

Outcome analysis of ilizarov and monorail fixators in the treatment of nonunion of long bones: A systematic review and proportion meta-analysis

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ABSTRACT

Introduction: Nonunion of long bones is a major complication following fractures that requires a substantial amount of investment both monetary and time from patients and surgeons. The need to comprehensively understand the complications, outcomes and distraction capability is profound, which necessitates a review of current evidence on special fixators used for distraction. The current systematic review aims to study the available literature on distraction osteogenesis using special fixators (Ilizarov and Limb Reconstruction System) in the management of nonunion (infected and non-infected).

Methods: Cochrane Library, PubMed, Scopus were searched until January 2022. The review included all original studies which used Ilizarov or Monorail Fixators/LRS in the treatment of nonunion of long bones. The quality of studies was assessed using the Modified Coleman Methodology Score.

Results: A total of 35 original studies with Ilizarov (n = 29) and LRS (n = 8) were selected including two comparative studies. The pooled data meta-analysis and the subgroup analysis of these studies found both Ilizarov and LRS fixator yield similar functional outcomes for the treatment of long bones nonunion.

Conclusion: The review was conducted to understand the scenario of nonunion in long bones. Pin tract infection is found to be the most common complication followed by adjacent joint stiffness and deformity. In our review we observed that both external fixator time and index were lower in LRS compared to Ilizarov group. Further RCT are required comparing Ilizarov and LRS fixators to effectively comment upon the superiority of the implants.

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1. Introduction

Nonunion of long bones is a major complication following fractures that requires a substantial amount of investment both monetary and time from patients and surgeons alike for treatment.^{1–3} Infected nonunions further curtail the progress and leads to multiple procedures, including debridement, bone transport, or bone grafting.⁴ The general consensus in literature favors to the use of radical debridement of necrotic bone and soft tissue

followed by external fixation.⁵

Nonunions (infected or non-infected) persistently produce gap defects due to the necrotic bone at the ends.⁵ Currently, there exist multiple methods for the management of nonunions. Among them, the most commonly used methods are Distraction Osteogenesis with external fixation, Masquelet technique, Huntington method, and bone grafting.^{6,7} Distraction osteogenesis is currently the most preferred method of treatment in gap nonunions, using a corticotomy and gradually distracting.^{7,8} The construct is held by Ilizarov special ring fixators or the newer Limb Reconstruction System (LRS) or the hybrid fixators.⁸

There is a volume of literature on the clinical outcomes and complications, however, some lacunae still exist in the literature to comprehensively assess the expected outcome and complications. Peng Yin et al. in their review, used 24 studies (n = 590) to assess the outcomes using ASAMI scores and noted that Ilizarov methods

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had high rates of good bone formation and high functional scores.⁹ The review failed to include all the available literature and comment on overall outcomes. Moreover, the outcomes of LRS in nonunions were not studied.⁹ The need to comprehensively understand the complications, outcomes and distraction capability is profound, which necessitates a review of current evidence on special fixators used for distraction.

The current systematic review aims to study the available literature on distraction osteogenesis using special fixators (Ilizarov and LRS) in the management of nonunion (infected and non-infected). The interests of outcomes for the study were complications, distraction capability, and outcomes in terms of The Association for the Study and Application of Methods of Ilizarov (ASAMI) functional and bone scores.

2. Material and methods

The current review and meta-analysis were performed in accordance with Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.¹⁰

3. Literature search and study selection

The online databases platform Pubmed, Scopus, and Cochrane

library were searched by three authors. The last date of the search was 31/01/2022, and all the databases were searched from 01/01/2001 to the above specified time. The search terms used were “Nonunion”, “Non-union”, “Ilizarov”, “Ilizarov method” or “Ilizarov methods”, and “Ilizarov technique” or “Ilizarov techniques”, “LRS”, “Limb reconstruction system”, “Femur”, “Tibia”, “Humerus”, “Long bone”, “outcome”, “complication”, “functional score” with Boolean operators “AND” and “OR”. The flow diagram representing the search is shown in Fig. 1. The abstracts were identified first by the above-mentioned search methods and were assessed for eligibility based on the criteria mentioned below. The shortlisted abstracts were followed up for full texts and again assessed for eligibility. An additional search of the reference list of the finalized articles was searched for further relevant studies. The process was repeated two times, and the senior author had final say regarding discrepancies between the authors.

4. Eligibility criteria

The review used the following eligibility criteria for articles selection: (1) Target population: patients with nonunion of humerus, tibia, and femur; (2) Intervention: Ilizarov methods and LRS, including bone transport, acute compression and lengthening, and compression osteosynthesis; (3) Studies with any of the two

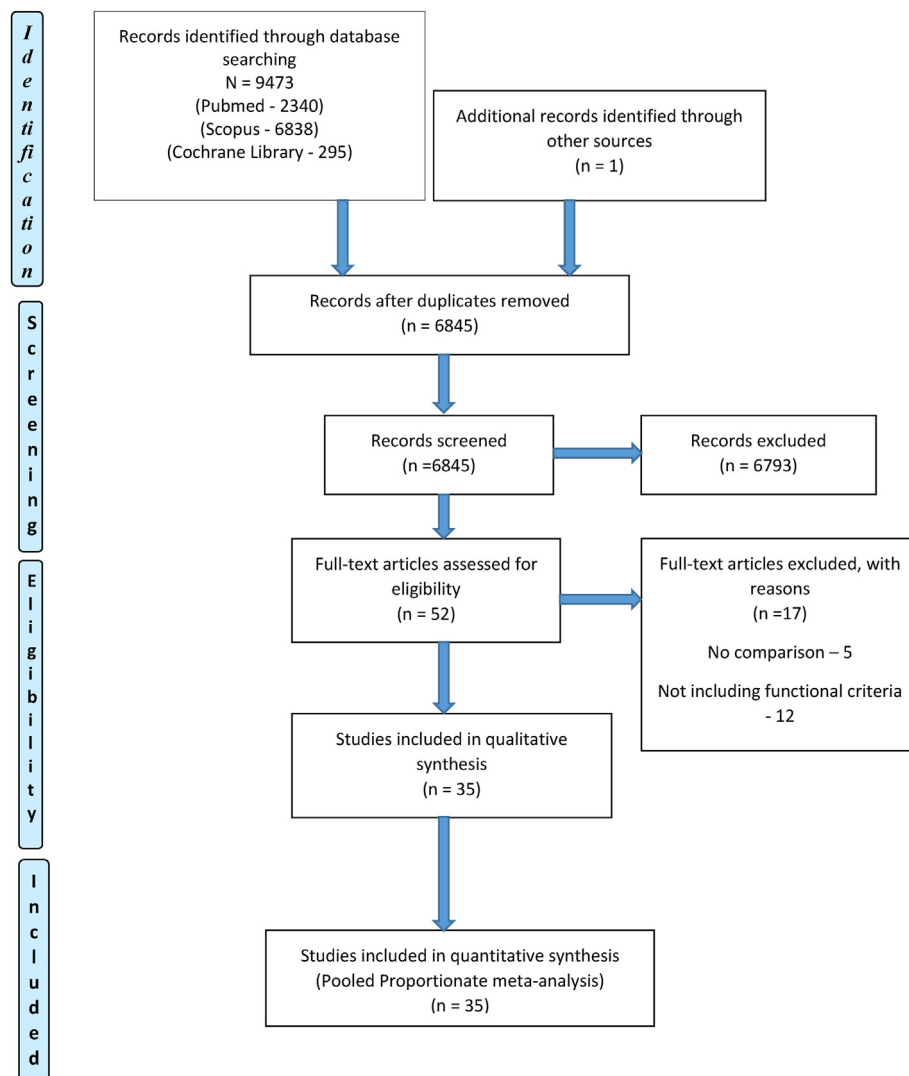


Fig. 1. PRISMA chart

Table 1
Study characteristics of Ilizarov and LRS group.

ILIZAROV DATA										
Author (year)	Study design	Sample size (n)	M/F (n)	Age (year)	Site of Intervention (N)	MPSP (n)	Mean bone defects (cm)	Technique/ Procedure	Mean follow up (month)	MCMS
V Barbarossa (2001)	Prospective	30	24/6	39.4± 14.4 (25–80)	Femur	4.4 ± NS	6.3 ± NS	Ilizarov	NS (24–126)	66
David W. Sanders (2002)	retrospective	19	12/3 (1 loss of f/u and 3 amputated NS)	45 ± NS (20–78)	Tibia	NS	8 ± NS (4.5–12)	Ilizarov	39 ± NS	50
S Patil (2006)	Retrospective	41	35/5	41 ± NS (10–73)	36 Tibia 5 Femur	3 ± NS (1–10)	NS	Ilizarov	61.1 ± NS	66
A Krishnan (2006)	Retrospective	20	17/3	38.4 ± NS (18–65)	Femur	4.4±2 (1–9)	NS	Ilizarov	62.8±25	54
MP Magadam (2006)	Retrospective	27	27/0	39±14 (15–65)	Tibia	2 ± NS (1–4)	NS	Ilizarov	27 ± NS (25–39)	58
Dror Paley (2006)	Retrospective	21	12/9	40 ± NS (12–63)	Tibia	NS	NS	Ilizarov	83.4 ± NS (26–144)	63
Ranjit Baruah (2007)	Retrospective	50	45/5	NS (18–56)	Tibia	NS	3.5 ± NS (2–9)	Ilizarov	NS (24–72)	59
M. Triguí (2008)	Retrospective	9	5/4	20 ± NS	8 Tibia 1 Femur	NS	4.1 ± NS (2–8)	Ilizarov	28 ± NS	53
Khaled M Emara (2008)	Prospective	33	22/11	2 ± NS	Tibia	NS	6 ± NS	Ilizarov	36 ± NS (22–48)	68
S. Robert Rozbruch (2008)	Retrospective	38	30/8	43 ± NS (8–72)	Tibia	4 ± NS (0–20)	5.9 ± NS (1.5–16)	Ilizarov	37 ± NS (15–63)	58
Michael D. Mckee (2008)	Retrospective	11	8/3	43.7 ± NS (30–71)	Tibia	4.5 ± NS (2–12)	NS	Ilizarov	41 ± NS (24–82)	56
Francesco Sala (2011)	Retrospective	12	8/4	44 ± NS (19–79)	Tibial	4.66 ± NS	8.06±2.6 (3.0–12.0)	Ilizarov	24.6±4.7 (18–32)	50
M Sayed (2013)	Retrospective	20	19/1	37.45 ± NS	Femur	1.95±1.05 (1–5)	NS	Ilizarov	36.65±15.8 (25–82)	62
P Yin (2014)	Retrospective	66	62/4	37.06 ± NS	Tibia	NS	6.27 ± NS (3–13)	Ilizarov	25.91 ± NS	63
Chang Seon Oh (2015)	Retrospective	7	6/1	14.4 ± NS (4.8–36.9)	5 Tibia 2 Femur	NS	7.3 ± NS (5.1–12.1)	Ilizarov	106.2 ± NS	59
Peng Yin (2015)	Retrospective	72	92/18	38.90 ± NS	Tibias	2.61 ± NS (1–8)	6.15 ± NS (3–13)	Ilizarov	23.12 ± NS (14–46)	60
Ramji Lal Sahu (2016)	Prospective	60	50/10	37.5 ± NS (25–45)	Tibia	3.5 ± NS (2–5)	3 ± NS (2–5)	Ilizarov	36 ± NS (26–50)	71
Kemal Aktuglu (2016)	Retrospective	24	21/3	35.04±17.19 (8–69)	Tibia	3.64±2.66 (range, 0–11).	7.01±2.88 (5–18)	Ilizarov	74.08±24.17	53
R Rohilla (2016)	Prospective	35	32/3	33.2 ± NS (18–64)	Tibia	1 ± NS	5.84 ± NS (3–9)	I-Ilizarov	33.8 ± NS	79
Martin McNally (2017)	Prospective	79	61/18	43.0 ± NS	Tibia	2.2 ± NS (1–5)	4.93 ± NS	Ilizarov	40.8 ± NS (6–131)	71
Gamal Ahmed Hosny (2018)	Retrospective	144	87/57	44.48 ± NS	18 Humerus 52 Femur 74 Tibia	4.35±1.21 (2–6)	5.98 ± NS (3–10)	Ilizarov	51.05 ± NS	60
K Bhowmick (2018)	Retrospective	8	7/1	41 ± NS (22–57)	Tibia	All 8 underwent 1 procedure	NS	Ilizarov	33±35.05 (12–20)	62
S Fahad (2019)	Retrospective	51	41/10	45.65±16.69	Tibia	2 ± NS (1–4)	3.5 ± NS (2–5)	Ilizarov	36.84 ± NS	69
G Testa (2020)	Retrospective	26	20/6	51.3±15.3 (22–68)	Tibia	All 26 underwent 1 procedure	NS	Ilizarov	28.25 ± NS (9–42.75)	62
I Sigmund (2020)	Prospective	47 ASR: 20, BT: 27	NS	ASR: 48.9 ± NS (21–78), BT: 50.9 ± NS (29–75), NS (18–65)	Tibia	ASR: 2.9 ± NS (1–5)	ASR: 4.0 ± NS (2–5)	Ilizarov	37.9 ± NS (16–128)	79
R K Baruah (2020)	Retrospective	86	72/24	NS (18–65)	Tibia	5 ± NS	5.04 ± NS (3–9)	Ilizarov	24 ± NS	69
Gamal Ahmed Hosny (2020)	Retrospective	13	11/2	9.1 ± NS (2–14.5)	Femur	3.3 ± NS	NS	Ilizarov	60.15 ± NS	65
A Chalak (2021)	Retrospective	30	16/14	39.27 ± NS (10–66),	Tibia	16 underwent 1 procedure	7.17 ± NS (2–12)	Ilizarov	39.36 ± NS (24–54)	69
Lukasz Szelereski (2021)	Retrospective	102	76/26	46.7 ± NS (11–84)	Tibia	NS	NS	Ilizarov	84 ± NS (24–144)	65

LRS DATA										
Author (year)	Study design	Sample size (n)	M/F (n)	Age (year)	Site of intervention (n)	MPSP (n)	Mean bone defects (cm)	Technique/ Procedure	Mean follow up (month)	MCMS
Hiranaya Seenappa (2013)	Prospective	30	28/2	29.28 ± NS (19–66)	16 Tibia, 10 Femur, 4 Humerus	2.67 ± NS (0–10)	5.06 ± NS (1–10)	LRS	27 ± NS (14–41)	66
Peng Yin (2015)	Retrospective	38	92/18	38.90 ± NS	Femur	2.61 ± NS (1–8)	6.15 ± NS (3–13)	Monorail	23.12 ± NS (14–46)	60
R Rohilla (2016)	Prospective	35	30/5	29.3 ± NS (18–65)	Tibia	1 ± NS	5.78 ± NS (3–10)	LRS	32.6 ± NS	79
Qun Jhang (2017)	Retrospective	41	31/10	44 ± NS (26–76)	Femur	NS	10.1 ± NS (6–17)	LRS	35 ± NS (20–60)	61
S Gupta (2018)	Retrospective	14	13/1	38.1 ± NS	Tibia	NS	6.4±1.3	LRS	33.2 ± NS (24–50)	60
Xun Chen (2019)	Prospective	23	19/4	37.8 ± NS (19–54)	Tibia	2.5 ± NS (2–4)	6.5 ± NS (5.2–8.1)	LRS	57.6 ± NS (36–72)	62
N Kushwaha (2020)	Prospective	21	19/2	29.43±14.07	Tibia	NS	NS	LRS	29.5 ± NS (16–50)	76
Victor Lu (2021)	Retrospective	8	8/0	37.75 ± NS	femur	4.5 ± NS	9.69 ± NS	Rail Fixator	57 ± NS	50

ASR, Acute Shortening and Relengthening; BT, Bone Transport; MPSP, Mean previous surgical procedures; MCMS, Modified Coleman Methodology score; NS, Not Specified; LRS, Limb Reconstruction System.

mentioned outcomes were included. Outcomes: bone union, bone evaluated by ASAMI (rated as excellent, good, fair and poor), and functional results evaluated by ASAMI (rated as excellent, good, fair and poor), complications, external fixation time and external fixation index. (4) Follow-up of >2 years; (5) All types of articles excluding case reports, case series with less than three patients, biomechanical studies, expert opinions, letters to editors, or editorials and review or non-English language. Duplicate or multiple publications of the same study were excluded.

5. Data extraction and statistical analysis

Three authors extracted the data using a standardized form. The following data were extracted from each included study: first author, year of publication, journal, study location, study design, level of evidence, technique, sample size, mean age, mean previous surgical procedures (number of the procedure the patient underwent before the enrolling into the study), mean bone defects, mean length of follow-up, bone results evaluated by ASAMI, functional results evaluated by ASAMI, complications per patient, external fixation time (months of treatment time), and external fixation index (days of treatment time divided by centimeters of the bone defect), and complications as events. The continuous variables were extracted and expressed as mean ± standard deviation. In case of missing data, the authors were contacted for the specific information, and the articles were excluded if responses were not obtained. Disagreements between the authors were discussed, and the senior author took the final decision.

Bone results was evaluated based on union, infection, deformity, and limb length discrepancy as excellent: union without infection, <7° deformity, and <2.5 cm limb length inequality; good: union with 2 of the above criteria; fair: union with one of the above criteria; poor: nonunion or re-fracture, and none of the above criteria fulfilled¹¹

The functional result was evaluated according to 5 adverse criteria: (1) observable limp, (2) stiffness of knee or hip (loss of >70° of knee flexion or >15° of knee extension), (3) loss of >50% of hip motion when compared with the normal contralateral side, (4) severe sympathetic dystrophy, pain that reduced activity or disturbed sleep, and (5) inactivity (unemployment or inability to return to daily activities). (11) Provided the patient was active, the result was deemed excellent if the other four criteria were also absent, good if one or 2 of the other criteria were present, and fair if 3 or 4 of them prevailed. The result was deemed poor if the patient was inactive, regardless of the other criteria.

The review and meta-analysis were done using the Medcalc version 20.211. The random-effects model was taken for pooled

estimates in the meta-analysis, assuming the heterogeneity in the methods and techniques and that the included studies represent a random sample from the larger population of such studies wherein each study has its own underlying effect size. The heterogeneity of the sample was assessed with the I² statistic, with values of 25, 50, and 75% considered as low, moderate, and high heterogeneity, respectively.¹² Other major data extracted in this study were recorded and statistically analyzed using weighted means based on the sample size in each study by Medcalc version 20.211, including the number of patients, mean age, mean previous surgical procedures, mean bone defects, mean length of follow-up, bone union, complications per patient, external fixation time (EFT), and external fixation index (EFI). If the standard deviation was not mentioned in the study, it was calculated using the range of values as per Hozo et al.¹³

6. Quality assessment

Two authors assessed the quality of the studies included in the review. Modified Coleman Methodology Score (MCMS) was used for the analysis, and it consisted of 10 (7 + 3) parameters for which each item had an individual score based on the reported outcome.¹⁴ The score was not used as an exclusion criterion for the selected articles. The senior author had final say regarding discrepancies between the authors, if any, by discussion to reach a consensus.

7. Results

7.1. Study characteristics

The initial literature search identified 9473 relevant records published from 01 January 2001 to 31 January 2022, out of which duplicates were removed, and a total of 35 original studies with Ilizarov (n = 29) and LRS (n = 8) were selected using the criteria mentioned above with two comparative studies. Twenty-four were retrospective, and eleven were prospective studies. The review found two studies that compared LRS vs. Ilizarov meeting the inclusion criteria^{4,7}

The review included a total of 1391 patients, of which 1181 underwent Ilizarov and 210 underwent LRS. The study demographics have been listed in Table 1. The mean age of patients was 37.42 years. 1104 were males, and 287 were females, with one study failing to mention sex of the study participants.¹⁵

7.2. Quality assessment

The quality assessment revealed that the average MCMS score

Table 2
Functional Outcome of Studies in Ilizarov and LRS group.

ILIZAROV DATA							
Author (year)	ASAMI (bone results) – E/ G/F/P	E + G	ASAMI (functional results) – E/G/F/P	E + G	External fixator time (month)	External fixator index (day/cm)	Complications per patient (number of complications/sample size)
V Barbarossa (2001)	13/9/2/5 with 1 amputation	22/30	5/10/8/6 (1 failure)	15/30	NS	NS	87/30 = 2.9
David W. Sanders (2002)	NS	NS	9/4/1/5	13/19	NS	NS	18/19 = 0.94
S Patil (2006)	17/14/4/6	31/41	14/14/2/4	28/41	14.1 ± NS	NS	56/41 = 1.36
A Krishnan (2006)	13/4/1/1	17/20	3/9/3/5	12/20	7.8±4.13	38.3±1.6 (36–42)	71/20 = 3.55
MP Magadum (2006)	19/5/0/1	24/27	15/8/1/1	23/27	6.3 ± NS (4–12)	NS	25/27 = 0.92
Dror Paley (2006)	10/9/1/1	19/21	15/3/2/1	18/21	7.8 ± NS	75 ± NS	61/21 = 2.9
Ranjit Baruah (2007)	24/24/0/2	48/50	23/22/2/2	45/50	6.08 ± NS	51.9 ± NS	33/50 = 0.66
Khaled M Emara (2008)	IMN – 17/0/0/0 Without IMN – 15/1/0/0	33/33	IMN – 13/2/2/0 Without IMN – 12/1/3/0	28/33	With IMN- 3.1 ± NS Without IMN – 8.5 ± NS	With IMN- 16.5 ± NS Without IMN – 45 ± NS	10/33 = 0.3
S. Robert Rozbruch (2008)	24/12/0/2	36/38	20/14/2/2	34/38	9.6 ± NS (3.9 –23.8)	NS	24/38 = 0.63
Michael D. McKee (2008)	NS	NS	9/1/1/0	10/11	6.5 ± NS (1.75 –10.5)	NS	25/11 = 2.27
M. Trigui (2008)	3/4/2/0	7/9	1/8/0/0	9/9	9 ± NS	57 ± NS	18/9 = 2
Francesco Sala (2011)	10/2/0/0	12/12	6/5/1/0	11/12	15.16 ± NS	NS	24/12 = 2
M Sayed (2013)	10/6/1/3	16/20	4/13/3/0	17/20	8.03±2.774 (5 –15)	NS	63/20 = 3.15
P Yin (2014)	44/15/5/2	59/66	24/26/10/0	50/66	NS	41.4 ± NS (34.5 –47.4)	NS
Chang Seon Oh (2015)	6/1/0/0	7/7	6/1/0/0	7/7	6.18 ± NS	26.0 ± NS (19.8 –32.5)	3/7 = 0.42
Peng Yin (2015)	46/17/7/2	63/72	25/27/13/0	52/72	2.3 ± NS	44.4 ± NS (34.5 –50.1)	192/110: 1.74
Ramji Lal Sahu (2016)	50/7/2/1	57/60	45/10/3/2	55/60	12 ± NS (8–14)	120 ± NS	69/60 = 1.15
Kemal Aktuglu (2016)	12/8/2/2	20/24	14/9/1/0	23/24	11.69±2.97 (8.7 –20.9)	52 ± NS (34.8 –62.8)	28/24 = 1.66
R Rohilla (2016)	1-21/12/0/2	33/35	1-16/17/1/1	33/35	11.1 ± NS	63.6 ± NS	1-60/35 = 1.71
Martin McNally (2017)	74/3/0/2	77/79	55/16/6/1 (1 amputation)	71/79	7.5 ± NS	45.6 ± NS	18/79 = 0.23
Gamal Ahmed Hosny (2018)	109/26/3/6	135/144	91/38/12/3	129/144	9.12±2.27 (6–16)	NS	35/144 = 0.24
K Bhowmick (2018)	8/0/0/0	8/8	5/3/0/0	8/8	11.5±8.03 (3–30)	NS	8/8 = 1
S Fahad (2019)	22/19/7/3	41/51	24/21/4/2	45/51	10 ± NS	60 ± NS (45–120)	24/51 = 0.47
G Testa (2020)	10/12/4/0	22/26	16/9/1/0	25/26	9.8±2.3 (6–13)	NS	6/26 = 0.23
I Sigmund (2020)	ASR: 18/2/0/0 BT: 22/5/0/0	47/47	ASR: 12/7/1/0 BT: 19/6/2/0	44/47	ASR: 8.8 ± NS (5–16) BT: 10.3 (7–17)	ASR: 60 ± NS (39 –84) BT: 54 ± NS (27 –81)	31/47 = 0.6531
R K Baruah (2020)	16/42/18/10	58/86	13/44/22/7	57/86	6.8 ± NS	40.5 ± NS	51/86 = 0.6
Gamal Ahmed Hosny (2020)	8/3/1/1	11/13	9/3/1/0	12/13	5.3 ± NS	NS	18/13 = 1.4
A Chalak (2021)	27/2/1/0	29/30	28/2/0/0	30/30	11.43 ± NS	51.3 ± NS (35–105)	20/30 = 0.66
Lukasz Szelereski (2021)	88/9/0/5	97/102	67/30/0/5	97/102	8.3 ± NS	NS	5/102 = 0.05

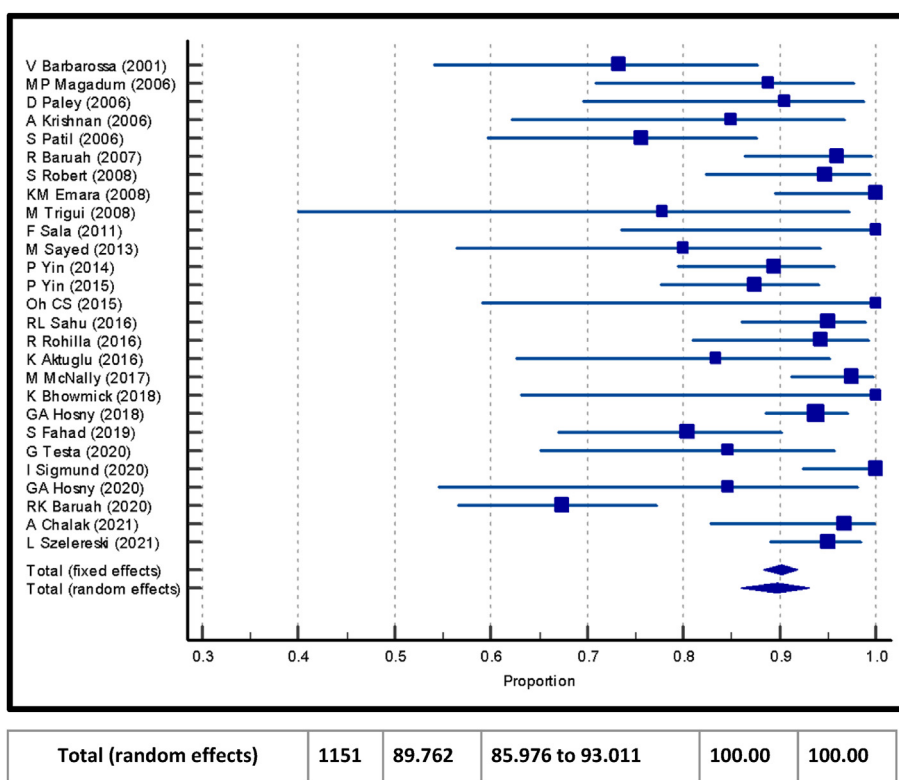
LRS DATA							
Author (year)	ASAMI (bone results) – E/G/F/P	E + G	ASAMI (functional results) – E/G/F/P	E + G	External fixator time (month)	External fixator index (day/cm)	Complications per patient (number of complications/sample size)
Seenappa (2013)	22/3/0/3	25/30	11/14/0/0 (Failure-3)	25/30	9.68 ± NS	57.3 ± NS	50/30 = 1.66
Peng Yin (2015)	22/11/5/0	33/38	12/15/8/0	27/38	64.45 ± NS (45–86)	45 ± NS (38.4–51.3)	192/110: 1.74

(continued on next page)

Table 2 (continued)

LRS DATA							
Author (year)	ASAMI (bone results) – E/G/F/P	E + G	ASAMI (functional results) – E/G/F/P	E + G	External fixator time (month)	External fixator index (day/cm)	Complications per patient (number of complications/sample size)
Rohilla (2016)	14/15/3/3	29/35	22/10/0/3	32/35	10.5 ± NS	63.3 ± NS	11-70/35 = 2
Jhang (2017)	30/6/5/0	36/41	21/9/7/4	30/41	13.3 ± NS	39 ± NS	58/41 = 1.41
Gupta (2018)	14/0/0/0	14/14	8/6/0/0	14/14	4.5 ± NS	21.2 ± NS	7/14 = 0.5
Chen (2019)	15/8/0/0	23/23	18/5/0/0	23/23	3.26 ± NS	22.4 ± NS	5/23 = 0.22
Kushwaha (2020)	9/10/2/0	19/21	11/9/1/0	20/21	11.2 ± NS (6–18)	NS	10/21 = 0.47
Victor Lu (2021)	4/2/0/2	6/8	NS	NS	2.29 ± NS	24 ± NS (11.2–42.0)	17/8 = 2.125

ASAMI, The Association For The Study And Application Of Methods Of Ilizarov; E/G/F/P/F, Excellent/Good/Fair/Poor/Failure; EFT, External fixation time; EFI, External fixation index.



Test for heterogeneity

Q	95.9968
DF	26
Significance level	P < 0.0001
I ² (inconsistency)	72.92%
95% CI for I ²	60.34 to 81.50

Publication bias

Egger's test	
Intercept	-0.4914
95% CI	-2.7604 to 1.7775
Significance level	P = 0.6594
Begg's test	
Kendall's Tau	-0.1343
Significance level	P = 0.3258

Fig. 2. Proportion meta-analysis of ASAMI bone score - ilizarov.

was 65, of which 30 studies scored between 55 and 69 (Fair group), and five studies showed scores between 70 and 84 (Good Group). Details have been tabulated in Table 1.

7.3. Mean previous surgical procedures

A total of 25 studies reported on the mean previous surgical procedures patients underwent before being part of the study. The Ilizarov group noted 3.18 mean previous surgical procedures in 21 studies, whereas the LRS group noted a mean of 2.30 procedures in 5 studies. Details have been tabulated in Table 1.

7.4. Mean bone defect

A total of 25 studies reported on the mean bone defects in patients before being part of the study. The Ilizarov group noted a mean of 5.43 cm in 19 studies, whereas the

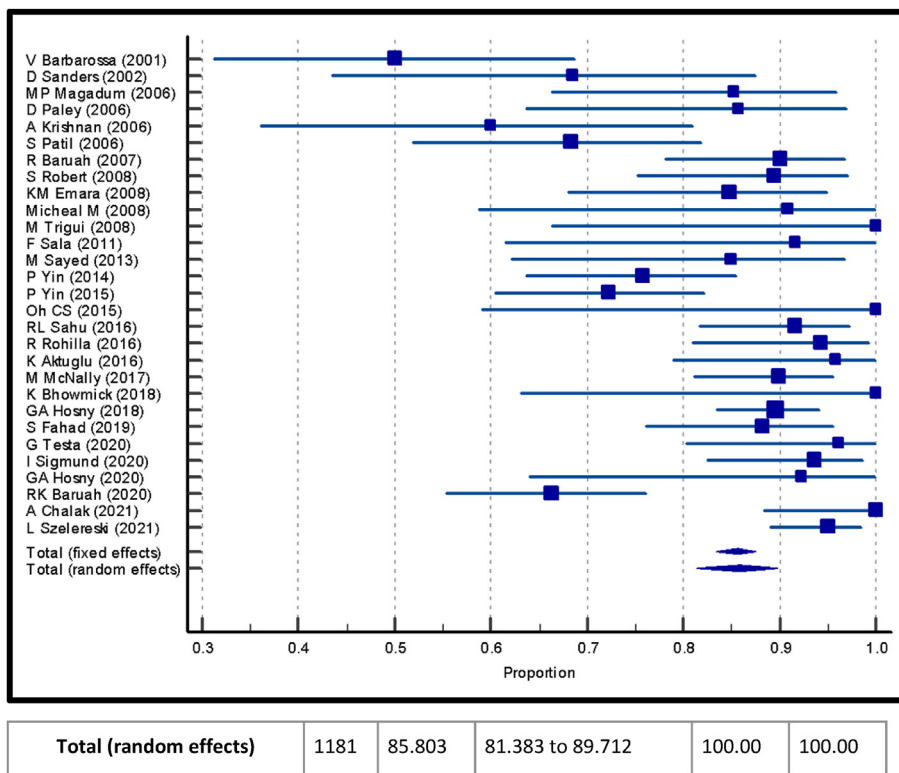
LRS group noted a mean of 6.97 cm in 7 studies. Details have been tabulated in Table 1.

7.5. External fixator index (day/cm)

Twenty-one studies reported on the External fixator index, including the comparative study. 16 studies in the Ilizarov group with the average being 54.46 day/cm, while in the LRS group, seven studies reported on the outcome with the average being 43.64 day/cm. Details have been tabulated in Table 2.

7.6. External fixator time (month)

Thirty-two studies reported on the follow-up, including the comparative study. Twenty-six studies were in the Ilizarov group, with the average being 8.52



Test for heterogeneity

Q	112.3084
DF	28
Significance level	P < 0.0001
I ² (inconsistency)	75.07%
95% CI for I ²	64.28 to 82.60

Publication bias

Egger's test	
Intercept	0.3080
95% CI	-1.9196 to 2.5356
Significance level	P = 0.7788
Begg's test	
Kendall's Tau	0.01481
Significance level	P = 0.9102

Fig. 3. Proportion meta-analysis of ASAMI Functional Score - Ilizarov.

months, while in the LRS group, all studies reported on the outcome with the average being 7.98 months.^{4,7,33–35,42,43,46} Details have been tabulated in Table 2.

7.7. Follow up

Thirty-three studies reported on the follow-up, including the comparative study. Twenty-seven studies in the Ilizarov group with the average follow-up being 41.03 months,^{4,7,15,17–32,36–41,44,45} while in the LRS group, all studies reported the outcome with an average of 33.95 months.^{4,7,33–35,42,43,46} Details have been tabulated in Table 1.

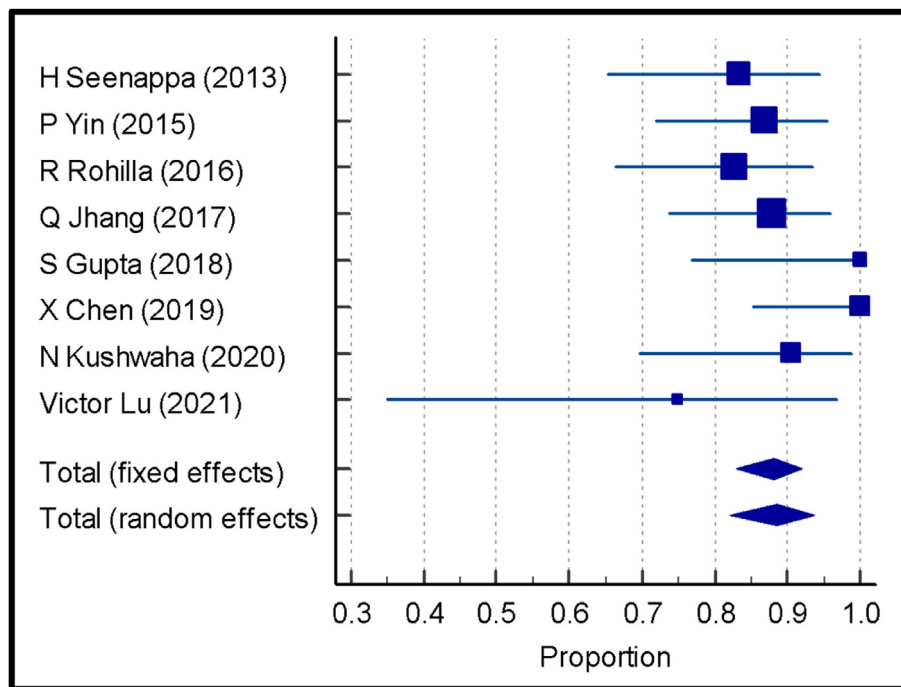
7.8. Outcome assessment

The review included studies with a standardized protocol for reporting the outcomes. The Association for the Study and Application of Methods of Ilizarov (ASAMI) scoring system in which Bone and Functional results were assessed separately.

Total of 27 studies reported on the ASAMI Bone results in the Ilizarov group,^{4,7,15–21,23–32,37–41,44,45} with a total of 1029 patients reported with excellent to good results among the 1170 total number of patients accounting for about 89.31% of patients. In the LRS group, all studies reported on the ASAMI Bone results with a total of 185 patients reported with excellent to good results among the 210 total number of patients accounting for about 88.3% of patients.^{4,7,33–35,42,43,46}

Total of 29 studies reported on the ASAMI Functional results in the Ilizarov group with a total of 1001 patients reported with excellent to good results among the 1181 total number of patients accounting for about 85.87% patients.^{4,7,15–32,36–41,44,45} In the LRS group, a total of 7 studies reported on the ASAMI Functional results with a total of 171 patients reported with excellent to good results among the 210 total number of patients accounting for about 87.74% of patients.^{4,7,33,34,42,43,46}

The results have been tabulated in Table 2, and the proportion meta-analysis is in Figs. 2–5. Proportion meta-analysis for both



Total (random effects)	172	89.036	81.402 to 94.843	100.00	100.00
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Test for heterogeneity

Q	12.3088
DF	6
Significance level	P = 0.0554
I ² (inconsistency)	51.25%
95% CI for I ²	0.00 to 79.29

Publication bias

Egger's test	
Intercept	1.0339
95% CI	-5.7154 to 7.7831
Significance level	P = 0.7100
Begg's test	
Kendall's Tau	0.04762
Significance level	P = 0.8806

Fig. 4. Proportion meta-analysis of ASAMI bone score - LRS

bone and functional results showed significant level of test of heterogeneity in ilizarov group ($p < 0.0001$) compared to LRS group.

7.9. Complications

The complications noted were subgrouped into implant-related complications, adjacent joint-related complications, Nerve injuries, bone-related complications, Limb length discrepancy, nonunion, other infection, intractable pain, and Miscellaneous.

Of all the complications, implant related complications were most common in all studies and among both groups. Among the implant-related complications - Pin Tract Infection accounted for almost 90% and was the most common individual complication which almost all patients suffered during the postoperative period, which was managed conservatively by changing the dressing

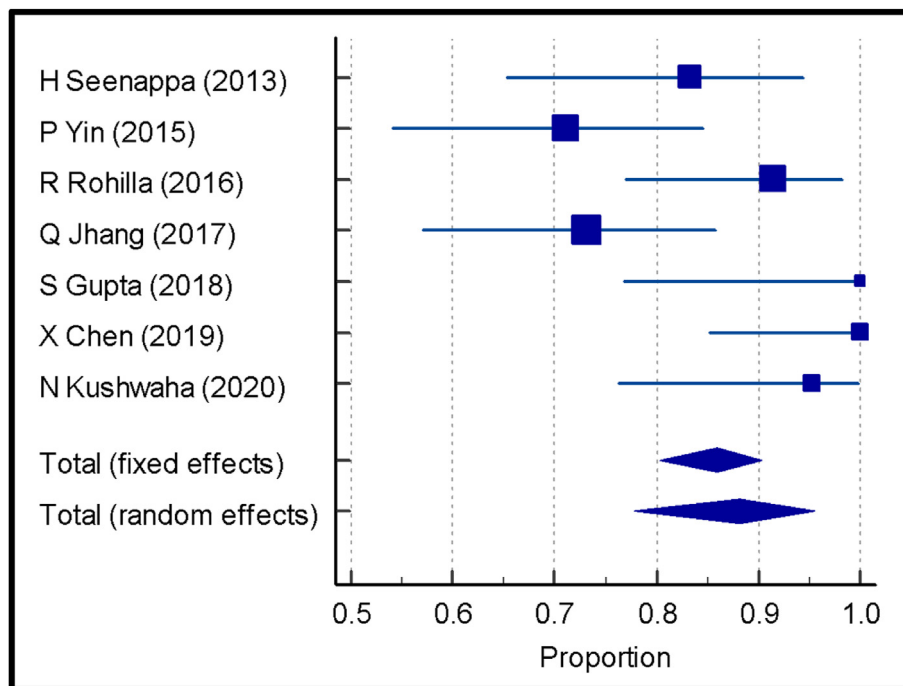
regularly, and few required further surgical management.^{4,7,15-19,21-37,39,41-44,46}

The 2nd most common complication noted was adjacent joint stiffness, managed by physiotherapy, and few requiring further surgical management.^{4,16-19,21-25,27,28,31,33,36,37,39,42}

All complications were noted and tabulated individually and as complications per patient in Table-2,3 and a graphical representation in Figs. 6 and 7.

8. Discussion

Long bone defects with no union that may or may not be segmental require appropriate treatment for adequate outcomes.⁴⁷⁻⁴⁹ Distraction osteogenesis by Ilizarov or monorail fixator, masquelet technique, and vascularized fibular grafting are currently the methods to treat segmental long bone defects.⁶⁻⁸ The



Total (random effects)	164	90.160	82.551 to 95.767	100.00	100.00
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Test for heterogeneity

Q	10.6635
DF	5
Significance level	P = 0.0585
I ² (inconsistency)	53.11%
95% CI for I ²	0.00 to 81.27

Publication bias

Egger's test	
Intercept	5.7349
95% CI	-2.3707 to 13.8405
Significance level	P = 0.1209
Begg's test	
Kendall's Tau	0.4667
Significance level	P = 0.1885

Fig. 5. Proportion meta-analysis of ASAMI Functional Score – LRS.

Table 3
Complications of Ilizarov and LRS group.

ILIZAROV DATA									
Author (Year)	Implant Related Complications	Adjacent Joint Complications	Nerve Injuries	Bone Related Complications	LLD	Nonunion	Infection	Intractable Pain	Others
V Barbarossa (2001)	PTI - 1	Stiffness – 15 Axial Deviation - 13	Dysesthesia - 3	Refracture - 1	LLD - 6	Nonunion – 4 Amputation - 1		Intractable Pain - 2	Mental Depression - 3
David W. Sanders (2002)	PTI - 10	Stiffness – 3 Deformity - 3	Nerve Palsy - 1		LLD - 2	Nonunion – 1	Leg Abscess - 1		Osteopenia - 7
S Patil (2006)	PTI - 41 Wire Break - 1	Equinus Contracture – 1		Poor Regenerate - 3 Refracture - 2 Fracture Of Regenerate - 1		Amputation - 1	Persistent Infection – 2 Chronic OM – 2 Septic Arthritis - 1		DVT – 1
A Krishnan (2006)	PTI - 11	Joint Stiffness – 11 Angular Deformity – 1 Axial Deviation – 14 Edema – 5 Deformity – 2		Refracture - 1 Delayed Consolidation – 2 Premature Consolidation - 1	LLD - 1	Nonunion – 1 Amputation - 1		Intractable Pain - 3	Severe Dystrophy – 7 Weight Loss – 9 Depression - 3
MP Magadum (2006)	PTI – 21 Wire Loosening – 0			Refracture - 0		Nonunion – 1 Amputation - 1			
Dror Paley (2006)	PTI - 27 Pin Breakage - 1	Knee Effusion - 1	Nerve Palsy - 2	Premature Consolidation - 4 Delayed Consolidation - 2	LLD - 1		Infection – 7		
Ranjit Baruah (2007)	PTI – 5	Axial Deviation – 13 Equinus Deformity - 2		Delayed Consolidation - 7 Early Consolidation - 1 Refracture - 2 Hyporegenerate - 4		Nonunion – 4			Aneurysm - 1 Interposition Of Soft Tissue - 6
Khaled M Emara (2008)	PTI -3 Pin Loosening – 1 Broken Nail – 2 (In IMN Group)	Joint Stiffness - 2							Unplanned Surgery - 2
S. Robert Rozbruch (2008)						Nonunion - 11 Amputation - 2	Infection - 11		
Michael D. McKee (2008)	PTI - 4	Osteoarthritis – 3 Ankle fusion – 1 Deformity - 2 Angular deformity - 4	Nerve Palsy - 2	Translation - 1 Refracture - 1	LLD - 2	Amputation- 1	Osteomyelitis - 2 Cellulitis - 2	Intractable Pain - 1	
M. Trigui (2008)		Axial Deviation - 4			LLD - 6	Nonunion – 0	Infection - 0		
Francesco Sala (2011)	PTI - 10	Equinus - 3			LLD - 2				Pseudoaneurysm - 1
M Sayed (2013)	PTI – 16 Pin Loosening – 2 Frame Adjustment - 2	Joint Stiffness – 12 Deformity – 8 Edema – 5		Refracture - 1	LLD - 4	Nonunion – 2	Persistent Infection – 1	Intractable Pain - 3	Depression - 3
P Yin (2014)						Nonunion – 0	Infection – 0		
Chang Seon Oh (2015)	PTI - 1					Nonunion – 1			Recurrence Of Tumor - 1
Peng Yin (2015)	PTI - 46 Wire loosening - 4	Axial deviation - 20		Refracture - 2	LLD - 2	Nonunion – 7	Local inflammation - 66		
Ramji Lal Sahu (2016)	PTI - 60	Equinus - 4 Angular Deformity - 2 Stiffness - 5 Equinus - 3		Angulation - 5	LLD - 6	Nonunion – 1			Soft Tissue Dystrophy - 3
Kemal Aktuglu (2016)	PTI - 17								Skin Tethered - 7 Soft Tissue Injury – 11
R Rohilla (2016)	PTI - 21 Broken Screw – 2	Joint Stiffness – 14 Angular Deformity - 4			LLD - 3				
Martin McNally (2017)	PTI – 3 Broken Wire - 4			Refracture - 8	LLD - 3				

Table 3 (continued)

ILIZAROV DATA									
Author (Year)	Implant Related Complications	Adjacent Joint Complications	Nerve Injuries	Bone Related Complications	LLD	Nonunion	Infection	Intractable Pain	Others
Gamal Ahmed Hosny (2018)	PTI - 11	Deformity - 3	Nerve Palsy - 2	Lengthening - 2	LLD - 4	Nonunion - 3		NS	
K Bhowmick (2018)	PTI - 1	Deformity - 2 Axial Deviation - 1		Refracture - 1		Nonunion - 2	Soft Tissue Infection - 1		
S Fahad (2019)	PTI - 9 Pin Loosening - 2 Screw Broken - 1				LLD - 7	Nonunion - 2 Amputation - 1	Re- Infection - 1 Leg Abscess - 1		
R K Baruah (2020)	PTI - 23	Equinus - 3	Nerve Palsy - 2	Delayed Consolidation - 10		Nonunion - 2	Septic Arthritis - 1		False Aneurysm - 1 Soft Tissue Interposition - 10
G Testa (2020)	PTI - 3 K-Wire Break - 1 Screw Break - 2								
I Sigmund (2020)	PTI - 22 Pin Removal - 1	Deformity - 0		Premature Consolidation - 2	LLD - 0			Painful Thethred Skin - 1	
Gamal Ahmed Hosny (2020)	PTI - 9	Joint Stiffness - 2 Angular Deformity - 2		Delayed Union - 1 Refracture - 1	LLD - 3				
A Chalak (2021)	PTI - 5			Soft Tissue Invagination At The Docking Site - 2					
Lukasz Szelereski (2021)				Refracture - 5					
LRS DATA									
Author (Year)	Implant Related Complications	Adjacent Joint Complications	Nerve Injuries	Bone Related Complications	LLD	Nonunion	Infection	Intractable Pain	Others
Hiranaya Seenappa (2013)	PTI - 22 Pin Loosening - 8	Joint Stiffness - 13 Angular Deformity - 2		Refracture - 1	LLD - 4				
Peng Yin (2015)	PTI - 24 Wire loosening - 4	Axial deviation - 12		Refracture - 2 (in total)	LLD - 2	Nonunion - 5	Local inflammation: 66 (in total)		
R Rohilla (2016)	PTI - 30 Pin Loosening - 1	Joint Stiffness - 8 Angular Deformity - 3			LLD - 6				
Qun Jhang (2017)	PTI - 23 Pin Loosening - 2	Joint Stiffness - 14 Angular Deformity - 3		Refracture - 1		Nonunion - 5			Bone grafting - 1
S Gupta (2018)	PTI - 5								
Xun Chen (2019)	PTI - 5								
N Kushwaha (2020)	PTI - 4			Refracture - 1			Persistent Infection - 5		
Victor Lu (2021)	PTI - 5	Osteoarthritis - 1				Nonunion - 2	Osteomyelitis - 2	Intractable Pain - 1	Myositis Ossificans - 1

B/K, Below Knee; DVT, Deep Vein thrombosis; LLD, Limb Length Discrepancy; OM, Osteomyelitis, PTI – Pin tract infection.

use of monorail fixators has risen in the last decade and is employed in many cases of nonunions. The Ilizarov fixators are the mainstay of treatment. The bone transport can be performed with both systems. However, both the modes of fixation have some biomechanical differences. Ilizarov due to its 3 dimensional fixation with tensioned wire/pins provides uniform loading where as LRS due to its uniplanar fixation has a cantilever effect at fracture site. The current review focuses on both LRS and Ilizarov fixators in the nonunion of long bones separately.

In our study, we found that the overall complication rate with the use of Ilizarov was 89.4%. The most common complication was pin tract infection. The rest of the complications were joint stiffness, angular deformity, wire breakage, nonunion, refracture, amputation. Multiple studies have highlighted the advantages, such as better bone and functional results with a low rate of

refracture, infectious recurrence, and amputation.^{49–52} The ring fixator with multiple rings and wires is prone to pin tract infection and pin breakage. The study noted pin tract related complication as most common.^{53,54} The rate of refracture and amputation were 2.05% and 0.65%, respectively, in the Ilizarov group, which was less than 4% and 4% reported by Ying P et al.⁹ and 5% and 2.9% reported by Papakostidis et al.⁵⁵ The incidence of deformity of long bones in LRS was 7.4%. The analysis showed most common complication was pin tract infection, with an incidence of nearly 90% in both treatment arms, which was similar to that reported by Papakostidis et al. and Ying P et al.^{9,55,56}

The average external fixator time was 8.52 months with Ilizarov and 7.98 months with LRS, both being lower than that reported in the meta-analysis on Ilizarov fixator in segmental long bone defect by Ying P et al., which was 10.69 months.⁹ The external fixator

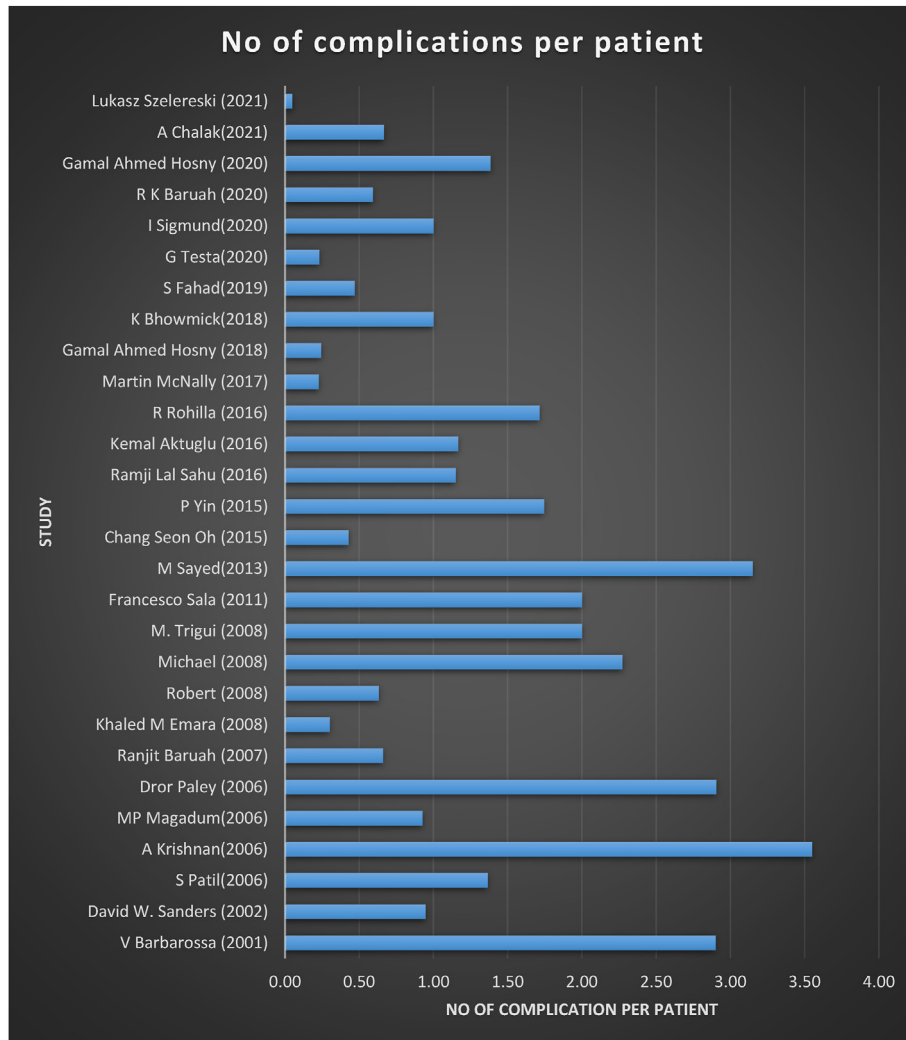


Fig. 6. Complication per patient – Ilizarov.

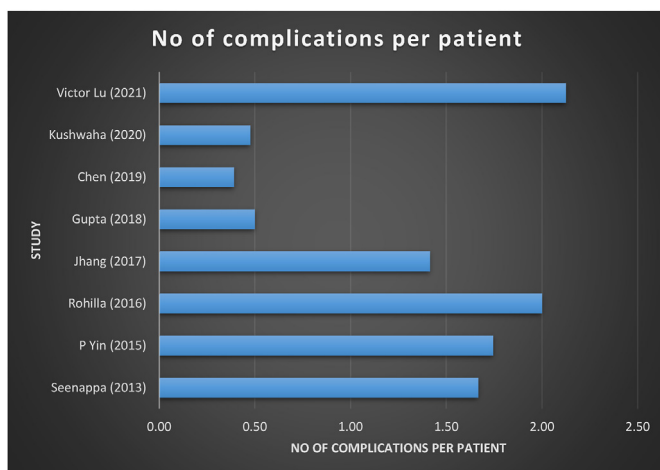


Fig. 7. Complication per patient - LRS.

index is the time required to cover the bone gap present. EFI in Ilizarov and LRS group was respectively 54.46 days/cm and 43.64 days/cm, which was less than that reported in the study by Ying P et al.⁹ Treatment with LRS appears to have less fixator time which

may increase compliance in the long term.

Outcome assessment was done by ASAMI functional score in all of the studies on Ilizarov and seven studies on LRS fixator, whereas ASAMI bone score was used in 27 studies on Ilizarov and eight studies on LRS. In the Ilizarov group, 85.87% reported excellent to good results as compared to the LRS group, where 87.74% reported excellent to good results on ASAMI functional scoring showing the use of both Ilizarov and LRS have a comparable functional outcome in patients. Similar was the case with the ASAMI bone score, where both groups had similar results, 89.31%, and 88.3% had excellent to a good outcome in Ilizarov and LRS groups, respectively.

To our best knowledge, this is the first systematic review involving both Ilizarov and LRS fixator for long bone nonunion, where we studied 1219 patients treated with Ilizarov fixator and 282 patients with LRS fixator. Ying P et al., in their review, looked at Ilizarov fixator in 590 patients⁹

Overall, the treatment arms were similar in terms of functional and bone outcomes. Pin tract infection was the most common complication in both groups. However, joint stiffness was more frequent in the LRS group, and deformity was more common with the Ilizarov fixator. So clinically, both Ilizarov and LRS fixator yield similar results in the management of long bone nonunion.

Our study does have its limitations. The review included a mixture of study designs. Ideally, one would survive for

randomized controlled trials for accurate results. The literature currently lacks such studies. Second, there were very few studies comparing Ilizarov vs LRS methods. Such comparative studies are the need of the day. Third, even though a thorough search was conducted, a few studies might be missed. Fourth, the protocol for this systematic review was not preregistered or published.

9. Conclusion

The review was conducted to understand the scenario of nonunion in long bones. We found that both Ilizarov and LRS fixator yield similar clinical results for the treatment of long bones nonunion. Pin tract infection is found to be the most common complication followed by adjacent joint stiffness and deformity. In our review we observed that both external fixator time and index were lower in LRS. Further RCT are required comparing Ilizarov and LRS fixators to effectively comment upon the superiority of the implants.

Consent to participants

Not Applicable.

Consent to publish

All authors have read the final prepared draft of the manuscript and approve this version, in its current format if considered further for publication.

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Availability of data and materials

All included studies used in this retrospective study are available online. The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request. Data regarding this study is not available in any electronic databases.

Informed consent

Not Applicable.

Ethics approval

Approval from the institutional ethics committee was not required for this review article.

Authors contribution

V.M – Conceptualization, project administration Planning of study, literature search, writing the manuscript, quality assessment of the included studies.

B.S.R - Data curation, outcome assessment, manuscript preparation.

B.B – Formal analysis, Data management, manuscript preparation.

A.R- Methodology, Literature search, writing the manuscript, quality assessment of the included studies.

M.D - Quality assessment of the included studies, writing and revising the manuscript, Correspondence.

A.K.S.G - Data management, outcome assessment, revising the

manuscript.

Declaration of competing interest

All authors declare that they do not have any competing interest, concerning this research, authorship, and/or publication of this article.

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Abbreviation

- LRS: Limb Reconstruction System
 MPSP: Mean previous surgical procedures
 ASAMI: The Association For The Study And Application Of Methods Of Ilizarov
 E/G/F/P/F: Excellent/Good/Fair/Poor/Failure
 EFT: External fixation time
 EFI: External fixation index
 PRISMA: Preferred Reporting Items for Systematic Reviews and Meta-Analyses
 ASR: Acute Shortening and Relengthening
 BT: Bone Transport
 MCMS: Modified Coleman Methodology score
 RCT: Randomized Control Trial
 PFI: Pin tract infection