



ELSEVIER

Effectiveness of revision following linked versus unlinked total elbow arthroplasty

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Purpose: The purpose of this study is to specifically evaluate the implications of unlinked and linked designs on the survivorship of revision surgery.

Methods: Between 1972 and 1990, 352 linked and 151 unlinked prostheses were inserted at our institution. One-hundred and twenty-two elbows (24%) underwent subsequent revision: 55 linked (16%) and 67 unlinked (44%). Survivorship of the initial and revision total elbow replacement was calculated using a Kaplan-Meier analysis. Comparisons were made between revisions done after a failed primary linked or unlinked designs. The unlinked revised to a linked device was more reliable than when revised to another unlinked device: 1 year survival 84% compared to 47%.

Results: Initial survival was 56% at 367 months and 84% at 371 months for the unlinked and linked cohorts, respectively ($P < .001$). A second revision was required in 12 of the 35 elbows (30%) in the linked cohort and 14 of the 50 elbows (28%) in the unlinked.

Conclusions: At our institution, primary linked implants display significantly better long-term survivorship ($P < .001$) than did the unlinked designs. Unlinked designs are most reliably converted to a linked implant.

Level of evidence: Level 3; Treatment study, retrospective case-control study.

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As total elbow replacement surgery becomes more prevalent, the success of modern elbow arthroplasty should be judged on the ability to achieve satisfactory outcomes with reoperation. Some of the most important elements of a prosthetic design are the impact that the prosthesis may have on future revisions and how the design is suited to deal with the challenges seen in the revision setting. Therefore,

analysis of the effect of primary surgery on subsequent revisions must be considered in the context of the initial implant design selection.

Both unlinked and linked total elbow arthroplasty have been used successfully in the primary setting to treat patients with rheumatoid arthritis,^{14,21,22} post-traumatic arthritis,¹¹ distal humerus nonunions,¹¹ acute distal humerus fractures,^{3,7,8} instability,^{13,16} and osteoarthritis.¹⁰ While success has been reported using total elbow arthroplasty in the setting of a revision for fracture, complications can be seen in up to 60% of cases.^{1,9,15,17-19,23} However, there has been

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Table I Unlinked and linked total elbow arthroplasty designs used

Linked designs	Number of elbows	Unlinked designs	Number of elbows
Coonrad-Morrey	242	Mayo	63
Coonrad II	3	Prichard ERS	41
Coonrad I	60	Capitellocondylar	45
Prichard-Walker	38	London	2
Schlein	5		
G.S.B	4		
Total	352		151

little discussion on how each design used as a primary replacement influences the results of future revisions. The purpose of this study is to evaluate the effect of prosthetic design (linked or unlinked) on survivorship of subsequent revision total elbow arthroplasty.

Materials and methods

A retrospective review was performed for all patients treated with a primary total elbow arthroplasty between 1972 and 1990 at a single institution. Data regarding these surgeries and subsequent follow-up had been acquired prospectively and entered into the institutional arthroplasty database, and were reviewed. A total of 503 primary total elbow arthroplasties were performed over this 18-year period. Two cohorts were established based on whether the primary total elbow arthroplasty was performed using a linked or an unlinked prosthesis. There were 352 total elbow prostheses in the linked cohort and 151 in the unlinked (Table I). Five different unlinked and 6 different linked implant designs were utilized by 14 different surgeons.

An analysis of the 116 patients (122 elbows) primary total elbow replacements that subsequently required revision for a variety of reasons was then performed (Table II). Twenty-six of these patients were treated with resection arthroplasty and 11 patients underwent revision at another institution. Data on 79 remaining patients (85 elbows) were, therefore, available for analysis. Survivorship of the revision surgery was calculated using a Kaplan-Meier Survivorship Analysis with removal or revision of any portion of the prosthesis as the endpoint (MedCalc version 9.0.1.0; Mariakerke, Belgium Medcalc). Comparisons were made between revisions done after a failed primary linked design (linked cohort) and revisions done after a failed primary unlinked design (unlinked cohort).

Statistical analysis

Differences between groups were analyzed using *t* test analysis assuming equal differences. Survivorship of the initial primary total elbow was calculated using a Kaplan-Meier survivorship analysis with removal or revision of any portion of the prosthesis as the endpoint (MedCalc version 9.0.1.0; Mariakerke). Comparisons were then made between the unlinked and linked cohorts using a Chi-square analysis. Differences occurring with less than

a 5% likelihood of being by chance were considered statistically significant.

Results

Primary total elbow arthroplasty was performed for a variety of indications. The most common indications were rheumatoid arthritis, distal humerus nonunion, post-traumatic arthritis, acute distal humerus fracture, spontaneous ankylosis, and tumor reconstruction (Table III). Comparison of the unlinked and linked cohorts noted a statistically significant difference in regards to age. The average age of the linked cohort was 60, whereas the average age of the unlinked cohort was 54 ($P < .0001$). Additionally, there was a statistically higher percentage of patients (Chi-square $P < .001$) treated for rheumatoid arthritis in the unlinked cohort (131/151, 87%) than within the linked cohort (189/352, 54%) (Figures 1 and 2).

The average length of time before revision in the linked cohort was 73.9-91.2 months in the unlinked cohort ($P = .1663$). Results of the Kaplan-Meier survivorship analysis noted a survival rate for the linked cohort of 84% at 371 months and 56% at 367 months for unlinked cohort. The average time from surgery to the endpoint used for this analysis was 134.8 months (range, 1 day to 370.5 months) for the linked cohort and 147.4 months (range, 3 weeks to 366.9 months) for the unlinked cohort. The patient followed for only 1 day died of a fatal pulmonary embolism on postoperative day 1.

Analysis of revision surgeries identified a total of 85 revision procedures. There were 50 revisions in the linked cohort (30%) and 35 revisions in the unlinked cohort (10%). The frequency of revision was statistically greater in the unlinked group (Chi-square $P < .001$). The initial diagnosis for those elbows that required revisions differed between the unlinked and linked groups (Table IV). For the unlinked cohort, 92% (46/50) of elbows were done for the initial indication of rheumatoid arthritis; whereas 60% (21/35) of the elbows revised in the linked cohort were for the initial indication of distal humerus fracture. There was no difference in the need for revision in those with rheumatoid

Table II Reason for initial revision

Indication for initial revision	Linked (%)	Unlinked (%)
Infection	16 (29) 3 Coonrad I; 1 Coonrad-Morrey 2 GSB 7 Mayo-Coonrad 2 Pritchard Walker 1 Schlein	10 (15) 1 Capitellocondylar 5 Eswald 3 Mayo 1 Pritchard ERS
Ulna loosening	8 (15) 1 Coonrad I 1 Coonrad II 4 Mayo-Coonrad 2 Pritchard-Walker	11 (17) 2 Eswald 1 London 3 Mayo 5 Prichard ERS
Humeral loosening	11 (20) 6 Coonrad I 5 Mayo-Coonrad	11 (16) 6 Mayo 6 Prichard ERS
Global loosening	3 (5) 2 Mayo-Coonrad 1 Pritchard Walker	10 (15) 6 Mayo 4 Prichard ERS
Undefined loosening	0	1 (2) 1 Pritchard ERS
Ulna component fracture	6 (11) 2 Coonrad-Morrey 4 Mayo-Coonrad	4 (6) 2 Mayo 2 Pritchard ERS
Humeral component fracture	3 (5) 2 Coonrad-Morrey 1 Mayo-Coonrad	1 (2) 1 Mayo
Peri-prosthetic Fracture	6 (11) 2 Coonrad I 1 Coonrad-Morrey 3 Pritchard-Walker	8 (12) 2 Eswald 1 Mayo 5 Pritchard ERS
Instability	0	10 (15) 4 Eswald 6 Pritchard ERS
Metastatic tumor	1 (2) 1 Mayo-Coonrad	0
Total (%)	55/352 (16)	66/151 (44)

arthritis who received a linked (1 in 5) (20%) and an unlinked implant (13/33) (28%) – (Chi-square = .154-N.S.)

Second revisions were required in 12 of the 35 revisions performed after linked designs (linked cohort) and 14 of the 50 revisions performed after unlinked designs (unlinked cohort). Revision surgery in the linked cohort had a survival rate of 66% at 288 months; whereas the survival rate of revision in the unlinked cohort was 72% at 284 months. The success of revision of patients with rheumatoid arthritis was not statistically different (Chi-square = .154) (Table IV) between the unlinked (33/46) (72%) and linked implants (3/4) (75%).

Further analysis of the unlinked cohort noted differences in survival rates depending on the type of implant used for revision surgery. When primary unlinked designs were revised using an unlinked design, the survival rate of the

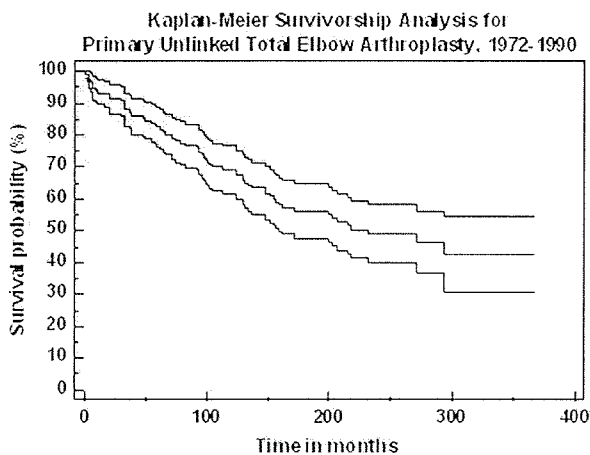
revision was 47% at 284 months; however, when primary unlinked designs were revised to a linked design, the survival rate was 84% at 271 months.

Discussion

As the success and indications of total elbow arthroplasty continue to expand, the frequency for revision arthroplasty will also increase. Revision of failed total elbow arthroplasty is a challenging procedure, with difficult reconstructions and high rates of complications. In order to meet this challenge, not only is there a need for implants that allow for successful revision reconstruction, but there is also a need for primary implant designs that will facilitate

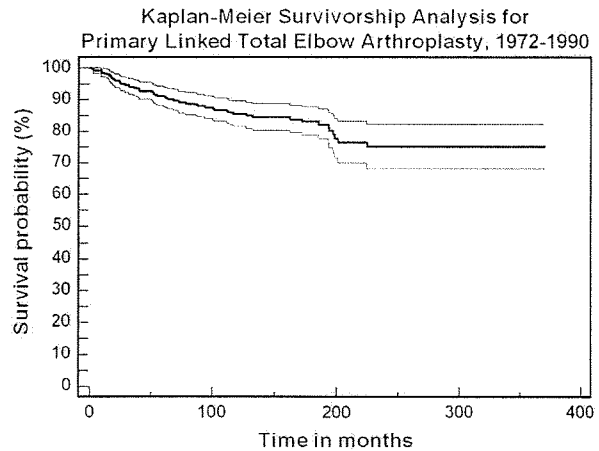
Table III Underlying diagnosis requiring primary total elbow arthroplasty

Diagnosis	Linked (%)	Unlinked (%)
Rheumatoid arthritis	189 (54)	131 (87)
Nonunion	57 (16)	0
Post-traumatic arthritis	53 (15)	9 (6)
Acute distal humerus Fracture	13 (4)	0
Spontaneous ankylosis	12 (3)	4 (3)
Tumor	10 (3)	0
Juvenile rheumatoid arthritis	7 (2)	3 (2)
Osteoarthritis	4 (1)	2 (1)
Arthrodesis	2 (0.5)	0
Instability	2 (0.5)	0
Hemophilia	2 (0.5)	0
Chondrocalcinosis	1 (0.3)	0
Avascular necrosis	0	1 (1)
Previous septic arthritis	0	1 (1)
Total	352	151

**Figure 1** Kaplan-Meier survivorship analysis for primary unlinked total elbow arthroplasty from 1972 to 1990.

have a low failure rate, and are designed to facilitate future reconstructions.

Some of the considerations of employing an unlinked device are the expectation of a lower loosening rate and the potential for a more reliable revision when necessary. This study is the first analysis to compare long-term survival rates of primary total elbow arthroplasty using unlinked and linked designs. Previous studies of either linked or unlinked designs noted long-term survival rates of greater than 90% in patients with rheumatoid arthritis, comparable to that seen after hip and knee arthroplasty.^{2,4-6,21} Little et al reported a systematic review of the entire literature on total elbow arthroplasty up to the end of 2003, and found an overall revision rate of 13%.¹² To date, however, no long-term comparison has been made between survival rates of unlinked and linked designs

**Figure 2** Kaplan-Meier survivorship analysis for primary linked total elbow arthroplasty from 1972 to 1990.

performed at the same institution by the same physicians. In the current study, survivorship analysis of primary total elbow replacements performed over an 18-year period demonstrated approximately a 25% difference between the survival of unlinked and linked designs with up to 30-year follow-up (Figures 1 and 2; 84% months vs 56% at 367 months). The difference of survival between these 2 designs is statistically different (Chi-square < .001). Hence, the hope or expectation of a better survival rate with unlinked implants used in this study was not demonstrated in our experience.

Assessment of these data reveals the 2 groups are not comparable according to diagnosis, a bias that favors the unlinked implant due to the recognized better prognosis in the rheumatoid patient.^{10,11,14,16,21,22} Specifically, rheumatoid arthritis was the primary indication for surgery in 87% of the unlinked cohort (131/151) and 54% in the linked (189/352). As patients with rheumatoid arthritis typically place lower demands on the reconstructed elbow and typically have excellent long-term survivorship following total elbow arthroplasty,^{2,4-6,21} one might have expected lower survivorship of the unlinked cohort based on patient diagnosis alone. This was not the case.

Additionally, a different age distribution occurred between the 2 cohorts. In the past, the use of an unlinked device was recommended for the younger patient, which would tend to suggest a less favorable prognosis for the longevity of the unlinked design.²⁰ The average age of patients treated with linked designs was 60 years, compared to an average age of 54 in the unlinked cohort ($P < .0001$). Long-term survival rates of total elbow arthroplasty are thought to be lower in younger patients.²⁰ This difference is thought to be due to the increased demands that younger patients place on the elbow implant. Higher rates of revision in the unlinked cohort may thus to some extent be related to age-related demands as well as design concept. In the current series, the average length of time before revision

Table IV Initial diagnosis of elbows requiring first and second revision

Primary indication for TEA in patients requiring revision	Unlinked		Linked	
	Primary unlinked requiring 1 revision	Primary unlinked requiring 2 revisions	Primary linked requiring 1 revision	Primary linked requiring 2 revisions
Rheumatoid arthritis [#]	46 (92%)	13	5 (14%)	1
Distal humerus fracture			21 (60%)	8
Post-traumatic arthritis	3 (6%)	1	5 (14%)	2
Osteoarthritis	1 (2%)		1 (3%)	1
AVN			1 (3%)	
Tumor			1 (3%)	
Juvenile rheumatoid arthritis			1 (3%)	
Total	50/151*	14/50	35/352	12/35

* Statistically greater than in the initial group.

Not statistically significant between the groups.

was no different between the linked (average 73.9 months) and unlinked (average 91.2 months) groups ($P = .1663$). If failure rates were primarily related to increased demand in a younger patient population, the time to loosening would be expected to be less in the younger patient. This was not the case.

Finally, a variety of different prostheses and a number of different surgeons constituted each cohort. Many of the prostheses used were either early designs or implants that are no longer available for use. In the linked cohort, patients were treated with several modifications of a single implant design. The original Coonrad elbow was modified twice during the study period of 1972-1990. These modifications did not change significantly the design philosophy, and were directed primarily at improving surgical technique. In the unlinked cohort, high instability rates seen in some of the implant designs resulted in later design changes and modifications of surgical technique. Thus early experience with both unlinked and linked designs may be responsible for many of the implant failures seen in both cohorts.

One important and previously unreported finding was that unlinked designs that were revised to linked designs displayed significantly improved outcome when compared to a revision to another unlinked implant. The difficulty of revising an unlinked design to another unlinked design has been suggested by others.¹⁸ Ring et al noted a high failure rate after attempted revisions of capitellocondylar (Johnson and Johnson, Warsaw, IN) total elbow arthroplasty using the same unlinked implant design. At 6-year follow-up, 9 of the 12 elbows failed and 7 of the 12 patients were ultimately revised to a linked design.¹⁸ In contrast, in our series, conversion of an unlinked design to a linked design was quite reliable and resulted in a high survival rate of 84% at 271 months. Yet, in our experience, as noted by Ring et al, unlinked designs revised to another unlinked design had a statistically low survival rate of 47% at 284 months (Figure 3).

Conclusion

Linked total elbow arthroplasty displays quite acceptable long-term survivorship in the primary setting for all diagnoses. Linked designs have a statistically superior rate of survival than do the unlinked devices used at our institution, in spite of adverse selection of a greater number of patients treated with a linked device having a diagnosis with documented poorer prognosis. Unlinked implants have a better rate of survival when revised to a linked implant.

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