

# Mid-Flexion Instability in Total Knee Arthroplasty: A Systematic Review of Risk Factors, Diagnosis, and Strategies

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## ABSTRACT

**Objective:** To critically evaluate the available evidence on mid-flexion instability (MFI) following total knee arthroplasty (TKA), its recognition as a distinct clinical entity, associated risk factors, diagnostic considerations, and preventive strategies. **Materials and Methods:** A systematic search of PubMed, Embase, Scopus, and the Cochrane Library was conducted through May 2025 in accordance with PRISMA guidelines. Clinical and biomechanical studies specifically evaluating MFI following TKA were included. **Results:** Thirteen studies met the inclusion criteria. The factors most consistently associated with MFI were anteroposterior translation  $\geq 7$  mm at  $30^\circ$  of flexion, changes in posterior condylar offset  $>2$  mm, joint line elevation  $\geq 4$  mm, and preoperative ligamentous laxity. Medially stabilized implants provided greater mid-flexion stability than posterior-stabilized designs in the available randomized controlled trial. Surgical techniques aimed at optimizing ligament balance, particularly flexion-first balancing approaches, were associated with reduced mid-flexion laxity. However, considerable heterogeneity persists in the definition of MFI. **Conclusions:** The available evidence supports MFI as a distinct clinical entity with a multifactorial etiology. Prevention requires preserving the joint line and femoral geometry, optimizing ligament balance, selecting an appropriate implant design, and systematically assessing intraoperative stability between  $30^\circ$  and  $60^\circ$  of flexion. Higher-quality studies are needed to establish standardized diagnostic criteria and determine the true incidence of MFI.

**Keywords:** Total knee arthroplasty; mid-flexion instability; risk factors; implant design; surgical technique; robot-assisted surgery.

**Level of Evidence:** III

## Inestabilidad en flexión media en la artroplastia total de rodilla: revisión sistemática de factores de riesgo, diagnóstico y estrategias

## RESUMEN

**Objetivo:** Evaluar críticamente la evidencia disponible sobre la inestabilidad en media flexión (IMF) tras la artroplastia total de rodilla (ATR), su reconocimiento como una entidad clínica diferenciada, los factores de riesgo asociados, las consideraciones diagnósticas y las estrategias preventivas. **Materiales y Métodos:** Se realizó una búsqueda sistemática en PubMed, Embase, Scopus y Cochrane Library hasta mayo de 2025, según las directrices PRISMA. Se incluyeron estudios clínicos y biomecánicos que evaluaran específicamente la IMF tras la ATR. **Resultados:** Trece cumplieron los criterios de inclusión. Los factores asociados de manera más consistente con la IMF fueron una traslación anteroposterior  $\geq 7$  mm a  $30^\circ$  de flexión, alteraciones del *offset* condíleo posterior  $>2$  mm, elevación de la línea articular  $\geq 4$  mm y laxitud ligamentaria preoperatoria. Los implantes con estabilización medial tuvieron más estabilidad en media flexión que los diseños posteroestabilizados en el ensayo clínico aleatorizado disponible. Las técnicas quirúrgicas destinadas a optimizar el balance ligamentario, particularmente los enfoques de balance de flexión primero (*flexion-first balancing*), se asociaron con una menor laxitud en media flexión. Sin embargo, persiste una considerable heterogeneidad en la definición de IMF. **Conclusiones:** La evidencia disponible respalda la IMF como una entidad clínica diferenciada y de etiología multifactorial. Su prevención requiere preservar la línea articular y la geometría femoral, optimizar el balance ligamentario, seleccionar adecuadamente el diseño de la prótesis y evaluar sistemáticamente la estabilidad intraoperatoria entre

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30° y 60° de flexión. Se necesitan estudios de mayor calidad para establecer criterios diagnósticos estandarizados y determinar la verdadera incidencia de la IMF.

**Palabras clave:** Artroplastia total de rodilla; inestabilidad en media flexión; factores de riesgo; diseño protésico; técnica quirúrgica; cirugía robótica asistida.

**Nivel de Evidencia:** III

## INTRODUCTION

Instability after total knee arthroplasty (TKA) is one of the most common complications of joint replacement surgery, accounting for 10%–22% of all revisions.<sup>1,2</sup> Traditionally, it has been classified as flexion, extension, recurvatum, or global instability, depending on the range of motion affected.<sup>3–5</sup> In recent decades, however, mid-flexion instability (MFI) has emerged as a potentially distinct entity, characterized by symptomatic laxity at intermediate flexion angles (30°–60°), with preserved stability in full extension and deep flexion.<sup>6,7</sup>

The concept of MFI originated in a cadaveric study by Martin and Whiteside, who observed increased laxity at intermediate flexion angles after elevation of the joint line.<sup>8</sup> Since then, the phenomenon has gradually gained recognition in the orthopedic literature, although its clinical definition, relevance, and status as a distinct entity remain subjects of debate.<sup>9</sup>

MFI is primarily attributed to ligamentous incompetence in the mid-range of motion, often associated with changes in joint line height, preoperative ligamentous laxity, alterations in posterior condylar offset, and imbalances between the flexion and extension gaps.<sup>10–14</sup> Patients may report a sense of instability, pain, or recurrent joint effusions, particularly during functional activities such as descending stairs or walking on slopes.<sup>12</sup>

Although some authors consider MFI simply a variant of flexion instability,<sup>9</sup> others have documented it as a reproducible phenomenon with specific clinical implications.<sup>15,16</sup> Despite growing interest, the available evidence remains fragmented, with no clear consensus on its pathophysiology, diagnosis, or optimal management. This systematic review aims to critically evaluate the available evidence on MFI after TKA, including the risk factors, diagnostic methods, and preventive strategies described in the medical literature, to clarify its clinical relevance and guide future research.

## MATERIALS AND METHODS

### Study design and methodological framework

A systematic review of the medical literature was conducted in accordance with the PRISMA 2020 (*Preferred Reporting Items for Systematic Reviews and Meta-Analyses*) guidelines. Given the emerging nature of the MFI concept and the anticipated heterogeneity of the included study designs, a structured narrative synthesis without quantitative meta-analysis was planned from the outset.

The review protocol was not registered in PROSPERO because the primary aim was to explore a clinical syndrome that remains controversial and poorly standardized, drawing on both clinical and biomechanical evidence. This was considered to extend beyond the usual scope of reviews focused on comparative clinical interventions. Nevertheless, the methodology was defined *a priori* and applied systematically.

### Information sources and search strategy

A systematic search was conducted in PubMed/MEDLINE, Embase, Scopus, and the Cochrane Library, from the inception of each database to May 31, 2025.

The search strategy combined controlled vocabulary terms (MeSH and Emtree, where applicable) with free-text keywords, adapted to the syntax of each database. The general Boolean structure was: (“total knee arthroplasty” OR “total knee replacement” OR TKA) AND (“mid-flexion instability” OR “midflexion instability” OR “mid-range instability” OR “mid range instability”) AND (instability OR “knee instability” OR “instability after TKA”).

Filters for English-language publications and human studies were applied where supported by each database. The reference lists of included studies were also searched manually (*snowballing*) to identify additional relevant literature not retrieved in the initial electronic search.

## Operational definition of MFI

For eligibility purposes, MFI was defined as symptomatic laxity identified clinically, through instrumented assessment, or intraoperatively, occurring predominantly between 30° and 60° of flexion, with relative stability preserved in full extension (0°) and deep flexion (~90°). Laxity had to be reported in at least one plane of motion (coronal, sagittal, or axial).

Because no single diagnostic test or universally accepted criteria exist for MFI, definitions based on clinical assessment, physical examination, instrumented measurements, biomechanical models, or intraoperative confirmation were accepted, provided that the study explicitly stated the mid-flexion range assessed.

## Inclusion criteria

Studies meeting all the following criteria were included:

- Randomized clinical trials, observational studies (cohort or case-control studies), or consecutive case series with more than 10 patients that specifically evaluated MFI after TKA.
- Biomechanical, cadaveric, *in vitro*, or computational studies that explicitly analyzed MFI as an independent phenomenon.
- Studies describing risk factors, pathophysiological mechanisms, diagnostic methods, or preventive strategies related to MFI.
- Articles published in English in peer-reviewed journals.

## Exclusion criteria

The following exclusion criteria were applied:

- Individual case reports, letters to the editor, editorials, and technical notes without original data.
- Animal studies.
- Studies addressing only flexion or extension instability without specific reference to MFI.
- Gray literature (conference abstracts and unpublished theses).
- Systematic or narrative reviews, which were used only as secondary sources to identify references and were not included as primary studies.

## Study selection

Two independent reviewers selected studies in three stages: 1) title and abstract screening, 2) full-text assessment of potentially eligible studies, and 3) final inclusion according to the predefined criteria.

Disagreements were resolved by consensus, with a third reviewer consulted when necessary. References were managed and duplicates removed using Zotero®, while screening was performed using Rayyan®.

## Data extraction

Two reviewers independently extracted data using a standardized form. The following variables were collected: 1) author and year of publication, 2) study design and sample size, 3) implant type and prosthetic design evaluated, 4) MFI definition and diagnostic method, 5) risk factors analyzed, 6) clinical, radiographic, biomechanical, or instrumented outcomes, and 7) reported preventive strategies or surgical considerations.

## Risk of bias and level of evidence assessment

Risk of bias was assessed according to study design:

- The Cochrane Risk of Bias 2 (RoB 2) tool was used for randomized clinical trials.
- ROBINS-I was used for comparative observational studies.
- The MINORS instrument was used for nonrandomized, noncomparative studies because no specific tools were available for these designs (Figure 1).

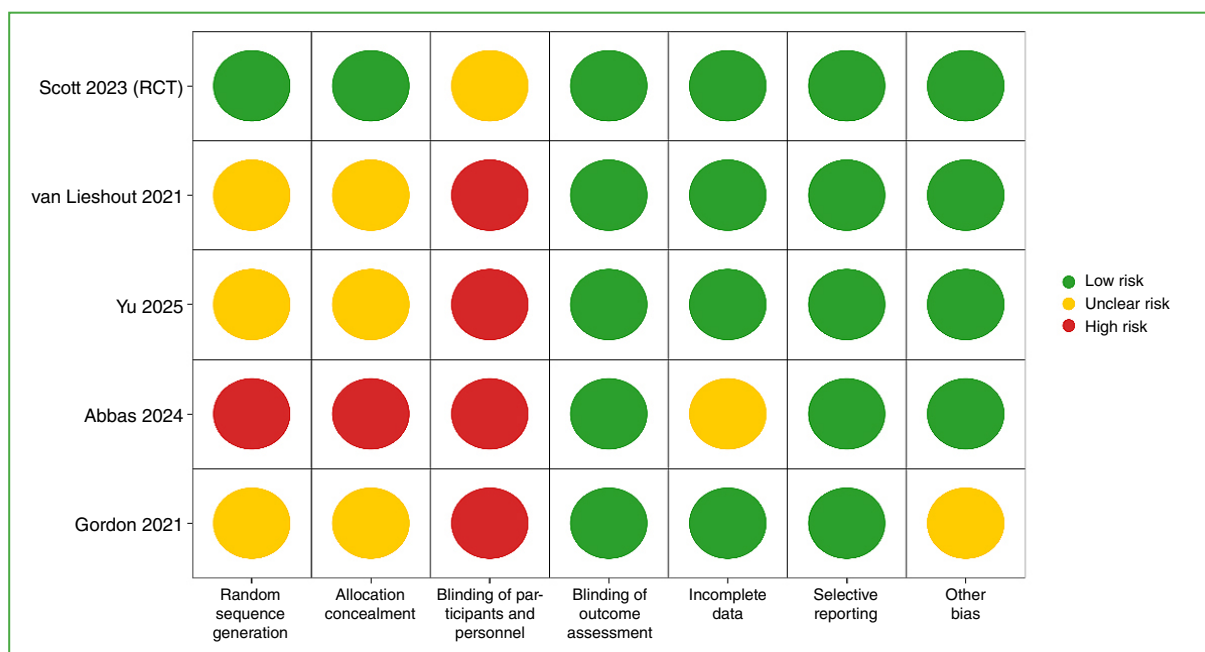


**Figure 1.** Risk of bias assessment of the included clinical studies, presented as a traffic light plot. Risk of bias domains were harmonized to allow randomized and nonrandomized studies to be assessed together. The Cochrane RoB 2 tool was used for the randomized clinical trial, and ROBINS-I/MINORS for observational studies, as appropriate. The plot does not include biomechanical, cadaveric, or computational studies.

- Biomechanical, cadaveric, and computational studies underwent a predefined qualitative assessment focusing on model validity, reproducibility, and the extent of experimental validation, as no universally accepted tool exists for these designs.

The level of evidence was also reported according to the *Oxford Centre for Evidence-Based Medicine* (OCEBM) classification, but was not used as a substitute for risk of bias assessment (Table).

## Synthesis of results

Because study designs, MFI definitions, diagnostic methods, and reported outcomes varied substantially, a quantitative meta-analysis was not possible. A structured narrative synthesis was therefore conducted, with findings organized into the following domains:

1. Evidence on the existence and definition of MFI.
2. Biomechanical and surgical risk factors.
3. Clinical, instrumented, and intraoperative diagnostic methods.
4. Preventive strategies, surgical techniques, and assistive technologies.

Areas of agreement and disagreement between clinical and biomechanical studies were highlighted, along with the main methodological limitations.

## Level of evidence of the review

According to the OCEBM classification, this systematic review provides level III evidence, as most included studies were observational, biomechanical, or experimental, with only one randomized clinical trial available.

**Table.** Methodological quality and level of evidence assessment of the included studies.

| Author (year)                            | Study type                                         | Level of evidence (OCEBM)* | Quality/risk of bias assessment       | Comments/limitations                                                        |
|------------------------------------------|----------------------------------------------------|----------------------------|---------------------------------------|-----------------------------------------------------------------------------|
| Scott and Hellie <sup>17</sup> (2023)    | Randomized clinical trial                          | Level II (1b)              | RoB 2: low–moderate risk              | Potentially incomplete blinding; limited sample size                        |
| van Lieshout et al. <sup>19</sup> (2020) | Prospective observational study                    | Level III (2b)             | ROBINS-I: moderate risk               | Nonrandomized design; potential residual confounding                        |
| Abbas et al. <sup>14</sup> (2024)        | Case series                                        | Level IV (4)               | MINORS: 14/24 (moderate quality)      | Small sample size; no control group                                         |
| Yu et al. <sup>18</sup> (2024)           | Observational case series                          | Level III (2b)             | MINORS: 15/24 (moderate quality)      | Limited follow-up; clinical heterogeneity                                   |
| Gordon et al. <sup>20</sup> (2021)       | Prospective consecutive series (robotics + sensor) | Level IV (4)               | MINORS: 16/24 (moderate–high quality) | No comparison group; potential selection bias                               |
| Wang et al. <sup>23</sup> (2008)         | Bilateral comparative biomechanical study          | Level V                    | Structured qualitative assessment     | Very small sample (n = 8); no clinical correlation                          |
| Stoddard et al. <sup>24</sup> (2013)     | Comparative <i>in vitro</i> study                  | Level V                    | Structured qualitative assessment     | Simplified experimental model; does not reproduce <i>in vivo</i> conditions |
| Incavo et al. <sup>25</sup> (2013)       | Comparative cadaveric biomechanical study          | Level V                    | Structured qualitative assessment     | Limited clinical extrapolation; small number of specimens                   |
| Luyckx et al. <sup>26</sup> (2018)       | Experimental cadaveric study + analytical model    | Level V                    | Structured qualitative assessment     | Experimental design; no direct clinical validation                          |
| Shalhoub et al. <sup>27</sup> (2018)     | Robotic cadaveric study (gap balancing)            | Level V                    | Structured qualitative assessment     | Highly controlled conditions; indirect clinical applicability               |
| Chalmers et al. <sup>16</sup> (2021)     | Experimental cadaveric study + analytical model    | Level V                    | Structured qualitative assessment     | Model-dependent results; no clinical correlation                            |
| Cross et al. <sup>15</sup> (2012)        | Robotic cadaveric study                            | Level V                    | Structured qualitative assessment     | Model does not fully reproduce physiological conditions; no clinical data   |
| Elmasry et al. <sup>28</sup> (2022)      | Computational study (biomechanical modeling)       | Level V                    | Structured qualitative assessment     | Theoretical model; limited clinical validation                              |

\*Because no universally accepted tool exists for assessing the methodological quality of biomechanical, cadaveric, or computational studies, these studies were classified as level V evidence and assessed qualitatively using a structured approach focused on model validity, reproducibility, and clinical applicability.

## RESULTS

### Study selection

The systematic search of electronic databases (PubMed, Embase, Scopus, and the Cochrane Library) identified 124 records. After removing 23 duplicates, 101 unique articles remained for initial assessment. Of these, 41 underwent formal title and abstract screening, while 60 were excluded at this stage because they were unrelated to the review topic or did not report specific data on MFI.

The 41 selected articles were assessed in full text. Twenty-eight were excluded because they did not meet the predefined eligibility criteria, mainly because they were systematic or narrative reviews, provided no primary data on MFI, used ineligible study designs, or reported overlapping results. Ultimately, 13 studies met all inclusion criteria and were included in the qualitative synthesis. The selection process is summarized in the PRISMA flow diagram (Figure 2).

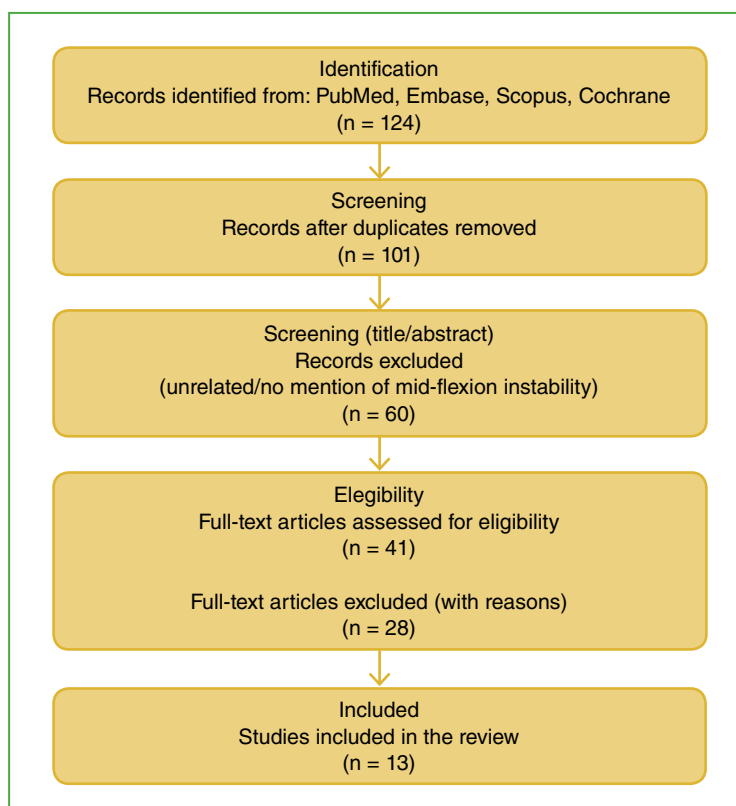


**Figure 2.** PRISMA 2020 flow diagram.

### General characteristics of the included studies

The 13 included studies, published between 2008 and 2025, investigated MFI after TKA using clinical, biomechanical, cadaveric, robotic, and computational designs. According to the OCEBM classification, most provided level IV or V evidence. Only one randomized clinical trial was identified (Scott et al.).<sup>17</sup>

From a clinical point of view, the studies by Scott et al.,<sup>17</sup> Yu et al.,<sup>18</sup> van Lieshout et al.,<sup>19</sup> Abbas et al.<sup>14</sup> and Gordon et al.<sup>20</sup> evaluated surgical factors, balancing techniques, and assistive technologies in cohorts of patients undergoing TKA. Experimental and biomechanical studies also examined how prosthetic design, the joint line, and ligament behavior influenced stability in the mid-flexion range.<sup>15,16,21-28</sup>

### Risk factors associated with MFI

Several clinical and experimental studies identified common risk factors for MFI. In the sagittal plane, anteroposterior translation  $\geq 7$  mm at 30° of flexion was identified as an independent predictor of MFI after TKA, suggesting that small variations in anterior stability may be amplified in the mid-range of motion.<sup>12,13</sup>

Changes in posterior condylar offset were another relevant determinant: alterations  $>2$  mm were associated with a significantly greater likelihood of instability, highlighting the importance of preserving native femoral geometry.<sup>12</sup> Biomechanical studies consistently found that joint line elevation  $\geq 4$  mm substantially increased mid-flexion laxity. However, some clinical studies suggested that controlled elevation of up to 2 mm could be tolerated with adequate soft tissue balancing.<sup>14-16</sup>

Preoperative ligamentous laxity and smaller implant size were also consistently identified as predisposing factors for MFI after TKA.<sup>11</sup>

### **Influence of prosthetic design**

Implant design was one of the most consistently evaluated determinants. In the only available randomized clinical trial, Scott et al.<sup>17</sup> demonstrated that medially stabilized implants provided greater anteroposterior control between  $30^\circ$  and  $60^\circ$  of flexion than posterior-stabilized designs, with a more pronounced effect in female patients. Yu et al.<sup>18</sup> reported similar findings in an observational cohort.

In a biomechanical study, Wang et al.<sup>23</sup> observed that single-radius designs were associated with greater anteroposterior control during functional activities such as sitting down and standing up, whereas multi-radius designs showed greater transient laxity between  $30^\circ$  and  $45^\circ$ . In contrast, Stoddard et al.,<sup>24</sup> found no significant differences between the two designs in cadaveric models and questioned whether femoral geometry alone was the main determinant of MFI.

### **Surgical technique and assistive technologies**

Surgical technique also significantly influenced mid-flexion stability. Comparative studies found that flexion-first balancing was associated with less mid-range laxity than conventional measured resection.<sup>29,30</sup>

Regarding assistive technologies, Gordon et al.<sup>20</sup> evaluated a clinical cohort undergoing robot-assisted TKA with intraoperative load sensors. They observed a measurable improvement in stability, with 87% of knees balanced throughout the range of motion, including mid-flexion. However, experimental robotic and cadaveric studies demonstrated that residual mid-range laxity of 2–4 mm persisted even with assisted planning and adequate balancing in extension and at  $90^\circ$  of flexion.<sup>27</sup>

The computational model developed by Elmasry et al.<sup>28</sup> supported these findings, showing that more constrained inserts could reduce axial rotation without fully eliminating the coronal laxity characteristic of MFI.

### **Biomechanical and experimental evidence**

Cadaveric and biomechanical studies provided consistent evidence of the effects of small anatomical variations. Cross et al.,<sup>15</sup> Chalmers et al.,<sup>16</sup> Incavo et al.<sup>25</sup> and Luyckx et al.<sup>26</sup> demonstrated that raising the joint line by just 2–4 mm significantly increased coronal laxity between  $30^\circ$  and  $70^\circ$  of flexion, even in knees adequately balanced in extension and deep flexion.

Luyckx et al.<sup>26</sup> measured a 60%–110% increase in mid-flexion coronal laxity after joint line elevation, while Shalhoub et al.<sup>27</sup> documented persistent mid-range instability in robot-assisted TKA using a gap-balancing technique. These findings suggest that MFI depends not only on prosthetic design but also on joint line height and the isometric behavior of the capsuloligamentous structures.

### **Overall synthesis of findings**

Taken together, the included studies indicate that MFI is a multifactorial phenomenon arising from the interaction between anatomical factors, prosthetic design, surgical technique, and ligament balance. Clinical and experimental evidence consistently shows that even apparently well-balanced knees may exhibit dynamic instability between  $30^\circ$  and  $60^\circ$  of flexion. This explains the diagnostic challenges and variability in reported outcomes.

## Level and quality of evidence

The overall methodological quality of the included studies was low to moderate. The only randomized clinical trial provided level II evidence,<sup>17</sup> while observational studies were classified as level III or IV, and biomechanical, cadaveric, and computational studies as level V. MFI definitions, diagnostic methods, and assessed outcomes varied substantially across studies, limiting the feasibility of a quantitative meta-analysis.

## DISCUSSION

The findings of this systematic review indicate that MFI after TKA is a reproducible and clinically relevant biomechanical phenomenon that remains underrecognized. Although some authors have questioned its existence as a distinct entity, considering it a variant of conventional flexion instability,<sup>9</sup> the clinical, biomechanical, and experimental evidence reviewed here supports a specific pattern of instability characterized by symptomatic laxity predominantly between 30° and 60° of flexion, with relative stability preserved in full extension and deep flexion.

The findings support a clearly multifactorial pathophysiological model. MFI does not appear to result from a single technical error or implant design alone, but from the interaction between patient-related predisposing factors, surgical variables, and prosthetic characteristics. Preoperative ligamentous laxity, changes in posterior condylar offset >2 mm, and excessive joint line elevation (≥4 mm) emerge as critical determinants that can destabilize the knee in its most vulnerable functional range.<sup>12-16,26</sup> Anteroposterior translation ≥7 mm at 30° of flexion should therefore be interpreted as a “quantifiable marker” of an underlying biomechanical imbalance rather than an isolated causal factor.

Prosthetic design plays a central role in modulating this interaction. The greater stability observed with medially stabilized implants in the only available randomized clinical trial<sup>17</sup> and confirmed in contemporary observational studies<sup>19</sup> may reflect their ability to reproduce more physiological kinematics, with a stable medial pivot and progressive control of lateral rotation. This explanation is consistent with earlier observations summarized in narrative and systematic reviews, which suggested biomechanical advantages of medial-pivot or highly medially congruent designs over standard posterior-stabilized (PS) designs.<sup>11,12,20</sup> Similarly, cruciate-retaining prostheses combined with medially congruent inserts have been proposed to provide better mid-flexion control than conventional PS systems.<sup>31</sup>

Nevertheless, the biomechanical and experimental findings caution against focusing exclusively on implant geometry. Comparisons of single-radius and multi-radius designs have yielded conflicting results,<sup>23,24</sup> suggesting that MFI depends not only on femoral geometry but also on how it interacts with ligament balance and restoration of joint line height. This view is consistent with previous conceptual reviews emphasizing that MFI is primarily a problem of ligament isometry rather than prosthetic design alone.<sup>9,10,18</sup>

Surgical technique is therefore a key element in preventing MFI. Approaches that prioritize flexion balancing, such as flexion-first balancing, have produced more stable knees in the mid-range than conventional measured resection techniques.<sup>19,29</sup> Earlier narrative reviews had already highlighted this technical principle as an important conceptual shift in modern joint replacement surgery.<sup>11,12</sup> The evidence suggests that perfectly symmetrical gaps in extension and at 90° do not guarantee functional stability in mid-flexion, and that even “well-balanced” knees may exhibit clinically significant dynamic laxity.

Assistive technologies add another dimension to this issue. Clinical and experimental studies have shown that robotic surgery combined with intraoperative load sensors allows mid-flexion laxity to be quantified and reduced.<sup>27,28</sup> However, the persistence of residual laxity of 2–4 mm, even in highly controlled systems, suggests an inherent anatomical and viscoelastic component that cannot be fully eliminated through technical adjustments. Computational models have supported this hypothesis, showing that greater prosthetic constraint can reduce axial rotation without eliminating the coronal laxity characteristic of MFI.<sup>28</sup> These observations agree with earlier analyses that noted the limitations of technology in compensating for subtle anatomical alterations.<sup>20</sup>

These findings have important implications for clinical practice. Intraoperative stability assessment should routinely include the range between 30° and 60° of flexion, using targeted manual maneuvers or, ideally, instrumented devices. In patients considered at high risk, such as women, those with preoperative ligamentous laxity,

or those requiring extensive distal resections, choosing implants with greater inherent mid-flexion stability and avoiding standard PS designs may be justified. Robotic surgery and kinematic alignment approaches have also been proposed as promising strategies for optimizing anatomical restoration and ligament balance, although definitive clinical evidence remains limited.<sup>26,32-36</sup>

The true incidence of MFI remains difficult to establish. Large national registries, such as the UK *National Joint Registry* and the *Australian Orthopaedic Association National Joint Replacement Registry*, group revisions for instability into a broad category accounting for approximately 17%–18% of all TKA revisions.<sup>37,38</sup> Without a specific MFI category, its actual impact is difficult to quantify. Nevertheless, growing recognition of the phenomenon in the medical literature suggests that a substantial proportion of revisions broadly classified as “instability” may involve unrecognized MFI.

This review has several strengths, including a comprehensive and up-to-date search, adherence to PRISMA guidelines, and the integration of clinical, biomechanical, and computational evidence. However, its conclusions should be interpreted in light of important limitations: the predominance of studies providing low- to moderate-level evidence, heterogeneity in MFI definitions, and the lack of standardized diagnostic criteria. These limitations highlight the need for well-designed randomized clinical trials, clinical validation of specific diagnostic tools, and registries that recognize MFI as a distinct reason for revision. These efforts are necessary to define the true clinical impact of MFI after TKA more precisely.

## CONCLUSIONS

This systematic review supports MFI as a distinct clinical entity and a potentially important cause of failure after TKA. The available evidence suggests a multifactorial etiopathogenic model in which technical factors—particularly joint line elevation >2–4 mm and changes in posterior condylar offset—combine with preoperative ligamentous laxity and an inappropriate choice of prosthetic design to produce symptomatic laxity between 30° and 60° of flexion.

Preventing MFI requires a comprehensive approach that prioritizes: 1) systematic intraoperative assessment of mid-flexion stability, ideally using instrumented tools; 2) selection of implants with greater inherent stability in this range, such as medially stabilized designs; and 3) consideration of assistive technologies, such as robotic surgery, to improve the precision of ligament balancing. Standardized diagnostic criteria and higher-quality clinical evidence are also essential to establish the true incidence of this complication and rigorously validate the proposed preventive strategies.

## Use of artificial intelligence

During the preparation of this manuscript, the author(s) used ChatGPT to improve readability and language. After using this tool, they reviewed and edited the content as needed and take full responsibility for the content of the publication.

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Conflicts of interest: The authors declare no conflicts of interest.

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