Factors influencing the outcomes of minimally invasive total hip arthroplasty: a systematic review

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Abstract
Introduction: The present systematic review investigated possible factors which may influence the surgical outcome of minimally invasive surgery for total hip arthroplasty (MIS THA).
Methods: In January 2022, the Embase, Google Scholar, PubMed, and Scopus databases were accessed. All the clinical trials investigating the clinical outcome of MIS THA were considered.
Results: Data from 9486 procedures were collected. Older age was moderately associated with greater Visual Analogue Scale (VAS) (P = 0.02) and Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) (P = 0.009) at last follow-up, and shorter surgical duration (P = 0.01). Greater body mass index (BMI) at baseline was moderately associated with greater cup anteversion (P = 0.0009), Oxford Hip Score (OHS) at last follow-up (P = 0.04), longer surgical duration (P = 0.04), increased leg length discrepancy (P = 0.02), and greater rate of infection (P = 0.04). Greater VAS at baseline was weakly associated with greater VAS at last follow-up (P < 0.0001), total estimated blood loss (P = 0.01), and lower value of Harris Hip Score (HHS) (P = 0.0005). Greater OHS at baseline was associated with greater post-operative VAS (P = 0.01). Greater WOMAC at baseline was associated with lower cup anteversion (P = 0.009) and greater VAS (P = 0.02). Greater HHS at baseline was associated with shorter hospitalisation (P = 0.001).
Conclusion: Older age and greater BMI may represent negative prognostic factors for MIS THA. The clinical outcome is strongly influenced by the preoperative status of patients.
Keywords: Hip, Arthroplasty, Replacement, Minimally invasive

Introduction
Minimally invasive surgery (MIS) for total hip arthroplasty (THA) has become popular [1]. The definition of MIS in THA is controversial. Currently, MIS surgery refers to a tissue sparring approach [2]; [3]. During the last decade, a variety of MIS approaches have been described. MIS THA has been introduced in an effort to speed recovery and decrease the length of hospitalisation [4–11]. MIS THA has been advocated to reduce the length of the surgical procedure, quadriceps damage, and the total estimated blood loss [12–16]. MIS THA can be performed in a single incision using the posterior [15]; [17], lateral [18]; [19], anterolateral [20] and anterior approach [21]. Also, multiple incisions MIS THA procedures have been described, such as the two-incision approach [22]; [23], and the minimally invasive anterior approach with accessory incision [21]. However, based on current available evidence, there are no clinically relevant benefits of MIS THA over traditional approaches.
in terms of functional outcome and components orientation, and MIS THA carries high rate of complications [12]; [15]; [24]; [25]. Nevertheless, MIS THA remains of special interest of patients and surgeons. To date, though the current literature includes several thousands of scientific reports, there is paucity of evidence concerning the role of prognostic factors for MIS THA. The goal of the present study was to investigate potential associations between the patient characteristics at admission, peri-operative data, imaging findings, and the clinical and functional outcome, and complications. A multiple linear regression analysis was conducted to identify possible prognostic factors which may influence the clinical outcome.

Material and methods
Search strategy
This systematic review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) [26]. The PICO algorithm was preliminarily set out:

- P (Population): end-stage OA;
- I (Intervention): MIS THA;
- C (Comparison): patients characteristics at admission;
- O (Outcomes): PROMs, radiological findings, complications;

Data source and extraction
Two authors (F.M. and A.P.) independently performed the literature search in January 2022 accessing the following databases: PubMed, Google Scholar, Embase, and Scopus. The following keywords were used and combined for the search: hip, total, arthroplasty, replacement, prosthesis, instrumentation, surgery, intervention, BMI, age, sex. The resulting abstracts were screened by the two authors and, if of interest, the full-text was accessed. The bibliographies were also screened by hand. Disagreement was debated and solved by the senior author (N.M.).

Eligibility criteria
All the clinical trials investigating the outcomes of MIS THA were accessed. Only studies comparing traditional versus MIS THA approaches were considered eligible. Given the authors languages capabilities, articles in English, German, Italian, French and Spanish were eligible. Only levels I to III of evidence, according to the Oxford Centre of Evidence-Based Medicine [27], were eligible. Reviews, letters, opinions, editorials, and technical notes were not considered, nor were abstracts and national registries. Animal, computational, biomechanics, cadaveric studies were not eligible. Studies reporting results from experimental surgeries and/or pre- and/or post-operative protocols were not included. Only articles reporting quantitative data under the outcomes of interest were considered for inclusion. Missing data under the outcomes of interest warranted the exclusion from this study.

Outcomes of interest
Two authors (F.M. and A.P.) independently performed data extraction. Study generalities (author, year, journal, study design, length of the follow-up) were collected. Data concerning the following endpoints at baseline were collected:

- Patient demographics: number of procedures, mean BMI and age, percentage of female;
- PROMs: Visual Analogue Scale (VAS), Oxford Hip Score (OHS), The Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), Harris Hip Score (HHS).

Methodology quality assessment
The methodological quality assessment was made by two independent reviewers (F.M. and A.P.). The risk of bias graph tool of the Review Manager Software 5.3 (The Nordic Cochrane Collaboration, Copenhagen) was used. The following risk of bias was assessed for each included study: selection, detection, attrition, reporting, and other source of bias.

Statistical analysis
The statistical analyses were performed by the main author (F.M.). For the analytical statistics, STATA MP 16 software (StataCorp, College Station, TX) was used. The Shapiro–Wilk test was performed to investigate
data distribution. For normal data, mean and standard deviation (SD) were calculated. For nonparametric data, median and interquartile range (IQR) were calculated. A multivariate analysis was performed through a multiple pairwise correlations according to the Pearson product-moment correlation coefficient (r). According to the Cauchy–Schwarz inequality, the final effect ranks between 1 (positive linear correlation) and −1 (negative linear correlation). Values of 0.1 < |r| < 0.3 and 0.3 < |r| < 0.5 and |r| > 0.5 were considered to have poor, moderate and strong correlation, respectively. Potential associations between one the endpoints and the outcomes of interest were evaluated singularly for each endpoint. Overall significance was evaluated using the χ² test, with values of P > 0.05 considered statistically significant.

Results
Search result
The literature search resulted in 684 articles. Of them, 277 were excluded because they were duplicates. A further 297 articles were excluded since they did not match our eligibility criteria. Another 36 articles were not included because they did not report quantitative data under the outcomes of interest. This left 74 studies for the present study: 33 randomised, 29 prospective, and 17 retrospective studies. The literature search results are shown in Fig. 1.

Methodological quality assessment
The risk of bias summary evidenced some limitations of the present study. Approximately half of the studies were randomised, and approximately one fifth were retrospective. This leads to a moderate risk of selection bias. Given the overall lack of blinding, the risk of detection bias was moderate-high. The authors’ judgements about the risk of attrition, reporting and other bias presented across all included studies was moderate. Concluding, the overall risk of bias was moderate, attesting to this study good quality assessment (Fig. 2).

Patient demographics
Data from 9626 procedures were collected. 57% (5487 of 9626 patients) were women. The median follow-up was 12 (IQR 9) months. The mean age was 63.0 (SD 4.9), the mean BMI 27.1 (SD 2.3) kg/m². Generalities and patient baseline of the included studies are shown in Table 1.

Outcomes of interest
Female gender was strongly associated with lower cup anteversion (r = −0.52; P = 0.0002). Older age was moderately associated with reduced surgical time (r = −0.28; P = 0.01), and with greater VAS (r = 0.42; P = 0.02) and WOMAC scores (r = 0.52; P = 0.009) at last follow-up. Greater BMI at baseline was associated with greater cup anteversion (r = 0.47; P = 0.0009), greater OHS at last follow-up (r = 0.47; P = 0.04), longer surgical duration (r = 0.20; P = 0.04), greater leg length discrepancy (r = 0.47; P = 0.02), and greater rate of deep infection (r = 0.44; P = 0.04). Greater VAS at baseline was associated with greater VAS at last follow-up (r = 0.98; P < 0.0001), greater overall estimated blood lost (r = 0.11; P = 0.01), and lower value of HHS (r = −0.98; P = 0.0005). Greater OHS at baseline was associated with post-operative greater VAS (r = 0.88; P = 0.01). Greater WOMAC at baseline was associated with lower cup anteversion (r = 0.89; P = 0.009) and greater VAS at last follow-up (r = 0.88; P = 0.02). Greater HHS at baseline was associated with shorter hospitalisation (r = 0.50; P = 0.001). No other statically significant associations were evidenced. The results of the multivariate analyses are shown in greater detail in Table 2.

Discussion
According to the main findings of this systematic review, older age and greater BMI were negative prognostic factors for the outcome of MIS THA. The analyses of the PROMs suggested that the clinical outcome is strongly related to the preoperative status of the patient.

The role of age is controversial. Previous studies observed greater improvements in pain and function after THA in older patients [28–32], while others demonstrated no substantially better clinical outcome [33–35]. Muscle trauma in older patients via MIS approach should be minimised to improve the functional outcome [36]; [37]. The greater rates of complication and overall worse outcome in patients with BMI exceeding 30 kg/m² has been extensively investigated. The negative influence of obesity for THA was likewise demonstrated by previous studies [38–42]. Lower PROMs scores, longer hospitalisation, greater blood loss, higher rate of wound complications, deep venous thrombosis, and infection are the most common complications [38–42]. The reduced access to the operative field, extensive bleeding surfaces, and greater force of retraction do not seem to have relevant influence in terms of component malpositioning, prolonged operative times, and higher intraoperative blood loss in obese patients during MIS THA [43–45]. Timing of mobilisation, length of hospitalisation, and functional outcome were similar between obese and non-obese patients [45], and obese patients should be strongly encouraged to lose weight prior to THA. However, it has been hypothesised that only bariatric surgery in obese patients before arthroplasty could realistically cut down complications [46–51]. Female gender was strongly associated with lower cup anteversion. However, the native anteversion of the femoral neck differs between males.
and females, with a physiological mean acetabular anteversion of approximately 16° and 12.5°, respectively [52]; [53]. Gender-specific anatomical differences increase data variability and may lead to inconsistency in results. Furthermore, to investigate the cup anteverision malpositioning, the acetabular inclination angle must also be considered [54]. MIS THA has been advocated to reduce consumption of pain medications [15]; [55]. High postoperative pain negatively influences the clinical outcome and predisposes to chronic pain [56]. Greater postoperative pain and the fear of it may lead to immobility and delayed post-operative rehabilitation [57]; [58]. The reduced surgical incision and tissues trauma may reduce pain and the blood loss and represent the main motivation to opt for a MIS approach [2]; [12]; [59]. However, previous studies did not evidence clinically relevant difference between standard and MIS THA in pain and total estimated blood lost [2]; [12]; [59]. The reduced damage to the tissues of the MIS approaches has been advocated to improve functional outcomes, and inflammation markers have been employed to evaluate soft tissue damage [60]; [61]. Recent evidence showed no significant differences in serum markers of muscle damage and inflammation between minimally and standard THA.
### Table 1  Generalities and patients baseline of the included studies

| Author          | Journal                  | Design       | Follow up (months) | Procedures (n) | Women (%) | Mean age | Mean BMI | Approach        |
|-----------------|--------------------------|--------------|-------------------|----------------|-----------|----------|----------|-----------------|
| Abdel et al. [7] | Arthroplasty             | Randomised   | 102.0             | 36             | 44.4      | 66.0     | 30.0     | P MIS           |
|                 |                          |              |                   | 35             | 45.7      | 66.0     | 30.0     | 2 incision      |
| Alecci et al. [82] | J Orthop Traumatol      | Retrospective | 0.5               | 221            | 54.8      | 70.7     |          | A MIS           |
| Barrett et al. [83] | Arthroplasty            | Randomised   | 12.0              | 43             | 32.6      | 61.4     | 30.7     | A               |
| Bennett et al. [11] | Arthroplasty            | Prospective  | 12.0              | 43             | 58.1      | 66.1     | 29.6     | Minimal invasive|
| Berend et al. [84] | Bone Joint Surg         | Randomised   | 1.5               | 258            | 56.4      | 63.0     | 28.9     | A (ASI)         |
| Bergin et al. [60] | Bone Joint Surg         | Prospective  | 1.0               | 29             | 66.0      | 68.8     | 26.3     | A               |
| Berstock et al. [85] | J Othopaedics           | Retrospective | 37.0             | 116            | 56.0      | 71.4     |          | L OMEGA         |
| Biau et al. [86] | Int Orthop               | Randomised   | 0.3               | 105            | 56.2      | 68.0     | 25.0     | P MIS           |
| Chen et al. [87]  | Arthroplasty             | Retrospective | 24.0             | 83             | 44.6      | 53.5     | 24.5     | MIS-2 THA       |
| Cheng et al. [88] | Arthroplasty             | Randomised   | 3.0               | 35             | 57.0      | 59.0     | 27.7     | A               |
| Chimento et al. [13] | Arthroplasty            | Randomised   | 24.0              | 28             | 42.9      | 67.2     | 25.2     | 8 cm incision   |
| Della Valle et al. [89] | Clin Orthop Rel Res    | Randomised   | 12.0              | 35             | 68.6      | 63.8     | 27.3     | P MIS           |
| Dienstknecht et al. [14] | J Orthop Surg         | Randomised   | 3.0               | 55             | 60.0      | 61.9     | 27.6     | A MIS           |
| DiGioia et al. [90] | Arthroplasty             | Prospective  | 12.0              | 33             | 57.6      | 65.0     | 27.0     | Mini-incision   |
| Dorr et al. [15]  | Bone Joint Surg         | Randomised   | 6.0               | 30             | 43.3      | 70.3     | 27.6     | Mini-incision   |

*Fig. 2* Methodological quality assessment
| Author                  | Journal                                      | Design         | Follow up (months) | Procedures (n) | Women (%) | Mean age | Mean BMI | Approach                      |
|-------------------------|----------------------------------------------|----------------|-------------------|----------------|-----------|----------|----------|-------------------------------|
| Downing et al. [91]     | Acta Orthop Scand                            | Prospective    | 12.0              | 49             | 51.0      | 67.0     | P        |                               |
|                         |                                              |                |                   | 51             | 58.8      | 65.0     | L        |                               |
| Engdal et al. [92]      | Am J Phys Med Rehab                         | Prospective    | 0.2               | 21             | 61.9      | 56.8     | 25.8     | L                             |
|                         |                                              |                |                   | 19             | 42.1      | 55.5     | 26.7     | P                             |
|                         |                                              |                |                   | 20             | 75.0      | 56.4     | 25.8     | A                             |
| Fink et al. [93]        | Orthopäde                                   | Prospective    | 1.5               | 50             | 54.0      | 71.5     | 28.0     | PL                            |
|                         |                                              |                |                   | 50             | 50.0      | 71.9     | 27.0     | Mini-posterior                |
| Fransen et al. [94]     | Acta Orthop Belg                             | Retrospective  | 12.0              | 38             | 62.9      | 62.6     | 27.6     | PL                            |
|                         |                                              |                |                   | 45             | 66.7      | 64.2     | 25.0     |                              |
| Goebel et al. [55]      | Int Orthop                                  | Retrospective  | 3.0               | 100            | 53.0      | 64.5     | 26.7     | Minimal A                     |
|                         |                                              |                |                   | 100            | 58.0      | 67.0     | 28.6     | L                             |
| Goosen et al. [95]      | Clin Orthop Rel Rev                         | Randomised     | 12.0              | 30             | 50.0      | 60.0     | 26.7     | AL MIS                        |
|                         |                                              |                |                   | 30             | 56.7      | 62.0     | 26.8     | PL                            |
|                         |                                              |                |                   | 30             | 50.0      | 60.0     | 26.4     | PL MIS                        |
|                         |                                              |                |                   | 30             | 46.7      | 62.0     | 26.1     | AL                            |
| Hananouchi et al. [96]  | Int J Med Robotics Comput Assist Surg        | Prospective    | 12.0              | 20             | 90.0      | 55.1     | 22.2     | A MIS                         |
|                         |                                              |                |                   | 20             | 90.0      | 57.0     | 21.0     | P MIS                         |
| Howell et al. [96]      | Orthop Clin N Am                             | Prospective    | 0.5               | 50             | 32.0      | 59.8     | 26.2     | MIS-AL                        |
|                         |                                              |                |                   | 57             | 52.6      | 62.3     | 28.8     | AL                            |
| Ilchmann et al. [97]    | Orthop Rev                                  | Prospective    | 24.0              | 142            | 47.0      | 70.0     | 27.4     | L                             |
|                         |                                              |                |                   | 113            | 47.0      | 70.0     | 27.4     |                              |
| Ji et al. [98]          | Arthroplasty Today                           | Prospective    | 37.9              | 99             | 45.5      | 51.0     | 24.3     | P                             |
|                         |                                              |                |                   | 97             | 40.2      | 52.0     | 24.3     | L                             |
| Joseph et al. [99]      | Arthroplasty Today                           | Prospective    | 6.0               | 98             | 54.1      | 61.1     | 30.4     | A                             |
|                         |                                              |                |                   | 69             | 50.7      | 62.9     | 30.7     | P                             |
| Khan et al. [100]       | Bone Joint Surg                             | Randomised     | 24.0              | 52             | 63.5      | 72.8     | 28.9     | P                             |
|                         |                                              |                |                   | 48             | 50.0      | 72.3     | 28.5     | Piriformis-sparing             |
| Ki et al. [101]         | Clin Orthop Surg                            | Retrospective  | 51.5              | 34             | 38.2      | 61.0     | 22.3     | PL MIS                        |
|                         |                                              |                |                   | 26             | 26.9      | 57.5     | 21.6     | 2 incision                    |
| Kim et al. [102]        | Arthroplasty                                 | Randomised     | 26.4              | 35             | 24.3      | 55.6     | 25.6     | PL MIS                        |
|                         |                                              |                |                   | 35             | 24.3      | 55.6     | 25.6     | PL                            |
| Kiyama et al. [103]     | Arthroplasty                                 | Randomised     | 6.0               | 10             | 90.0      | 60.3     | 23.4     | PL MIS                        |
|                         |                                              |                |                   | 10             | 80.0      | 63.8     | 23.5     | PL                            |
| Krych et al. [104]      | Clin Orthop Rel Rev                         | Randomised     | 1.5               | 10             | 38.1      | 63.0     | 30.0     | P MIS                         |
|                         |                                              |                |                   | 11             | 38.1      | 63.0     | 30.0     | 2 incision                    |
| Laffosse et al. [105]   | Rev Chir Orthop                             | Prospective    | 6.0               | 58             | 39.7      | 55.0     | 25.0     | AL MIS                        |
|                         |                                              |                |                   | 58             | 43.1      | 59.7     | 26.2     | P                             |
| Laffosse et al. [106]   | Arch Orthop Trauma Surg                     | Prospective    | 6.0               | 33             | 39.4      | 56.8     | 25.9     | AL MIS                        |
|                         |                                              |                |                   | 43             | 34.9      | 55.7     | 25.2     | P MIS                         |
| Leuchte et al. [107]    | Z'Orthop                                    | Retrospective  | 7.0               | 16             | 59.7      | 26.7     | AL MIS                        |
|                         |                                              |                |                   | 16             | 62.6      | 28.6     | L                             |
| Lawlor et al. [108]     | Clin Rehab                                  | Randomised     | 1.5               | 109            | 55.0      | 67.4     | 28.2     | P MIS                         |
|                         |                                              |                |                   | 110            | 47.3      | 65.9     | 28.9     |                              |
| Malek et al. [109]      | Bone Joint Surg                             | Retrospective  | 18.1              | 265            | 55.8      | 70.8     | 28.5     | A                             |
|                         |                                              |                |                   | 183            | 53.0      | 70.0     | 29.0     | P                             |
| Martin et al. [110]     | Arthroplasty                                 | Randomised     | 12.0              | 42             | 71.4      | 66.7     | 30.6     | AL MIS                        |
|                         |                                              |                |                   | 41             | 65.9      | 63.1     | 29.4     | L                             |
Table 1 (continued)

| Author          | Journal                     | Design            | Follow up (months) | Procedures (n) | Women (%) | Mean age | Mean BMI | Approach |
|-----------------|-----------------------------|-------------------|--------------------|----------------|-----------|----------|----------|----------|
| Martin et al. [111] | Arthroplasty                | Retrospective     | 6.0                | 47             | 65.0      | 63.0     | 28.5     | A        |
|                 |                             |                   |                    | 41             | 55.0      | 57.0     | 34.1     | P        |
| Mazoochian et al. [112] | Arch Orthop Trauma Surg | Randomised Prospective | 3.0              | 26             | 56.0      | 26.6     | LA MIS   |
|                 |                             |                   |                    | 26             | 65.4      | 26.4     | LAV/ Bauer|
| Migliorini et al. [113] | Surgeon                   | Restrospective    | 24                 | 70             | 78.6      | 67.2     | 26.9     | AL MIS   |
|                 |                             |                   |                    | 70             | 84.3      | 66.1     | 27.6     | AL       |
| Mjaaland et al. [114] | Clin. Ortho Rel Reas     | Randomised        | 24.0               | 84             | 70.0      | 67.0     | 28.0     | A        |
|                 |                             |                   |                    | 80             | 62.0      | 66.0     | 28.0     | L        |
| Müller et al. [115] | Arch Orthop Trauma Surg   | Randomised        | 12.0               | 24             | 50.0      | 66.0     | 28.0     | AL MIS   |
|                 |                             |                   |                    | 20             | 60.0      | 64.0     | 26.0     | L        |
| Nakata et al. [116] | Arthroplasty                | Retrospective     | 12.0               | 99             | 83.8      | 62.9     | 22.9     | A        |
|                 |                             |                   |                    | 96             | 86.5      | 65.6     | 23.3     | P MIS    |
| Ogonda et al. [9] | Bone Joint Surg            | Randomised        | 1.5                | 109            | 55.0      | 67.4     | 28.2     | P MIS    |
|                 |                             |                   |                    | 110            | 47.3      | 65.9     | 28.9     | P        |
| Palan et al. [117] | Clin Orthop Rel Res       | Prospective       | 60.0               | 699            | 60.9      | 68.4     | 27.5     | AL       |
|                 |                             |                   |                    | 390            | 64.1      | 67.4     | 27.0     | P        |
| Petis et al. [118] | Arthroplasty                | Prospective       | 0.1                | 40             | 62.5      | 66.9     | 27.9     | A        |
|                 |                             |                   |                    | 40             | 65.0      | 66.7     | 28.2     | P        |
|                 |                             |                   |                    | 40             | 65.0      | 65.5     | 29.1     | L        |
|                |                            |                   |                    |                |           |          |          |          |
| Poehling-Monaghan et al. [63] | Clin Orth Rel Res | Prospective       | 2.0                | 50             | 48.0      | 63.0     | 31.0     | A        |
|                 |                             |                   |                    | 50             | 56.0      | 63.0     | 30.0     | P MIS    |
| Pogliacomi et al. [119] | Hip Int                   | Retrospective     | 12.0               | 30             | 53.3      | 68.6     | 27.3     | L        |
|                 |                             |                   |                    | 30             | 50.0      | 67.7     | 27.0     | A MIS    |
| Pospischill et al. [3] | Bone Joint Surg          | Randomised        | 3.0                | 20             | 60.0      | 61.9     | 25.7     | AL MIS   |
|                 |                             |                   |                    | 20             | 40.0      | 60.6     | 25.7     | L        |
| Queen et al. [120] | Arthroplasty                | Prospective       | 12.0               | 10             | n.a       | 60.0     | 26.6     | Direct lateral |
|                 |                             |                   |                    | 10             | n.a       | 57.0     | 26.3     | P        |
|                 |                             |                   |                    | 10             | n.a       | 57.6     | 28.8     | AL       |
| Radoic et al. [121] | Int Orthop                 | Prospective       | 6.0                | 21             | 61.9      | 60.9     | 25.9     | DA       |
|                 |                             |                   |                    | 21             | 61.9      | 60.9     | 25.9     | P        |
| Rathod et al. [122] | Arthroplasty                | Retrospective     | 12.0               | 11             | 45.5      | 58.0     | 25.4     | P        |
|                 |                             |                   |                    | 11             | 45.5      | 61.8     | 25.4     | P        |
| Reichert et al. [123] | BMC Musculoskeletal Disorders | Randomised Prospective  | 12.0          | 73             | 43.8      | 62.5     | 28.3     | A        |
|                 |                             |                   |                    | 50             | 52.0      | 62.2     | 28.7     | P        |
| Rittmeister et al. [124] | Orthopäde                 | Retrospective     | 0.2                | 76             | 69.7      | 60.0     | 28.0     | P MIS    |
|                 |                             |                   |                    | 76             | 69.7      | 65.0     | 27.0     | AL       |
| Rodriguez et al. [125] | Clin Orth Related Res   | Prospective       | 12.0               | 60             | 53.3      | 60.0     | 27.0     | A        |
|                 |                             |                   |                    | 60             | 56.7      | 59.0     | 28.0     | P        |
| Rosenlund et al. [126] | Acta Orthop                | Randomised        | 12.0               | 38             | 31.6      | 60.0     | 27.0     | L        |
|                 |                             |                   |                    | 39             | 33.3      | 62.0     | 28.0     | P        |
| Rykov et al. [61] | Arthroplasty                | Randomised        | 1.5                | 23             | 65.2      | 62.8     | 29.0     | A        |
|                 |                             |                   |                    | 23             | 52.2      | 60.2     | 29.3     | PL       |
| Schleicher et al. [127] | Acta Orthop                | Prospective       | 6.0                | 64             | 68.7      | 69.1     | 28.8     | L        |
|                 |                             |                   |                    | 64             | 75.0      | 68.3     | 27.1     | P MIS    |
| Sendtner et al. [128] | Arch Orthop Trauma Surg   | Prospective       | 12.0               | 74             | 32.4      | 68.1     | 28.8     | A MIS    |
|                 |                             |                   |                    | 60             | 30.0      | 67.9     | 29.1     | L (Bauer) |
The present systematic review certainly has limitations. The current published literature lacks high-quality studies which analysed the influence of prognostic factors for MIS THA, and the limited number of included studies represent an important limitation. Several studies (277 of 683, 41%) were excluded for redundancy. To improve data pooling, both prospective and retrospective studies were included in the analysis, which inevitably increases the risk of selection bias. A limitation of this study is represented by the relative short length of the mean follow-up. Half of studies were randomised, but, given the overall lack of blinding methods, the risk of detection bias was moderate-high. Furthermore, the different approaches for THA were not considered separately, nor were the different implant designs [64–81]. Given these limitations, data from the present study must be interpreted with caution. Strengths of this work were the study size, the description of diagnosis and surgical techniques which were stated and adequate. Another strength of the present systematic review is the comprehensive nature of the literature search and rigorous assessment of methodological quality of the current available data.
Table 2  Overall results of the multivariate analyses

|                          | Sex—baseline | Age—baseline | BMI—baseline | VAS—baseline | OHS—baseline | WOMAC—baseline | HHS—baseline |
|--------------------------|--------------|--------------|--------------|--------------|--------------|----------------|--------------|
|                          | r            | P            | r            | P            | r            | P              | r            | P            | r            | P            |
| Cup inclination          | −0.16        | 0.2          | −0.05        | 0.7          | −0.15        | 0.2            | 0.45         | 0.5          | −0.32        | 0.3          | −0.23         | 0.5          | −0.02         | 0.9          |
| Cup anteverision         | −0.53        | 0.0002       | 0.20         | 0.2          | 0.47         | 0.001          | 1.00         | 1.0          | 0.04         | 0.9          | −0.89         | 0.009         | 0.07          | 0.8          |
| Stem alignment           | −0.04        | 0.9          | −0.15        | 0.5          | −0.07        | 0.7            | 0.29         | 0.4          | −0.81        | 0.1          | −0.39         | 0.2          | −0.39         | 0.2          |
| VAS                      | −0.26        | 0.2          | 0.42         | 0.02         | 0.17         | 0.4            | 0.98         | 0.0001       | 0.88         | 0.01         | 0.88          | 0.02          | 0.16          | 0.5          |
| OHS                      | −0.06        | 0.8          | 0.52         | 0.009        | 0.47         | 0.04           | −0.20        | 0.5          | 0.91         | 0.1          | −0.57         | 0.1          | −0.57         | 0.1          |
| WOMAC                    | 0.04         | 0.9          | −0.47        | 0.1          | −0.45        | 0.1            | 0.65         | 0.1          | 0.75         | 0.1          | 0.81          | 0.3          | 0.81          | 0.3          |
| HHS                      | −0.08        | 0.5          | −0.28        | 0.01         | −0.01        | 0.9            | −0.98        | 0.0005       | −0.34        | 0.3          | −0.66         | 0.1          | 0.36          | 0.05         |
| Surgical time            | 0.07         | 0.5          | −0.19        | 0.1          | 0.20         | 0.04           | 0.65         | 0.1          | −0.03        | 0.9          | 0.53          | 0.1          | 0.07          | 0.6          |
| Estimated blood lost     | 0.15         | 0.3          | −0.06        | 0.7          | −0.15        | 0.3            | 0.11         | 0.01         | 0.18         | 0.6          | 0.50          | 0.1          | 0.19          | 0.3          |
| Leg length difference    | 0.11         | 0.6          | −0.20        | 0.3          | 0.47         | 0.02           | −1.00        | 1.0          | 0.33         | 0.4          | −0.08         | 0.9          | −0.43         | 0.1          |
| Hospitalisation          | 0.20         | 0.1          | 0.11         | 0.3          | −0.22        | 0.1            | 0.94         | 0.1          | −0.51        | 0.2          | −0.55         | 0.2          | −0.50         | 0.001        |
| Dislocation              | −0.17        | 0.3          | 0.13         | 0.4          | −0.05        | 0.8            | 1.00         | 1.0          | 0.44         | 0.3          | −0.29         | 0.2          | −0.29         | 0.2          |
| Revision                 | 0.10         | 0.6          | 0.36         | 0.1          | 0.05         | 0.8            | 0.90         | 0.3          | −0.37        | 0.4          | −1.00         | 1.0          | 0.13          | 0.7          |
| Deep infection           | −0.08        | 0.7          | 0.30         | 0.2          | 0.44         | 0.04           | 0.61         | 0.6          | −0.98        | 0.2          | 0.00          | 1.0          | 0.00          | 1.0          |
| Aseptic loosening        | 0.07         | 0.9          | −0.28        | 0.5          | −0.51        | 0.1            | 0.42         | 0.6          | −1.00        | 1.0          | 0.24          | 0.7          | 0.24          | 0.7          |
| Fractures                | −0.06        | 0.7          | 0.08         | 0.6          | −0.04        | 0.8            | 0.41         | 0.5          | −0.24        | 0.5          | 0.54          | 0.3          | 0.24          | 0.3          |

Conclusion
Older age and greater BMI were negative prognostic factors for MIS THA. The analyses of the PROMs suggested that the clinical outcome is strongly related to the pre-operative performance status of the operated patients. There is no compelling evidence that MIS THA offers advantages over traditional approaches, especially when modern analgesia techniques and accelerated rehabilitation programmes are considered.

Abbreviations
MIS: Minimally invasive surgery; THA: Total hip arthroplasty; PROMs: Patient-reported outcome measures; PRISMA: Preferred reporting items for systematic reviews and meta-analyses; VAS: Visual Analogue Scale; OHS: Oxford Hip score; WOMAC: Western Ontario and McMaster Universities Osteoarthritis Index; HHS: Harris Hip Score; SD: Standard deviation; IQR: Interquartile range.

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FM contributed to the literature search, data extraction, methodological quality assessment, statistical analyses, and writing; NM was involved in the supervision, revision and the final approval; AP helped in the data extraction, and methodological quality assessment; JE contributed to the supervision; FO contributed to the supervision. All authors read and approved the final manuscript.

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