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Complications of PI to PIII hemipelvic resections for intermediate and malignant tumours

a systematic review and meta-analysis

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Aims
Surgical management of intermediate and malignant tumours in the pelvis is complex. Complications are frequent and either related to the surgery itself or to post-surgical failure of the reconstruction technique. This systematic review and meta-analysis aims at analyzing all reported complications following PI to PIII pelvic resections for intermediate and malignant tumours.

Methods
Based on a systematic literature search on PubMed adhering to the PRISMA guidelines, 1,683 study records were identifed , of which we included 90 original studies published until 22 July 2025. Overall complication rates were assessed with random-efec ts meta-analysis. Difer ences in complication rates between reconstruction types (i.e. megaprosthetic, mostly biological, none) were evaluated with meta regression analysis.

Results
Data on 2,199 patients (1,250 males (57%)) with mainly PI to PIII pelvic resections were analyzed. The most common reconstruction types were custom-made implants (21%; n = 451) and ice-cream cone prostheses (14%; n = 312). Pooled rates of infections, wound healing problems, nerve injuries, and deep vein thrombosis (DVT) amounted to 15% (95% CI 12% to 18%), 13% (95% CI 10% to 15%), 7% (95% CI 5% to 9%), and 4% (95% CI 2% to 6%), respectively. Further, pooled implant revision/removal and secondary external hemipelvectomy rates were 14% (95% CI 11% to 17%) and 4% (95% CI 3% to 5%). Mostly biological reconstructions were associated with higher rates of nerve injuries ($p < 0.001$), construct failures ($p = 0.010$), and secondary implant revision/removal ($p = 0.003$) compared to megaprosthetic reconstruction. Further, biological reconstructions were associated with increased secondary external hemipelvectomy rates compared to megaprosthetic reconstructions ($p = 0.005$) or no reconstructions ($p = 0.001$).

Conclusion
Treatment of pelvic malignancies is challenging, with technically demanding resections and complex reconstructions. Across all reconstruction techniques following sacrum-sparing pelvic resections, infections and wound healing problems are the most common complications, yet there is also a considerable proportion of patients with neurovascular complications and DVTs.

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Take home message

- The treatment of pelvic malignancies is complex, with technically demanding resections and reconstructions. According to this systematic review and meta-analysis, infections and wound healing problems are the most common complications following sacrum-sparing pelvic resections across all reconstruction types.
- Of note, there is also a considerable proportion of patients with neurovascular complications and
- deep vein thromboses.

Introduction

Primary malignant tumours of the pelvic region pose signifcan t diagnostic and therapeutic challenges. First, due to a lack of or non-specifc symptoms, tumours in this area often reach a considerable size until being diagnosed.[1] Second, the close vicinity to vital anatomical structures impairs surgical resection with adequate margins may necessitate large surgical procedures with increased morbidity or can even result in a hindquarter amputation.[2] Third, depending on the tumour location, surgeon preference, and the extent of surgical resection, restoration of the pelvic bony anatomy may be required.[3] Reconstruction techniques involve megaprosthetic implants, custom-made prostheses, biological reconstructions and no formal bony reconstruction, among others.[2,4] Further, navigation-assisted resection has been introduced in recent years to potentially improve surgical margins and thus local control rate.[5]

Complications are frequently encountered, either directly related to the surgical procedure, or secondary to failures associated with the reconstruction technique. In orthopaedic oncology, complications secondary to surgical resections of malignant tumours are usually defned according on the Henderson classifcation.[6] However, manipulation of nerves and vessels during pelvic resections also increase the risk for vascular and nerve injuries that are not covered by the Henderson classifcation. Yet, most previous systematic reviews on this topic have focused on complication rates directly associated with the reconstruction technique, rather than potentially fatal complications such as deep vein thromboses (DVTs) or pulmonary embolism (PE).[2,4,7,8]

With this systematic review and meta-analysis, we sought to quantify and compare all reported complications following PI to PIII pelvic resections for semimalignant and malignant tumours beyond implant-/reconstruction-associated complications.

Methods

All original English articles published until 22 July 2025 in PubMed (without start time limit) were potentially eligible. The following search terms were used: "pelvic resection AND reconstruction AND sarcoma", "pelvic resection P1 AND reconstruction", "pelvic resection P2 AND reconstruction", "pelvic resection P3 AND reconstruction", "pelvic resection AND reconstruction AND function", and "pelvic resection AND reconstruction AND function AND tumour" (Supplementary table 1). Studies were screened by two co-authors (MAS, FAW) using a pre-specifed protocol. In case of disagreement, accordance was reached using the pre-specifed protocol. Non-English articles, reviews, biomechanical studies, case reports and comments were excluded. The literature research

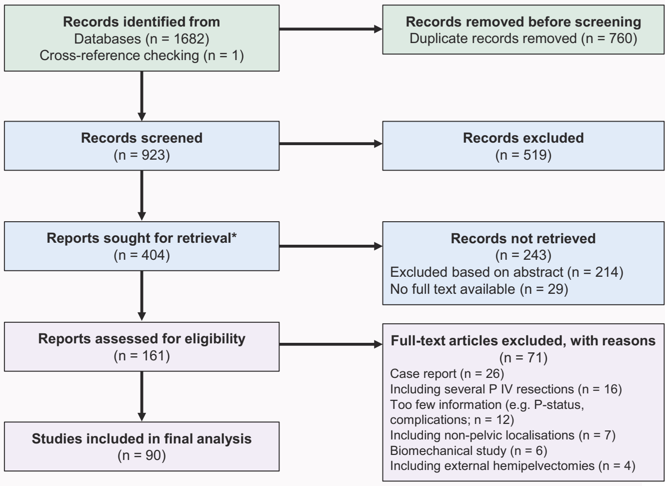


Fig. 1
Flowchart showing study selection. *based on abstract.

was carried out according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Supplementary Material).

The following information was retrieved from each included article: Start and end year of patient recruitment; continent and country, as well as city of main study centre; follow-up (in months as mean or median (if mean not available)); total number of patients included; number of males/females; patient age at surgery (in years as mean or median (if mean not available)); type of pelvic resection (according to Enneking and Dunham:[3] PI, PII, PIII, PI + II, PI + III, PII + III, PI + II+ III; for rare cases of PII to III resections combined with P IV resections: PI + IV, PII + IV, PI + II+ IV, PI to IV, PIV only); type of implant (modular, custom-made (3D-printed), ice cream cone, acetabular component/total hip arthroplasty, saddle prosthesis, allograft only, allograft-prosthetic composite, conventional autograft, irradiated autograft, autograft-prosthetic composite, rods and screws, hip transposition, no reconstruction, rare/unspecifed reconstructions); tumour type; postoperative function (Musculoskeletal Tumor Society (MSTS) score;[9] Toronto limb Salvage Score (TESS);[10] chemotherapy (CTX), radiotherapy (RTX); complications; secondary implant revision/removal (including revision/removal due to infection, dislocation, loosenings, construct failures, wound healing problems, recurrence); and secondary external hemipelvectomy. The following complications were retrieved from individual studies: infections; dislocations; nerve injuries; aseptic loosenings; construct failures (including fracture); wound healing problems (including superfcial infections, delayed wound healings); DVT; PE; arterial complications (including arterial embolisms); lymphoedema; hernia formation; local recurrences (LRs); and perioperative deaths.

For subgroup analysis, we grouped together megaprosthetic reconstructions (i.e. modular implants, custom made (3D-printed) implants, ice cream cone prosthesis, acetabular component/total hip arthroplasty, saddle prosthesis), mostly biological reconstructions (i.e. autograft, allograft, autograft/allograft prosthetic composites, rods and screws) and others/none (no reconstructions, hip transpositions).

Table I. Patient characteristics based on systematic literature review including 90 studies.

Variable (no of studies = 90)	n (%)
Total patients, n	2,199
Male	1,250/2,199 (57)
Mean age, yrs (SD)	39.3 (11.0)
Histology*	
Chondrosarcoma	924/2,164 (43)
Ewing's sarcoma	365/2,164 (17)
Osteosarcoma	336/2,164 (15)
GCT	87/2,164 (4)
Metastasis	206/2,164 (9)
Other	145/,2164 (7)
Unknown	101/2,164 (5)
Type of pelvic resection	
PI	143/2,155 (7)
PII	383/2,155 (18)
PIII	67/2,155 (3)
PI + II	458/2,155 (21)
PI + III	50/2,155 (2)
PII + III	641/2,155 (30)
PI + II+III	311/2,155 (14)
PI + IV	18/2,155 (0.9)
PII + IV	1/2,155 (0.1)
PI + II+IV	28/2,155 (1)
PI + II+ III+ IV	30/2,155 (2)
PIV	25/2,155 (1)
Reconstruction types	
Modular implant	283/2,199 (13)
Custom-made implant (± 3D printed)	451/2,199 (21)
Ice cream cone prosthesis	312/2,199 (14)
acetabular component/THA	164/2,199 (7)
Saddle prosthesis	63/2,199 (3)
Allograft (± prosthesis)	200/2,199 (9)
Autograft (± prosthesis)	142/2,199 (7)
Irradiated autograft	142/2,199 (7)
Rods and screws	51/2,199 (2)
No reconstruction	181/2,199 (8)
Hip transposition	121/2,199 (5)
Others	89/2,199 (4)
Additional treatments, n (%)	
CTX	464/2199 (21)
RTX	196/2199 (9)
Median MSTS score, % (IQR)	70.0 (62.4 to 76.7)
Median TESS, % (IQR)	71.3 (66.7 to 75.7)
Mean follow-up, mnths (SD)	55.5 (31.7)

*A detailed description of all histological subtypes is provided in Supplementary table 2.
CTX, chemotherapy; GCT, giant cell tumour of bone; MSTS, Musculoskeletal Tumor Society; RTX, radiotherapy; TESS, Toronto Extremity Salvage Score.

Patients with undefned reconstructions (i.e. “others”; n = 89) were not considered for comparative analyses.

Given the lack of disaggregated data across the included studies reporting on single patients undergoing PIV resections (alone or in combination with PI/II/III resections), our pooled analyses also contain 102 patients (5%) treated with P IV hemipelvectomies. Further, studies involving reconstruction types belonging to more than one of the defned groups (i.e. megaprosthetic, mostly biological, no reconstruction) could not be considered for comparative analyses. The quality of studies was evaluated with the Newcastle Ottawa Scale (NOS) for non-randomized cohort studies, as reported previously.[11] The NOS ranges from 0 points (low quality) to 9 points (high quality). It comprises the sum of 3 items per study, i.e. selection (4 points maximum), comparability (2 points maximum), and outcome (3 points maximum). According to local institutional policies, no ethical approval was sought for.

Statistical analysis

Categorical data are reported as counts and valid percentages. Continuous data are reported as mean with SD or a median with IQRs. Overall complication rates and difer ences in complication rates between reconstruction types (megaprosthetic, mostly biological, none) were assessed using random-efec t meta-analyses. First, the specifc complication rate within each study was calculated as the complication count within a study divided by the total patient number within that study. Thereafter, meta-analyses were carried out for each complication, overall and with reconstruction type as well as year of publication as a subgroup. Difer ences in complication rates between subgroups (reconstruction technique, period of publication) were assessed with meta-regression analysis. For each model, Higgins I^2 was calculated to evaluate heterogeneity between studies, with small values implying a comparable, and high values a substantially difer ing efec t size across studies.[12] Studies were only considered for complication-specifc analyses if they reported the occurrence of the respective complication or explicitly stated that no such complication had been observed.

The Kruskal-Wallis test was used to compare functional outcome (i.e. MSTS score, TESS score not compared to low rate of reporting) between reconstruction types, and to assess difer ences in complication rates depending on year of publication (prior 2015 or after 2015), as well as studies’ continents. A p-value < 0.05 was considered statistically

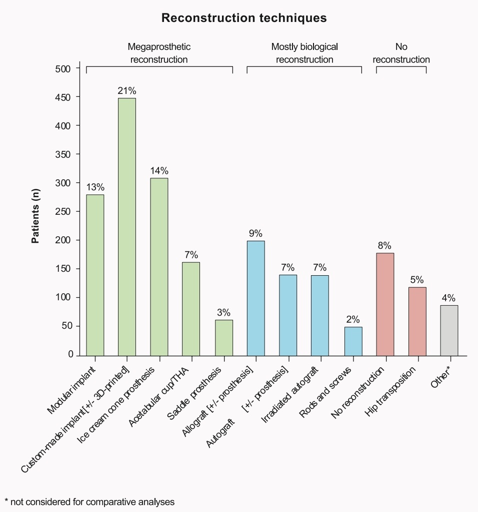


Fig. 2

Frequency of difer ent reconstruction techniques, grouped by megaprosthetic, mostly biological, and no reconstructions. Percentages are shown above each bar. THA, total hip arthroplasty.

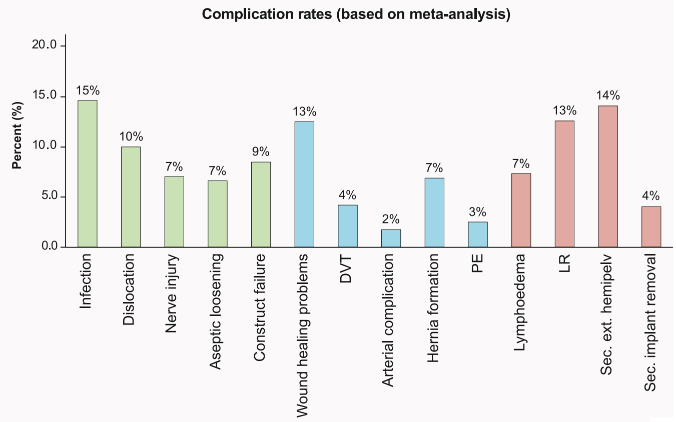


Fig. 3

Overall complication rates, based on individual meta-analyses per complication type. Numbers derived from meta-analyses. Bars show pooled complication rates across studies investigated. DVT, deep vein thrombosis; LR, local recurrence; PE, pulmonary embolism

signifcan t. All analyses were carried out with Stata v. 16.1 (StataCorp, USA).

Results

The initial literature search identifed 1,683 records. Of these, 760 duplicates were removed. Of the remaining 923 articles screened, 519 were excluded. The resulting 404 studies were sought for retrieval, of whom 214 were subsequently excluded based on the abstract, and further 29 not retrieved due to lack of full text. Of the remaining 161 articles, 71 were excluded for the following reasons: case reports (n = 26),[13–38] including several PIV resections (n = 16),[39–54] too little information (e.g. on type of resection, complications; n = 12),[5,55–65] including non-pelvic resections (n = 7),[66–72] biomechanical studies (n = 6),[73–78] and primary external hemipelvectomy (n = 4).[79–82] Finally, 90 original articles – all retrospective cohort studies – were included in the systematic review (Figure 1).[1,83–171]

Overall, data of 2,199 patients (1,250 males (57%)) with mainly PI to PIII pelvic resections was analyzed. The mean patient age at time of surgery across all studies was 39.3 years (SD 11.0). The most common type of pelvic resection was PII+ III (n = 641; 30%), followed by PI+ II (n = 458; 21%) and PII only (n = 383; 18%; Table I, Supplementary fgur e a). Chondrosarcoma (n = 924; 43%), Ewing's sarcoma (n = 365; 17%), and osteosarcoma (n = 336; 15%) were the prevailing histological subtypes (Table I; Supplementary table 2). The mean follow-up was 55.5 months (SD 31.7). Nearly half of studies came from centres in Asia (49%; n = 44), followed by Europe (37%; n = 33) and North America (12%; n = 11). Patients had been recruited in individual studies from 1971 until 2020 (Supplementary fgur e b).

The most frequent megaprosthetic reconstruction types were custom-made implants (21%; n = 451), ice-cream cone prostheses (14%; n = 312), and modular implants (13%; n = 283). Allograft ± prosthesis (9%; n = 200) was the most common biological reconstruction type (Table I**,** Figure 2**,** and Supplementary table 3). The mean NOS was 6.1 points (SD 0.6) (Supplementary table 4).

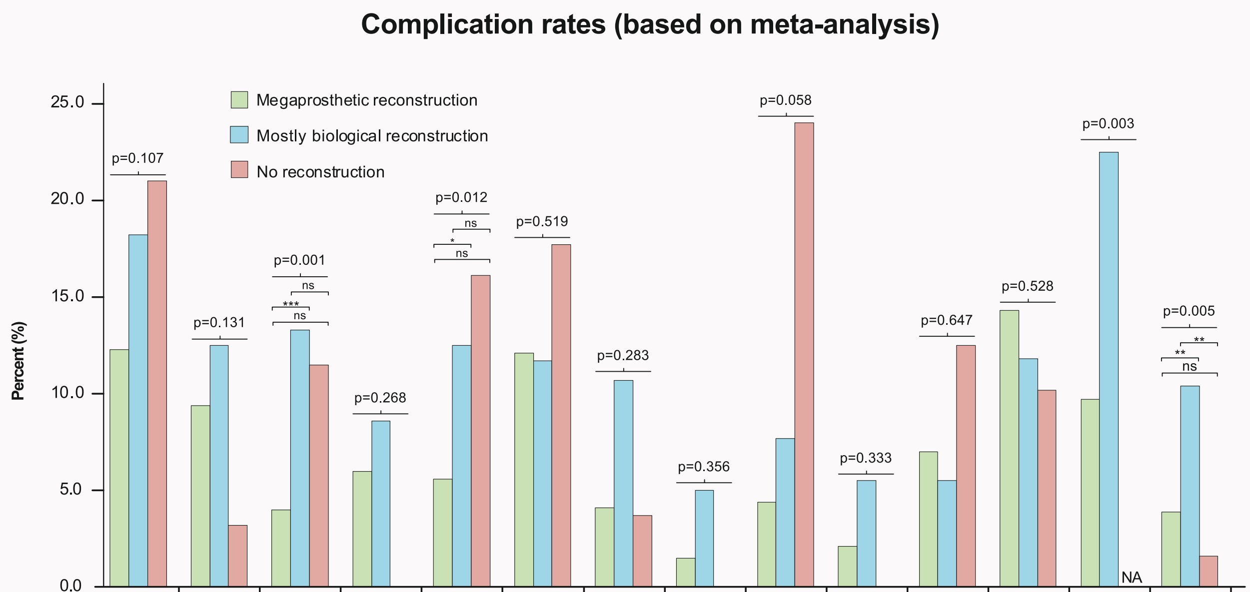
Complication rates

Across all patients and reconstruction techniques, pooled rates of infections, wound healing problems and dislocations were 15% (95% CI 12% to 18%), 13% (95% CI 10% to 15%), and 10% (95% CI 8% to 12%; Figure 3; Supplementary table 5, Supplementary fgur es 3 to 5), respectively. Pooled rates of construct failures and aseptic loosening were 9% (95% CI 6% to 11%) and 7% (95% CI 4% to 9%; Supplementary fgur es 6 and 7).

The pooled secondary implant revision/removal rate was 14% (95% CI 11% to 17%), the pooled secondary external hemipelvectomy rate was 4% (95% CI 3% to 5%), and the pooled LR rate was 13% (95% CI 11% to 14%; Figure 3; Supplementary table 5, Supplementary fgur es 8 to 10). In addition, pooled rates of lymphoedema, nerve injuries, and hernia formation were 7% (95% CI 3% to 12%), 7% (95% CI 5% to 9%) and 7% (95% CI 2% to 11%; Figure 3; Supplementary table 5, Supplementary fgur es 11 to 13), respectively. Pooled DVT, PE, and arterial complication rates amounted to 4% (95% CI 2% to 6%), 3% (95% CI 3% to 5%) and 2% (0% to 4%; Figure 3, Supplementary table 5, and Supplementary fgur es 14 to 16), respectively.

Furthermore, four studies each reported on one perioperative death (one of which was due to pulmonary embolism). The most common reasons for implant revision/removal and secondary external hemipelvectomy were deep infections (46%) and LRs (60%; Table II), respectively. Further reasons for implant revision/removal and secondary external hemipelvectomy are listed in Table II. Depending on the complication investigated, study heterogeneity (I^2 ranged between 0% and 60% (Supplementary table 6).

Mostly biological reconstructions were associated with signifcan tly higher nerve injury rates ($p < 0.001$), construct failure rates ($p = 0.010$), and secondary implant revision/removal rates ($p = 0.003$) than megaprosthetic reconstructions (Figure 4). Furthermore, mostly biological reconstructions associated with higher secondary external hemipelvectomy rates than megaprosthetic ($p = 0.005$) or no reconstructions ($p = 0.001$; Figure 4). All other complication rates also difer ed between reconstruction techniques, yet



Reconstruction type	Infection	Dislocation	Nerve injury	Aseptic loosening	Construct failure	Wound healing problem	DVT	Arterial comp.	Hemia formation	PE	Lymph-oedema	LR	Sec. implant rev./rem.	Sec. external hemipelv.
Megaprosthetic	12.3	9.4	4.0	6.0	5.6	12.1	4.1	1.5	4.4	2.1	7.0	14.3	9.7	3.9
Mostly biological	18.2	12.5	13.3	8.6	12.5	11.7	10.7	5.0	7.7	5.5	5.5	11.8	22.5	10.4
No reconstruction	21.0	3.2	11.5		16.1	17.7	3.7		24.0		12.5	10.2		1.6

*p < 0.05
**p < 0.01
***p < 0.001

Fig. 4

Complication rates separated by reconstruction type, based on individual meta-analysis per complication type. Numbers derived from meta-analyses, nd p-values derived from meta regression analysis. Studies reporting on reconstruction types of one defned group only (i.e., either megaprosthetic, mostly biological or no reconstruction) were considered. DVT, deep vein thrombosis; NA, not applicable; ns, not signifcan t.

Table II. Reasons for implant revision/removal and secondary external hemipelvectomy.

	Implant revision/removal (n = 181)	Secondary external hemipelvectomy (n = 78)
Reason	**Count, n (%)**	**Count, n (%)**
Deep infection	84/181 (46)	28/78 (36)
Fracture/aseptic loosening	52/181 (29)	/
Nonunion	4/181 (2)	/
Dislocation	23/181 (13)	/
Local recurrence	9/181 (5)	47/78 (60)
Unknown	9/181 (5)	3/78 (4)

without statistical signifcanc e (Figure 4). Apart from lower infection rates (p < 0.001), DVT rates (p = 0.028), and secondary implant revision/removal rates (p = 0.016) in studies published after 2015, no signifcan t difer ence in complication rates depending on publication period was found (Supplementary table 7).

Functional outcome

Information on functional outcome was available in 74 of 90 studies. The most reported outcome measure was the MSTS score (n = 60), followed by the TESS (n = 8). Across all studies, median MSTS score and TESS were 70% (IQR 62% to 77%) and 71% (IQR 67% to 76%), respectively. No signifcan t difer ence in MSTS score between reconstruction techniques was found (megaprosthetic: 70% (IQR 63% to 77%); mostly biological: 73% (IQR 63% to 77%); and no reconstruction: 73% (IQR 63% to 76%); p = 0.720; Figure 5).

Discussion

After sacrum-sparing pelvic resections, the most frequent complications are infections, wound healing problems, and dislocations, occurring in one of ten patients. Further, nerve injuries and DVTs are observed in over 4% each. Further, a secondary external hemipelvectomy is necessary in over 4% of sacrum-sparing pelvic resections, and in most cases due to LR.

Previous studies reporting on complications from pelvic resections and reconstruction for malignant tumours have focused on implant-associated complications and LRs as defned by the Henderson classifcation,[2,4,7,8] but did not report on other, potentially life-threatening adverse events as PEs and arterial complications. Therefore, the authors have analyzed all reported complications observed following predominantly sacrum-sparing pelvic resections.

Given the forces acting on the pelvic ring, any reconstruction is at risk for failure, including loosening, mechanical failure, stress fracture, or dislocation.[7] In addition, foreign material, prolonged surgical time and radiotherapy increase the risk for infection.[172] This is refec ted by our fndings , with infections, wound healing problems and dislocations being most common. Of note, mostly biological reconstructions were associated with higher nerve injury, construct failure and secondary implant revision/removal rates than megaprosthetic reconstructions. Further, secondary external hemipelvectomy rates were higher for mostly biological reconstructions compared to megaprosthetic or no reconstruction. A potential explanation for the higher construct failure rates following biological reconstruction can be a progressive failure of bone grafts (alone or as composite grafts) over time in previously large bony defects, ultimately requiring implant revision/removal or even external hemipelvectomy. Long surgical time has been linked to higher risk for iatrogenic nerve damage.[100,144] This could partly explain higher rates of nerve injuries in patients undergoing time-consuming biological reconstructions. However, other factors, such as the tumour's proximity to or infltration of neurovascular structures, may also play a role. Indeed, manipulation of nerves and vessels during the dissection of large pelvic tumours may lead to iatrogenic injuries. Pulmonary embolisms, DVT, and arterial complications occurred in 3% to 4%, and nerve injuries in 7% of patients following pelvic resections. This mirrors a report by Lex et al,[173] identifying hip and pelvic resections as risk factors for PEs in orthopaedic oncology. Interestingly, no signifcant diference in DVT, PE, and arterial complication rates depending on the reconstruction technique was found, suggesting that the dissection itself has a contributing role in development of these complications.

Secondary implant revisions/removals became necessary in over 14% of patients and were more common following mostly biological compared to megaprosthetic implants, mirroring higher construct failure rates in this group. Further, the rate of secondary hemipelvectomy was over 4%, highlighting the complexity and hazardousness of pelvic resections for malignancies. Local recurrence was the predominant reason for secondary external hemipelvectomy. Of note, no signifcant diference in LR rates were found depending on the reconstruction technique employed. Of note, we did not stratify our analyses towards use of navigation-assisted surgery that has been linked to improved local control rates.[5,106,174]

Overall, lower infection and implant revision/removal rates were observed in recently published studies. Although our analyses do not support any defnite conclusions, one may speculate that lower infection and implant revision/removal rates in recent years may be attributable to refned treatment approaches and improved implant designs.

Finally, bearing in mind the morbidity associated with complex pelvic resections and reconstructions, the median reported MSTS score across all studies of 70% can be considered good. Function was comparable between reconstruction techniques, suggesting that reconstruction techniques had been chosen carefully depending on tumour extent, prevailing comorbidities and patient expectations.

Strengths of the present systematic review include the large number of studies and patients included, outnumbering previous reviews on this topic.[2,7] Further, detailed analysis of complications by pooling data across studies provides valuable insight into reconstruction-specifc and time-dependent diferences. To the best of our knowledge, the current study comprises the largest systematic review on this topic,

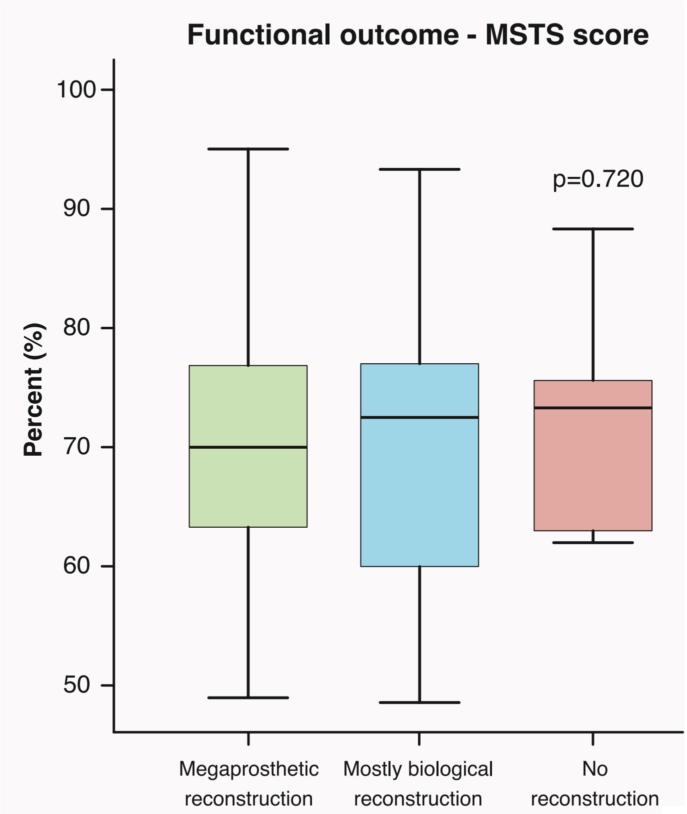


Fig. 5
Functional outcome depicted by the Musculoskeletal Tumor Society (MSTS) score, separated by reconstruction type.

aggregating data of nearly 2200 patients with PI to PIII pelvic resections.

However, some limitations warrant consideration when interpreting our fndings. First, given that we carried out a systematic literature review, no individual-level data were available. Thus, we had to exclude studies from meta-analyses if further diferentiation between reconstruction types was not possible. Related to this, studies were only considered for meta-analyses if they explicitly stated that a specifc event had occurred or not. This favoured relatively low patient and event counts in some analyses, especially regarding rare complications (e.g. DVT). Related to this, depending on the complication type investigated, study heterogeneity was high, urging a careful interpretation of fndings. Second, given the lack of prospective evidence in this feld, all included studies were retrospective, which may lead to various types of biases including selection (i.e. patients with unfavourable course of disease are not considered) und reporting bias (i.e. poor outcomes tend to be underreported). Third, a potential overlap of studies from identical institutions published over several years may be present. Further, we focused on PI to PIII pelvic resections, thus our fndings are not directly applicable to P IV resections. In this context, we were unable to disaggregate data in studies reporting on selected cases (n = 102; 5%) of PIV resections (alone or in combination with PI to PIII resections). Next, some studies also included patients treated with internal hemipelvectomy for giant cell tumours of bone (GCT; 4%) that are of intermediate malignancy. However, the largest limitation of our study is due to reporting bias from large centres with greater experience than small centres. Unpublished surgeon-reported data from the BOOM Consensus group suggests that real-world complication rates are signifcan tly higher, and that individual surgeon experience has a signifcan t efec t on complication rates.[175]

Taken together, the treatment of pelvic malignancies is challenging, with technically demanding resections and complex reconstructions. Depending on the type of reconstruction, which is closely connected with the type of resection carried out, complication rates vary. Across all reconstruction techniques following predominantly sacrum-sparing pelvic resections, infections and wound healing problems are the most common complications, yet the frequency of neurovascular complications including nerve injuries and DVTs should not be underestimated. Of note, local recurrence is the main reason for secondary external hemipelvectomy. In practice, surgeons should remain aware of potential complications ensuing the surgical procedure, including those linked to manipulation of neurovascular structures and the reconstruction itself. Ultimately, the decision on type of reconstruction, or no reconstruction at all following internal hemipelvectomy, should be based on the expected bone defect, the surgeon's preference, and patient expectations.

Supplementary material

List of all co-authors of the BOOM Consortium, detailed PubMed search terms, a description of histological subtypes and modular implants, the Newcastle-Ottawa Scale for studies included, detailed information on overall complication rates, study heterogeneity and temporal trends in complication rates, alongside individual forest plots on various complications per reconstruction type.

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