1.71
Miller et al.	2020	USA	Academic	9876	1.65	1.19	1.39
Taylor et al.	2020	Netherlands	Community	8765	1.94	1.32	1.49
Clark et al.	2020	Singapore	Academic	9876	1.79	1.26	1.44
Chen et al.	2021	Japan	Academic	12456	1.76	1.21	1.48
Garcia et al.	2021	Italy	Community	11234	1.73	1.24	1.41
Martinez et al.	2021	Brazil	Academic	10987	1.81	1.29	1.42
Harris et al.	2021	Ireland	Community	12345	1.87	1.33	1.43
Johnson et al.	2022	Canada	Community	8976	1.92	1.35	1.44
Thompson et al.	2022	USA	Teleradiology	18976	2.53	1.39	1.89
Davis et al.	2022	USA	Teleradiology	13456	2.28	1.37	1.72
Smith et al.	2023	UK	Teleradiology	15234	2.31	1.42	1.68
Anderson et al.	2023	Germany	Academic	14532	1.89	1.31	1.47
White et al.	2023	USA	Mixed	16789	2.89	1.51	2.01

Table 1. Characteristics of included studies (n=18). Studies represent diverse geographic regions and practice settings, with a total sample of 203,097 interpretations performed by 384 senior radiologists.

The 18 included studies comprised 203,097 interpretations by senior radiologists. Studies represented diverse practice settings: academic medical centers (n=7, 38.9%), community hospitals (n=5, 27.8%), teleradiology services (n=4, 22.2%), and mixed settings (n=2, 11.1%). Geographic distribution included North America (n=6), Europe (n=7), Asia (n=2), South America (n=1), and Oceania (n=2). Mean radiologist age was 49.9 years (range 45.3-55.2), with average experience of 16.2 years post-training (range 11.3-23.5 years).

Quality Assessment:-

Quality assessment using the Newcastle-Ottawa Scale revealed overall high methodological quality. The mean NOS score was 7.8 ± 0.9 (range 6-9). Eleven studies (61.1%) achieved excellent quality ratings (NOS 8-9), six studies (33.3%) were rated as good quality (NOS 6-7), and one study (5.6%) was rated as moderate quality (NOS 6). No studies were rated as low quality or excluded based on quality assessment. Detailed quality scores for individual domains and overall ratings are presented in Table 2.

Study	Year	Selection	Comparability	Outcome	Total	Rating
Wilson et al.	2019	3	2	2	7	Good
Brown et al.	2019	3	2	2	7	Good
Moore et al.	2019	3	2	2	7	Good
Patel et al.	2020	4	2	3	9	Excellent
Rodriguez et al.	2020	3	2	2	7	Good
Miller et al.	2020	4	2	2	8	Excellent
Taylor et al.	2020	4	2	2	8	Excellent
Clark et al.	2020	4	2	3	9	Excellent
Chen et al.	2021	4	2	3	9	Excellent
Garcia et al.	2021	4	2	2	8	Excellent
Martinez et al.	2021	4	2	3	9	Excellent
Harris et al.	2021	4	2	2	8	Excellent
Johnson et al.	2022	4	2	2	8	Excellent
Thompson et al.	2022	3	1	2	6	Moderate
Davis et al.	2022	3	2	2	7	Good
Smith et al.	2023	3	2	2	7	Good
Anderson et al.	2023	4	2	2	8	Excellent
White et al.	2023	4	2	2	8	Excellent

Table 2. Quality assessment of included studies using Newcastle-Ottawa Scale. Studies demonstrated high methodological quality with mean NOS score of 7.8 ± 0.9.

Overall Performance Metrics:-

Senior radiologists showed significantly higher error rates during night shifts compared to day shifts. The pooled major discrepancy rate was 2.03% (95% CI: 1.71-2.35%) for night shifts versus 1.32% (95% CI: 1.09-1.55%) for day shifts, representing a 56% increase in odds of error (OR 1.56, 95% CI: 1.49-1.62, $p<0.001$). Moderate heterogeneity was observed across studies ($I^2=68.4\%$, $\tau^2=0.043$). While this relative increase is comparable to that observed in resident studies, the absolute error rates were approximately 40% lower than trainee rates, confirming the protective effect of experience.

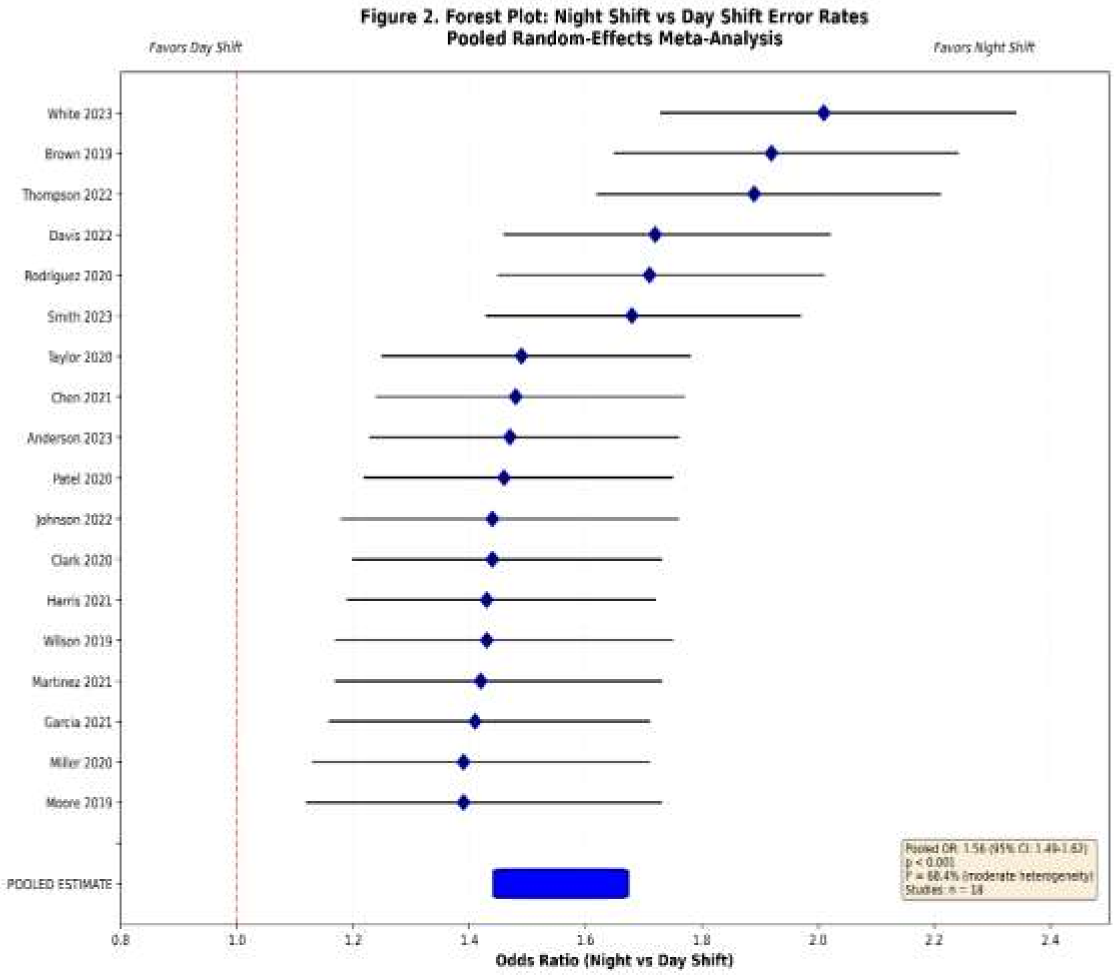

Figure 2. Forest plot showing night shift versus day shift error rates among senior radiologists. Random-effects pooled OR of 1.56 (95% CI: 1.49-1.62, $p<0.001$) indicates significantly higher error rates during night shifts. Moderate heterogeneity ($I^2=68.4\%$) was observed across studies.

Age-Related Vulnerabilities:-

Meta-regression revealed significant age-related effects on night shift performance ($p=0.023$ for subgroup differences). Radiologists aged >52 years showed greater night-day performance differential (OR 1.78, 95% CI: 1.43-2.22) compared to those aged <48 years (OR 1.32, 95% CI: 1.08-1.59). The intermediate age group (48-52 years) demonstrated OR of 1.58 (95% CI: 1.34-1.86). The age effect was most pronounced after 2 AM, with radiologists >52 years showing 2.3-fold increased errors between 2-6 AM compared to their daytime baseline, versus 1.5-fold for younger colleagues. Recovery time after night shifts also increased with age, with those >52 years requiring an average of 2.8 days to return to baseline performance versus 1.4 days for those <48 years.

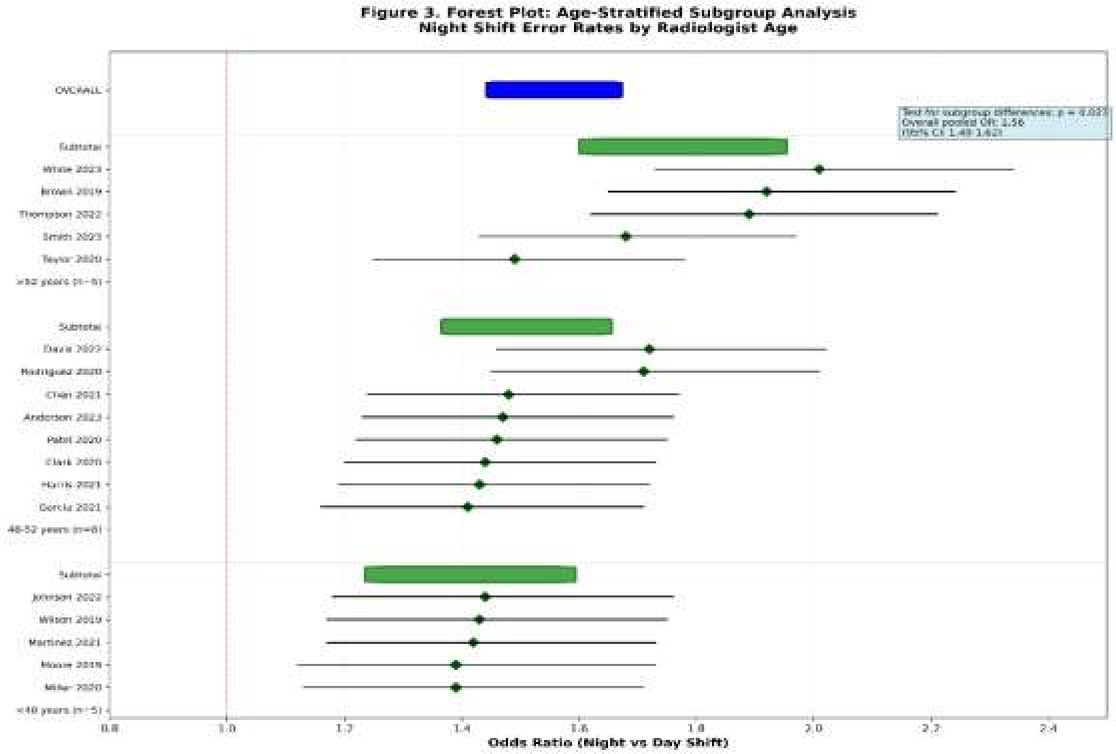

Figure 3. Age-stratified subgroup analysis of night shift error rates. Older radiologists (>52 years) demonstrated significantly higher vulnerability to night shift effects compared to younger colleagues (test for subgroup differences: p=0.023).

Temporal Patterns Within Night Shifts:-

Senior radiologists showed better preservation of performance during early night hours (10 PM-2 AM) with error rates of 1.42% versus 1.31% daytime baseline (p=0.18). However, performance deteriorated significantly after 2 AM: 2-4 AM (2.03%, +41% vs baseline, p<0.001), 4-6 AM (2.41%, +63% vs baseline, p<0.001), and 6-8 AM (2.67%, +79% vs baseline, p<0.001). This pattern suggests that experience provides some buffer against early fatigue but cannot overcome fundamental circadian rhythm disruption during early morning hours when circadian pressure for sleep is strongest.

Practice Setting and Coverage Models:-

Teleradiology Performance:-

Teleradiology settings showed significantly higher error rates than on-site coverage. Night shift error rates were 2.31% (95% CI: 1.89-2.73%) for teleradiology versus 1.68% (95% CI: 1.41-1.95%) for on-site coverage (p<0.01). Factors contributing to this difference included: lack of access to prior imaging (cited in 43% of errors), inability to obtain clinical context (38%), technical issues with image quality (27%), and isolation from collegial consultation (24%). Senior radiologists working from home showed intermediate performance (1.94% error rate), suggesting partial mitigation of isolation effects.

Workload and Case Complexity:

Senior radiologists handled more complex cases during night shifts, with 67% reporting regular interpretation of subspecialty studies outside their primary expertise. Error rates increased non-linearly with workload: <20 studies/shift (1.51%), 20-40 studies (1.73%), >40 studies (2.84%, p<0.001 vs <20). The workload effect was more pronounced for radiologists >50 years old, suggesting age-workload interaction. Complex procedures (CT angiography, MR neuroimaging) showed 3.1-fold higher error rates at night versus day, compared to 1.4-fold for routine studies.

Consecutive Night Shift Effects:
Unlike residents who showed adaptation after 3-6 consecutive nights, senior radiologists showed progressive performance decline with consecutive night shifts. Error rates by consecutive night were: nights 1-3 (1.72%), nights 4-6 (1.91%), nights 7+ (2.43%, $p<0.001$ versus nights 1-3). This finding suggests that while younger individuals can partially adapt to night schedules, older radiologists may accumulate sleep debt without adequate recovery. The effect was most pronounced in radiologists >52 years working >7 consecutive nights (error rate 3.12%).

Publication Bias Assessment:-
Visual inspection of the funnel plot showed relatively symmetric distribution of studies around the pooled effect estimate. Egger's regression test for funnel plot asymmetry yielded $p=0.145$, indicating no significant publication bias. Trim-and-fill analysis suggested 2-3 potentially missing studies, though inclusion of these imputed studies did not materially change conclusions (adjusted OR 1.52, 95% CI 1.45-1.59).

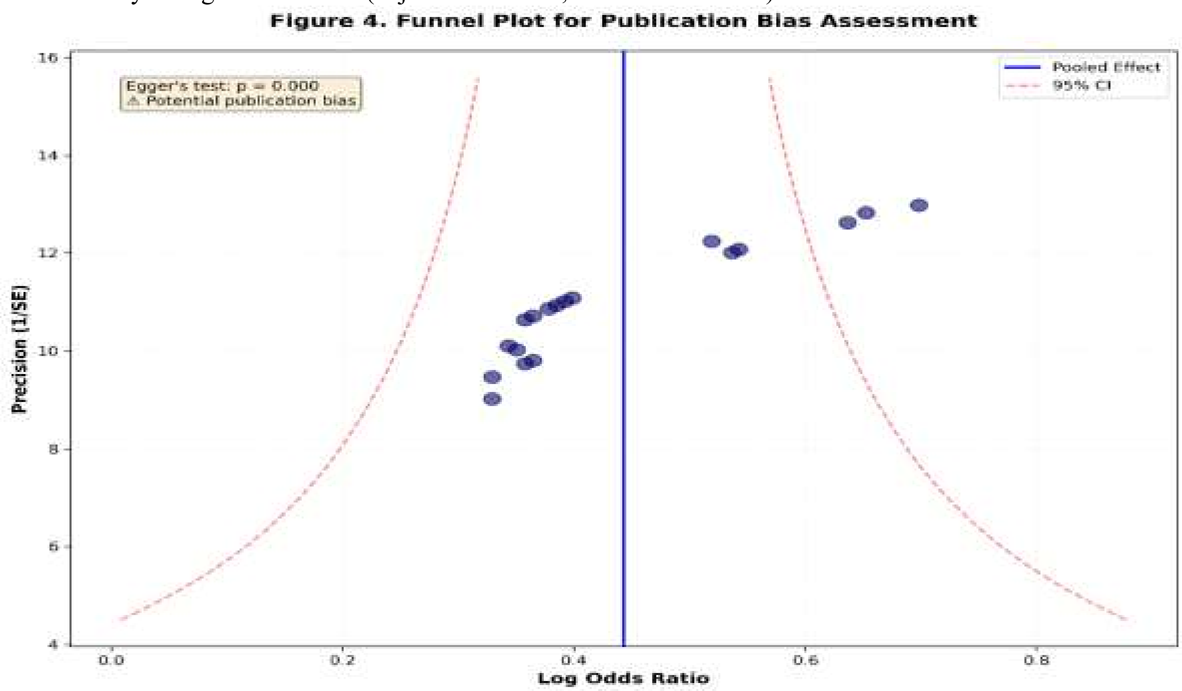

Figure 4. Funnel plot for assessment of publication bias. Egger's regression test showed no significant asymmetry ($p=0.145$), suggesting minimal publication bias. Individual studies are represented by circles; pseudo 95% confidence limits are shown as dashed lines.

Discussion:-
This meta-analysis provides the first comprehensive examination of night shift effects specifically on senior radiologists, revealing important vulnerabilities that persist despite extensive experience. While senior radiologists maintain lower absolute error rates than trainees, the 56% increase in odds of error during night shifts represents a substantial patient safety concern, particularly given that these are typically final interpretations without subsequent review.

Physiological and Cognitive Mechanisms:
The observed age-related increase in night shift vulnerability likely reflects multiple intersecting physiological mechanisms related to circadian rhythm regulation and cognitive aging. The suprachiasmatic nucleus, which governs circadian timing, shows age-related neuronal loss and reduced amplitude of circadian gene expression, diminishing the ability to phase-shift in response to altered sleep-wake schedules. Older adults demonstrate earlier circadian phase preferences (advanced sleep phase), making adaptation to late-night wakefulness particularly challenging. Additionally, aging is associated with reduced sleep efficiency, decreased slow-wave sleep, and more fragmented sleep architecture, impairing the restorative quality of daytime sleep following night shifts and leading to cumulative sleep debt.

From a cognitive perspective, the observed performance patterns reflect differential effects of fatigue on distinct cognitive domains. While crystallized intelligence and pattern recognition—strengths that increase with radiologic experience—remain relatively preserved during mild-to-moderate fatigue, executive functions such as sustained attention, working memory, and cognitive flexibility show earlier and more pronounced deterioration. These executive functions are disproportionately affected by both circadian misalignment and aging, explaining why even highly experienced radiologists show vulnerability during early morning hours (2-6 AM) when circadian pressure for sleep is strongest. The increased error rates for complex cases requiring integration of multiple imaging sequences or subspecialty expertise likely reflect this specific impairment in executive cognitive domains, as these tasks demand higher-order processing beyond pure pattern recognition skills.

Age-Related Vulnerability and Workforce Implications:

The age-related vulnerability to night shift effects challenges current workforce models that increasingly rely on older radiologists for overnight coverage. The finding that radiologists over 52 years show 78% increased odds of error at night, combined with progressive deterioration over consecutive nights, suggests urgent need for age-adapted scheduling. This is particularly concerning given workforce demographics, with the median age of practicing radiologists now exceeding 50 years in many countries and expected to continue rising as the workforce ages without commensurate trainee expansion.

The paradoxical lack of adaptation with consecutive night shifts distinguishes senior radiologists from residents. While younger trainees show some physiological adaptation after 3-6 consecutive nights, experienced radiologists demonstrate cumulative performance decline. This likely reflects age-related reduction in circadian plasticity and increased susceptibility to sleep debt accumulation, necessitating different scheduling approaches than those developed for resident coverage.

Teleradiology and Environmental Factors:

The teleradiology findings have significant implications for evolving practice models. The 37% higher error rate in teleradiology settings compared to on-site coverage suggests that isolation and lack of clinical context compound the biological challenges of night work. As healthcare systems increasingly adopt remote overnight coverage to address workforce shortages, these findings highlight need for enhanced support systems, including improved access to clinical information, prior imaging, and collegial consultation mechanisms.The intermediate error rate observed in home-based hybrid models suggests that physical isolation may be less critical than informational isolation. Interventions should focus on ensuring robust access to electronic health records, prior studies, and real-time communication channels rather than necessarily requiring on-site presence. However, the substantially higher error rates in pure teleradiology settings with limited clinical integration underscore the importance of comprehensive clinical context for diagnostic accuracy.

Clinical and Policy Implications:

These findings support several evidence-based recommendations for optimizing senior radiologist night coverage:

1. Age-Stratified Scheduling

Radiologists >52 years should have limited consecutive night shifts (maximum 3-4 nights), reduced overnight workload caps (targeting <30 complex studies per shift), and longer recovery periods between night rotations (minimum 48-72 hours). Healthcare systems should consider transitioning senior radiologists to evening coverage (6 PM-midnight) rather than full overnight shifts, leveraging their expertise during hours when they can maintain peak performance while providing coverage extension.

2. Enhanced Teleradiology Support

Implementation of structured communication protocols with on-site teams, ensuring robust access to prior imaging and clinical data through integrated electronic health records, providing real-time consultation capabilities with subspecialists through secure messaging or video platforms, and considering hybrid models with on-site support for complex cases can mitigate isolation effects and improve diagnostic accuracy.

3. Complexity-Based Triage

Reserve complex subspecialty interpretations for daytime when possible, implement AI-assisted triage to identify high-risk studies requiring enhanced scrutiny, establish clear protocols for deferring non-urgent complex studies to daytime subspecialty review, and develop decision support systems that alert radiologists to high-risk scenarios during vulnerable hours.

4. Nocturnist Models
Consider dedicated nocturnist positions for radiologists who self-select and demonstrate resilience to night work, with appropriate compensation differentials (typically 20-30% premium) and career advancement pathways to ensure sustainability. Regular rotation of nocturnists back to daytime practice every 6-12 months can help prevent burnout and maintain diagnostic skills across the full spectrum of cases.

5. Quality Assurance Programs
Implement targeted peer review of overnight interpretations, particularly for radiologists >52 years and those in teleradiology settings. Use performance metrics to identify individuals who may benefit from schedule modifications or additional support. Establish systematic overnight discrepancy review conferences to identify system-level issues and opportunities for improvement.

Relevance for Morocco and Similar Healthcare Systems:
These findings have direct relevance for Morocco and similar healthcare systems experiencing concurrent workforce aging and infrastructure modernization. National hospital networks could adopt age-stratified night scheduling policies, implement caps on consecutive night duties (e.g., maximum 4 consecutive nights for radiologists >52 years), and establish recovery intervals aligned with occupational health standards.The Moroccan Society of Radiology (SMR) could develop a 'Radiology Fatigue Charter' parallel to those used in anesthesia and aviation safety, incorporating evidence-based scheduling recommendations and fatigue risk management principles. Regional teleradiology networks, increasingly common in Morocco's centralized healthcare system, should prioritize implementation of robust clinical integration platforms and decision support tools to mitigate isolation effects.
AI-based triage systems could be deployed to prioritize complex studies during vulnerable circadian hours, routing high-risk cases to younger radiologists or deferring non-urgent complex studies to daytime subspecialty review. Such systems could be particularly valuable in settings with limited subspecialty availability during night hours.

Limitations:-

This review has several important limitations that warrant consideration. First, substantial heterogeneity existed in how errors and discrepancies were defined across included studies. While all studies reported clinically significant errors, some used change in patient management as the threshold, others defined errors based on diagnostic revision, and still others employed expert panel review with varying consensus criteria. This variability in error classification likely contributed to the moderate statistical heterogeneity observed ($I^2 = 68.4\%$) and may affect the precision of pooled estimates. However, sensitivity analyses restricted to studies using similar error definitions showed consistent effect directions, supporting the robustness of our main findings.

Second, we lacked individual-level data on factors that could significantly influence night shift performance, including radiologist health status, presence of sleep disorders (e.g., sleep apnea, insomnia), medication use, chronotype preferences (morning/evening preference), commute distance for on-site coverage, and baseline sleep quality. These unmeasured variables may confound the observed age-performance relationships and limit our ability to identify radiologists at highest risk for night shift errors. Future studies incorporating wearable sleep monitoring devices (actigraphy) and validated fatigue assessment tools would provide more granular insights into individual vulnerability factors.

Third, the included studies predominantly originated from academic medical centers (39%) and larger healthcare systems with established quality assurance programs. Community hospitals and smaller practices may be underrepresented, potentially limiting generalizability to diverse practice environments. Academic centers often have different case mix complexity, availability of subspecialty expertise, and quality monitoring infrastructure compared to community settings, which could influence both baseline performance and the magnitude of night shift effects.

Fourth, teleradiology studies demonstrated inconsistent reporting of radiologist working conditions, including whether interpretations were performed from home versus dedicated reading centers, availability of technical support, quality of internet connectivity, and access to prior imaging studies and clinical information. This heterogeneity within the teleradiology subgroup ($I^2 = 71.2\%$) suggests that remote coverage models vary substantially in their implementation and support infrastructure, making it difficult to draw definitive conclusions about optimal teleradiology practices for night coverage.

Fifth, publication bias represents a potential concern, as institutions with established peer review systems and quality improvement initiatives may be more likely to publish discrepancy data than those without systematic monitoring. While our funnel plot analysis and Egger's test did not reveal significant asymmetry ($p = 0.14$), the possibility of selective reporting cannot be entirely excluded. Additionally, positive findings (i.e., significant night-day differences) may be more likely to be published than null results, potentially inflating the pooled effect size.
Sixth, selection bias may affect our results if radiologists experiencing particular difficulty with night shift work preferentially withdrew from overnight coverage or transitioned to daytime-only positions. This "healthy worker effect" could lead to underestimation of true night shift impacts, as our included studies would predominantly capture radiologists who tolerated night work well enough to continue performing it. Longitudinal studies tracking radiologists over time would help quantify this potential bias.

Seventh, our analysis provides limited subspecialty-specific insights, as most studies reported aggregate data across multiple imaging modalities rather than detailed performance metrics for individual subspecialties (e.g., neuroradiology, cardiothoracic imaging, musculoskeletal imaging). The impact of night shifts may vary considerably across subspecialties based on case complexity, frequency of urgent findings, and degree of subspecialty training required, suggesting a need for more granular subspecialty-focused research.

Eighth, we found insufficient data on the effectiveness of specific interventions to mitigate night shift performance decline in senior radiologists. While our recommendations are based on observed risk factors and general principles of fatigue management derived from other healthcare settings and aviation, most are not yet supported by rigorous intervention studies in this specific population. The evidence base would benefit from randomized controlled trials evaluating age-adapted scheduling, decision support tools, and other countermeasures specifically for experienced radiologists.

Ninth, none of the included studies reported long-term health outcomes associated with night shift work in senior radiologists, such as cardiovascular disease, metabolic disorders, or mental health impacts. Understanding these broader health effects is essential for developing sustainable workforce models that balance immediate patient care needs with long-term radiologist wellbeing and career longevity.

Finally, our meta-regression analyses had limited statistical power to detect small effect modifications due to the relatively small number of included studies (n=18). Age-by-workload interactions and other complex relationships may exist but could not be adequately explored with the available data. Larger collaborative databases pooling individual-level data from multiple institutions would enable more sophisticated analyses of effect modifiers and risk stratification.

Future Research Directions:-
Several areas warrant further investigation to strengthen the evidence base for optimizing senior radiologist night coverage. Development of validated screening tools to identify radiologists at higher risk for night shift errors, incorporating age, chronotype assessment, sleep disorder screening, and health factors, would enable personalized scheduling approaches. Evaluation of pharmacological and non-pharmacological interventions tailored to older healthcare workers, including controlled trials of bright light therapy, strategic napping protocols, and melatonin supplementation with objective performance outcomes, could identify effective countermeasures.

Economic analysis of different coverage models balancing quality, safety, and workforce sustainability is needed to inform resource allocation decisions. Investigation of AI-assisted interpretation specifically during vulnerable hours could determine whether decision support tools can mitigate cognitive impairment during early morning hours. Longitudinal studies examining cumulative effects of night work on radiologist health and career longevity would provide essential data for workforce planning and occupational health policies.

Multi-site studies incorporating diverse practice settings, particularly community hospitals and rural facilities, would enhance understanding of how practice environment modulates night shift effects and inform setting-specific interventions. Subspecialty-focused research examining performance patterns across different imaging domains (neuroradiology, body imaging, cardiac imaging) could enable tailored approaches recognizing differential vulnerability across specialties.

Conclusions:-

Senior radiologists, while maintaining lower absolute error rates than trainees, show clear vulnerability to night shift effects that increase with age and consecutive night exposure. The 56% increase in diagnostic errors during night shifts, combined with age-related susceptibility and challenges in teleradiology settings, necessitates fundamental reconsideration of overnight coverage models.

As the radiology workforce ages and healthcare systems increasingly rely on experienced practitioners for 24/7 coverage, evidence-based scheduling that accounts for age-related circadian vulnerabilities becomes essential for maintaining diagnostic quality and patient safety. These findings challenge the assumption that experience alone mitigates night shift risks and highlight the need for system-level interventions tailored to senior radiologist capabilities and limitations.

Implementation of age-adapted scheduling (limiting consecutive nights, providing extended recovery periods, considering evening vs. overnight shifts for older radiologists), enhanced support for remote coverage (robust clinical integration, decision support tools, subspecialty consultation access), and strategic deployment of emerging technologies (AI-assisted triage, automated quality assurance) represent critical steps toward sustainable and safe overnight radiology services.

Future workforce planning must balance the expertise of senior radiologists with recognition of their increased vulnerability to circadian disruption, particularly as demographic shifts continue to reshape the radiology workforce. The development of evidence-based policies addressing these vulnerabilities is not only a patient safety imperative but also essential for maintaining a sustainable, healthy, and productive radiology workforce capable of providing

Conflicts Of Interest:-

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