ORIGINAL RESEARCH ARTICLE

Minimally Invasive Sacroiliac Joint Fusion with Triangular Titanium Implants: Cost-Utility Analysis from NHS Perspective

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Abstract

Objective The aim was to identify the cost-effectiveness of minimally invasive sacroiliac joint fusion (MI SIJF) surgery with titanium triangular implants for patients with sacroiliac joint (SIJ) pain who have failed conservative management, compared to non-surgical management (NSM) from a National Health Service (NHS) England perspective.

Methods Over a time horizon of 5 years, a cohort state transition model compared the costs and outcomes of treating patients with MI SIJF to those of traditional NSM treatment pathways. The NSM arm included two treatments: grouped physical therapy and corticosteroid injections (PTSI) or radiofrequency ablation (RFA). Three different strategies were considered: (1) a stepped pathway, (2) patients split between PTSI and RFA, and (3) RFA only. The outcome measure was incremental cost-effectiveness ratio (ICER), reported in 2018 British pounds per quality-adjusted life year (QALY) gained. One-way and probabilistic sensitivity analyses were used to test the robustness of the model results.

Results Patients undergoing MI SIJF accrued total procedure-related and pain-management costs of £8358, while NSM treatment strategy 1 had total costs of £6880. The MI SIJF cohort had 2.98 QALYs compared to strategy 1 with 2.30 QALYs. This resulted in an ICER for MI SIJF versus strategy 1 of £2164/QALY gained. Strategy 2 of the NSM arm had lower costs than strategy 1 (£6564) and 2.26 QALYs, and this resulted in an ICER of £2468/QALY gained for MI SIJF. Strategy 3 of the NSM arm had lower costs than strategy 1 (£6580), and this resulted in 2.28 QALYs and an ICER of £2518/QALY gained for MI SIJF. Probabilistic sensitivity analysis shows that at a threshold of £20,000/QALY gained, MI SIJF has a probability of being cost-effective versus NSM strategies of 96%, 97%, and 91% for strategies 1, 2, and 3, respectively.

Conclusion MI SIJF appears to be cost-effective over a 5-year time horizon when compared to traditional NSM pathways in an NHS context.

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Key Points for Decision Makers

In patients with sacroiliac joint (SIJ) pain who have failed conservative management, patients treated with minimally invasive sacroiliac joint fusion (MI SIJF) are estimated to accrue total procedure-related and pain-management costs of £8358 over a 5-year period compared to non-surgical management (NSM) costs of £6880 over the same period.

Treatment with MI SIJF results in quality-adjusted life year (QALY) gains of 2.98 QALYs compared to 2.30 QALYs with NSM over the same period.

MI SIJF appears to be cost-effective over a 5-year time horizon when compared to traditional NSM pathways in a National Health Service (NHS) context.

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1 Introduction

Lower back pain affects up to a third of the UK adult population [1], and sacroiliac joint (SIJ) pain is estimated to affect between 15 and 30% of sufferers of chronic lower back pain [2]. Amongst those with continued or new onset lower back pain after lumbar fusion, the prevalence of SIJ pain is even higher at 32–43% [3, 4]. The cost to the UK economy attributable to lower back pain has been estimated at £12.3 billion in 1998 [5, 6], equivalent to £38.4 billion in 2018. Lower back pain is also ranked within the global top ten disease areas with the highest impact on disability-adjusted life years [7].

Nonsurgical management (NSM) for chronic SIJ pain include medical management, physical therapy, intra-articular or peri-articular steroid injections, and radiofrequency ablation (RFA) of sacral nerve root branches. However, the evidence base supporting the efficacy of these interventions is limited [8–12].

Surgical fusion of the SIJ has been carried out since the 1920s. Several single-centre, retrospective case series suggest modest efficacy for open SIJ fusion, combined with a high morbidity rate such that open SIJ fusion is no longer commonly used [13]. There is a large body of compelling clinical evidence demonstrating minimally invasive SIJ fusion (MI SIJF), using titanium triangular implants (TTIs) (iFuse Implant System, SI-BONE, Santa Clara, CA, USA) delivers benefit to patients with confirmed SIJ pain. The National Institute for Health and Care Excellence (NICE) interventional procedure guidance [14] recommends SIJ fusion using a lateral transarticular approach. There are several available devices for MI SIJ fusion that are placed laterally. However, the majority of the clinical evidence which supports the safety and effectiveness of the procedure, including multiple randomized controlled clinical trials (RCTs) [15, 16], a large prospective multicentre study [17], multiple comparative cohorts [17–19], and long-term studies, evaluated procedures performed with TTIs. Results from these surgeries indicate that MI SIJ fusion results in a substantial immediate and sustained improvement in pain, disability, and quality of life. The procedure to insert TTIs takes about an hour and is performed under general anaesthetic. Typically, three implants are placed across the SIJ through a small incision (< 6 cm).

In 2018, NICE evaluated MI SIJF for treating chronic severe SIJ pain [22] under the Medical Technology Evaluation Programme (MTEP), concluding that MI SIJF results in pain relief, less disability, and improved quality of life compared with NSM. The results of a cost-minimization analysis suggested that while MI SIJF is initially more expensive, at 8 years and beyond, it becomes cost saving when compared to non-operative management. A positive recommendation under this NICE programme does not oblige National Health Service (NHS) England decision makers to make funding available. Showing evidence of cost-effectiveness over a shorter time horizon will be helpful to facilitate the decision-making process, demonstrating that MI SIJF is cost-effective in the short and medium term when the utility benefits are considered.

The objective of this analysis is to incorporate both clinical outcome and cost data in a cost-effectiveness model to determine the short- and medium-term clinical and economic benefits of MI SIJF.

2 Methods

2.1 Model Design

We constructed a Markov decision model in Microsoft Excel to estimate 5-year costs (2018 British pounds) and quality-adjusted life years (QALYs) from an NHS perspective with 3-month model cycles. Both costs and QALYs were discounted by 3.5% as per the recommendations in the NICE reference case. The model population was adults with chronic, disabling SIJ pain unrelated to acute trauma or underlying inflammatory disease who have failed conservative management. The population had a mean age of 50 years and a baseline Oswestry Disability Index (ODI) of 56.1 as per the trial populations of the INSITE [15], SIFI [17], and iMIA [16] trials.

The model structure described in the Medical Technology Guidance (MTG) 39 External Assessment Centre (EAC) report [23] was adapted to capture health state utility, and is illustrated in Figs. 1 and 2. A Markov structure was selected as it allows modelling of transitions in health states over fixed periods of time. This is relevant to this decision problem for the following reasons: (1) patients appear to transition from highly symptomatic to much less symptomatic within a month or two post SIJF; (2) patients treated with steroid injections in the physical therapy and corticosteroid injections (PTSI) arm may show some temporary improvement, but often worsen quickly; and (3) patients treated with RFA show somewhat longer periods of response, but then routinely worsen over time.

A 3-month time horizon was applied to allow patients to transition from a health state for responding well to treatment to a health state for recurring pain over a relatively short time period. It is assumed that treatment in any of the interventions occurs in a 3-month period, during which the patient maintains baseline utility scores, but does not incur additional pain-management costs on top of their intervention. This is because patients with a response to treatment with MI SIJF experience symptom relief within 1 month of

surgery. Similarly, patients' immediate and temporary pain relief is assumed with steroid injections and RFA. After the 3-month treatment period, if a patient moves to a response state, it is assumed that they do not incur further healthcare and pharmacy costs related to SIJ pain management, but if they move to a poor ODI response state, their pain-management costs revert to baseline. Patients with chronic SIJ joint pain were assumed not to experience relief from pain naturally, and patients in a response state after surgery were assumed not to experience any deterioration in condition over time. Mortality was modelled as per the general population, no mortality hazard ratio for SIJ joint pain patients was applied, and there was no difference between patients experiencing a response to treatment and those remaining in pain states, an assumption biasing against effective treatments because disability is associated with higher comorbidity.

In the MI SIJF treatment arm, patients enter the model in the surgical health state. This is a tunnel state, and after one model cycle, patients achieve a response to treatment, they fail to achieve an ODI response, or they require an early

surgical revision for implant malposition (which can cause new onset radicular pain). Patients indefinitely remain in these health states unless they require a late revision surgery, after which they may move to 'response' or 'no response'. Late revision surgery is occasionally performed to address late recurrence of pain or disability [24], which is captured in the model.

MI SIJF was compared to NSM, which included three alternative treatment strategies:

1. A stepped pathway where patients are initially treated with a combination of conservative management techniques such as PTSI and/or RFA and may transition from treatment with PTSI to RFA
2. A combination pathway where a proportion of patients are treated with PTSI and are not allowed to transition to RFA and a proportion of patients start treatment with RFA
3. Treatment with RFA only

Fig. 1 Diagram of model structure used to simulate patient history following surgery with MI SIJF. *MI SIJF* minimally invasive sacroiliac joint fusion
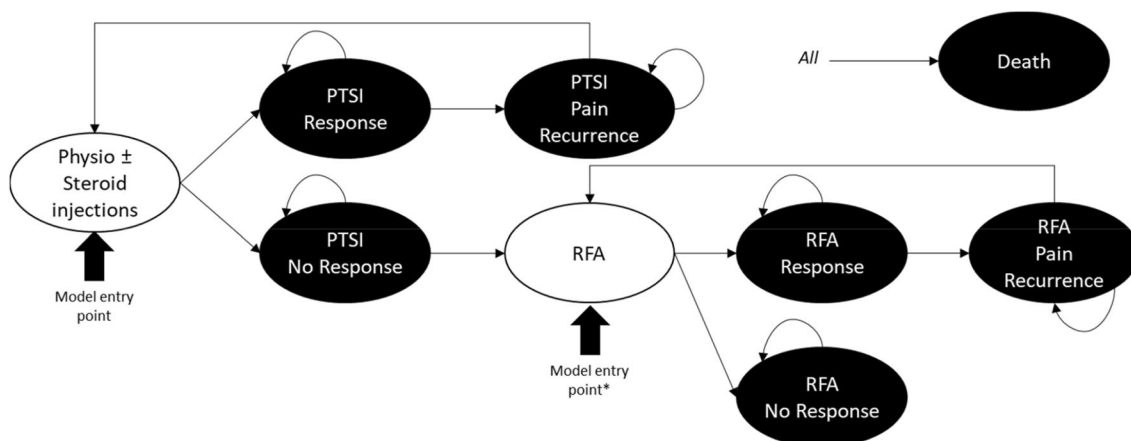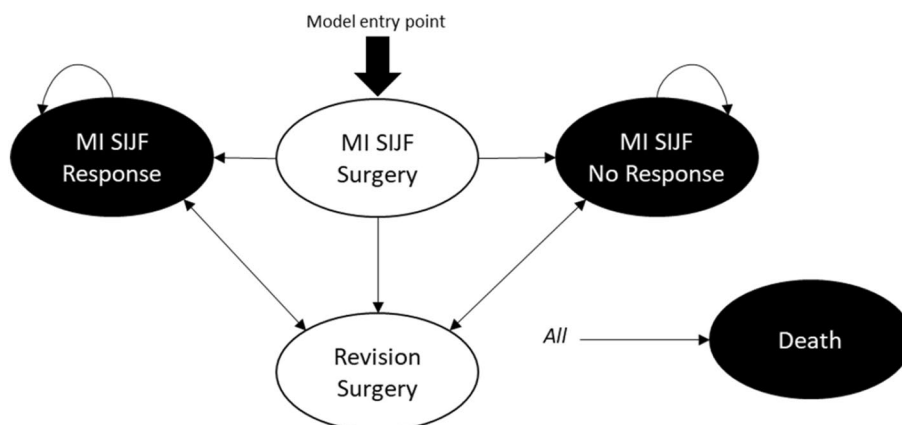
Fig. 2 Diagram of model structure used to simulate patient history through a non-surgical intervention pathway. *PTSI* physical therapy and corticosteroid injections, *RFA* radiofrequency ablation. *Model entry point only used for comparator strategies 2 and 3

Feedback from UK consultants interviewed prior to developing the model (details in the electronic Supplementary material) suggests a stepped pathway is the most common practice in the NHS in England. The latter two strategies were also considered in the model to reflect variation in practice because steroid injections or RFA may not be funded in some localities due to mixed perceptions on their efficacy.

The NSM arm includes nine health states, four for each of the two interventions (PTSI or RFA) plus death. In strategy 1, all patients start in the PTSI health state, which is assumed to be the standard first-line treatment. They then either achieve an ODI response of ≥ 15 points or fail to do so. Responders remain in this health state for the duration of the treatment effect, after which they transition to the pain recurrence state and receive a repeat procedure on the next cycle. Where first-line treatment of PTSI fails, patients may stay in the no response health state or progress to RFA as a second-line treatment where the model structure mirrors that for PTSI. It is assumed that there is a 20% probability of them undergoing RFA in each subsequent model cycle, reflecting feedback provided by the UK consultants interviewed (see the electronic supplementary material). However, in strategies 2 and 3, this probability is assumed to be 0%, to consider localities where RFA is not funded. In strategy 2, 50% of the patients start in PTSI and 50% in RFA, and in strategy 3, all patients start in RFA. For both PTSI and RFA, it was assumed that 100% of patients receiving a positive treatment response to PTSI or RFA would have repeat interventions when the treatment effect wore off. The duration of treatment effect for PTSI required an assumption due to the low quality of evidence; it was assumed, based on available literature, that the median duration of effect was 3 months [25, 26]. The median duration of effect for RFA was assumed to be 7.9 months [39].

2.2 Model Parameters

Details of all cost inputs and sources that are used in the base-case model are reported in Tables 1 and 2.

2.2.1 Outcomes

The minimum clinically important difference (MCID) after SIJ treatment was estimated as a reduction of ≥ 15 points in a patient's ODI irrespective of baseline [27]. For the purposes of this study and to consider effect at similar time points for MI SIJ and RFA, this reduction in ODI was observed 3 months after the initial intervention.

The effectiveness measures for MI SIJF were sourced from the published literature, focusing primarily on three prospective clinical trials, the most robust published evidence on MI SIJF at the time of publication. Detailed descriptions of the trial protocols are provided elsewhere [28].

Briefly, INSITE was a prospective, 2-year, multicentre RCT conducted at 19 centres in the USA. It included 148 patients with diagnosed SIJ dysfunction unresponsive to at least 6 months of conservative care. Subjects were randomized in a 2:1 fashion to either SIJF or NSM. NSM included anti-inflammatory and opioid pain medications, physical therapy, intra-articular SIJ steroid injections, and RFA, delivered serially as needed to manage pain and disability.

SIFI was a prospective, multicentre, single-arm clinical trial (n = 172) conducted at 26 centres in the USA. Study parameters were identical to those of INSITE.

iMIA, a prospective, multicentre RCT (n = 103), was conducted at nine European centres. Key differences between iMIA and INSITE include iMIA using 1:1 randomization and the NSM arm in iMIA including only physical therapy per European guidelines [29]. There is 'moderate' level evidence for the short-term effectiveness of intra-articular SIJ injections [8]. Because of the paucity of literature, the use of steroid injections was grouped together with physical therapy and response rates for the grouped set of treatments were based on responses observed in the NSM arm in the two MI SIJF RCTs. Although the protocols were different, the data were pooled for convenience. This is likely to be a conservative approach because of the 45.7% of patients in the INSITE study who underwent RFA. This is likely to have bolstered outcomes for these patients. The current evidence suggests RFA can provide temporary pain relief, but there remains variability in patient selection, nerves targeted, and types of RFA technology and techniques utilized [11, 12]. Effectiveness data for RFA were sourced from an RCT that assessed the efficacy of lateral branch neurotomy for chronic SIJ pain against placebo [30]. There are two recent RCTs that demonstrated minimal effectiveness of SIJ RFA [31, 32].

In England, the preferred outcome measure in economic evaluation is QALYs. The NICE reference case prefers the utility to be measured using the Euro-Qol EQ-5D questionnaire. Although both INSITE and iMIA collected EQ-5D-3L data valued using the UK tariff set at baseline and follow-up, health utility data following an RFA intervention were not found in the published literature. Therefore, to allow the comparison to RFA, a mapping procedure was used in which EQ-5D-3L data collected from MI SIJF clinical trials (INSITE [15] and iMIA [16]) were linearly regressed against a patient's ODI score. Patient baseline characteristics were incorporated in the model, and only age was found to be a significant additional predictor of EQ-5D-3L value (data illustrated in the electronic Supplementary material). This approach was similar to the indirect method to determine utilities with RFA reported in the NICE cost-effectiveness analysis of RFA [33].

Table 1 Clinical effectiveness measures

		Distribution	Source
Response to procedure			
MI SIJF	65.4%	Beta (210, 111)	3-month response rate. Data pooled from INSITE [15], iMIA [16], and SIFI [17]
PTSI	25.0%	Beta (24.25, 72.75)	3-month response rate. Data pooled from INSITE [15] and iMIA [16]
RFA	26.0%	Beta (9, 25)	3-month response rate. Patel et al. [30]
ODI change by health state[1]			
Response: MI SIJF	− 33.3	Normal (− 33.3, 12.5)	Data pooled from INSITE [15] and iMIA [16]. No treatment effect observed
No response: MI SIJF	− 1.9	Normal (− 1.9, 9.2)	Data pooled from INSITE [15] and iMIA [16]. No treatment effect observed
Response: PTSI	− 33.3	Normal (− 33.3, 12.5)	Data pooled from INSITE [15] and iMIA [16]. No treatment effect observed
No response PTSI	− 1.9	Normal (− 1.9, 9.2)	Data pooled from INSITE [15] and iMIA [16]. No treatment effect observed
Response: RFA	− 33.0	Normal (− 33.0, 9.22)	[30]
No response: RFA	− 1.64	Normal (− 1.64, 11.03)	[30]
Duration of treatment effect (months)			
PTSI	3	Log normal (1.10, 0.35)[2]	[25, 26]
RFA	7.9	Log normal (2.07, 0.10)	[39]
Risk of revision surgery			
Risk of early revision[3]	0.81%	Beta (10,490, 85)	[24, 40]
Risk of late revision[4]	0.17%	(10,490, 18)	[24, 40]

CI confidence interval, *MI SIJF* minimally invasive sacroiliac joint fusion, *ODI* Oswestry Disability Index, *PTSI* physiotherapy + corticosteroid injection, *RFA* radiofrequency ablation

[1]Negative values refer to improvement in scores

[2]Assumed a 95% CI of ± 33%

[3]Cumulative risk of symptomatic malposition at 12 months. Assumed to occur in subsequent model cycle

[4]Cumalative risk of revision surgery for other reasons at 12 months. Converted to 3-month probability

$$EQ\text{-}5D = 0.92 − 0.009 \times ODI + 0.0011 \times Age$$

2.2.2 Costs

The total hospital length of stay, procedure times, surgical training hours, and follow-up consultations for MI SIJF were derived from the clinical literature and were used in the NICE MTG39 EAC analysis [22]. The number of consumables required for each MI SIJF surgery was estimated in consultation with clinical experts (further details reported in the electronic supplementary material). The cost of surgery-related adverse events was not considered separately in the model because adverse events following MI SIJF surgery are very low and mainly related to wound problems treated in hospital; therefore, the cost of treatment was already captured in the hospital stay cost.

All the resources were costed using routine NHS costs and prices. Where costs were available in the NHS reference cost schedule, these were taken from the latest 2017/2018 costs. Where costs were taken from elsewhere, they were inflated to costs in 2018 from the year of publication using the UK consumer price index (CPI) health indices available from the Office of National Statistics.

2.3 Analytical Methods

Transition probabilities were derived using values from published literature; the values used in the model are presented in Table 3. Where probabilities required converting from one time period to another, the probability was first converted to a 3-month rate and then translated into the corresponding transition probability [34].

To test the impact of the 5-year time horizon, results are also reported over a lifetime as a sensitivity analysis. Benefits of MI SIJF have been shown to be durable up to 5 years [20, 21]. Longer term follow-up data are not available, but it is reasonable to expect the effect of surgical intervention to persist. Therefore, reporting results at 5 years is a conservative approach, which is aimed at reducing the uncertainty over an NSM pathway over the long term.

Deterministic sensitivity analysis (DSA) was performed on all model inputs, varying each input individual to 20% of the base-case value. Although this approach does not test all inputs to the maximum range of uncertainty by varying within the 95% confidence intervals, this approach was used to identify the model parameters particularly important to model outcomes.

Table 2 Cost inputs and sources

	Unit cost	Distribution	Source	Any use (%)	Distribution	Source	Mean use	Distribution	Source
MI SIJF									
Procedure (min)	£20.00	Gamma (14, 1)	[41]	100	–	–	59	Log normal (4.08, 0.07)	[42]
Length of stay (days)	£366.19	Gamma (66, 6)	HN13A-F[a]	100	–	–	0.80	Log normal (−0.22, 0.85)	[22]
Training (h)	£108.00	Gamma (44, 2)	[43]	1.11	Log normal (0.13, 1.39)	Assumption	4	Log normal (1.39, 0.13)	[42]
Surgical implants (−)	£1155.00	–	b	100	–	–	3	–	b
Surgical accessories (−)	£275.00	–	b	100			1	–	b
Steinmann pins (−)	£47.00	–	b	100			3	–	b
Exchange pin (−)	£47.00	–	b	100			1	–	b
Drills (−)	£131.00	–	b	100			1	–	b
Pre-surgery consult (visits)	£146.00	Gamma (96, 2)	WF01B[a]	100	–	–	1	–	[42]
Post-surgery follow-up (visits)	£119.00	Gamma (96, 1)	WF001A[a]	100	–	–	4	Log normal (1.39, 0.13)	[42]
Corticosteroid injections									
Procedure (−)	£397.00	Gamma (96, 4)	HC29B[a]	73.9	Beta (34, 12)	[44]	1	–	–
Pre-procedure consult (visit)	£193.00	Gamma (96, 2)	WF01B[a]	73.9	Beta (34, 12)	[44]	1	–	–
Radiofrequency ablation									
Procedure (−)	£776.14	Gamma (96, 8)	AB15Z, AB16Z[a]	100-	–		1	–	–
Pre-procedure consult (visit)	£193.00	Gamma (96, 2)	WF01B[a]	73.9	Beta (34, 12)	[44]	1	–	–
Physiotherapy									
Initial physiotherapy session (visit)	£61.00	Gamma (96, 0.6)	WF01B[a]	97.8	Beta (45, 1)	[44]	1	Not varied	[45]
Follow-up physiotherapy session (visit)	£52.00	Gamma (96, 0.5)	WF01A[a]	97.8	Beta (45, 1)	[44]	5	Log normal (1.61, 0.22)	[45]
Resource use in no response health state									
Medication (£ per month)	£30.80	Gamma (5.3, 5.8)	[45]	100	–	–	1	–	–
Pain-management resource cost (£ per month)	£83.92	Gamma (8.8, 9.5)	[45]	100	–	–	1	–	–

Min minutes, *MI SIJF* minimally invasive sacroiliac joint fusion, *NHS* National Health Service

[a]NHS reference costs 2017/2018

[b]The consumable costs are taken from SI-BONE UK list prices, and the resources required to perform each surgery were informed via consultation with clinical experts

Table 3 Transition probabilities used in the model

Starting state	Ending state	Value	Source
iFuse model			
MI SIJF*	MI SIJF response	0.6487	a
	MI SIJF no response	0.3432	a
	Revision surgery	0.0081	b
MI SIJF response	Revision surgery	0.0017	c
MI SIJF no response	Revision surgery	0.0017	c
Revision surgery	MI SIJF response	0.6540	d
	MI SIJF no response	0.3460	d
NSM model			
PTSI*	PTSI response	0.2500	e
	PTSI no response	0.7500	e
PTSI response	PTSI pain recurrence	0.5000	f
PTSI no response	RFA	0.2000	g
PTSI pain recurrence	PTSI	1.0000	h
RFA*	RFA response	0.2600	i
	RFA no response	0.7400	i
RFA response	RFA pain recurrence	0.2314	j
RFA pain recurrence	RFA	1.0000	h

MI SIJF minimally invasive sacroiliac joint fusion, *PTSI* physiotherapy + corticosteroid injection, *RFA* radiofrequency ablation

*These intervention states are both potential entry points to the model and tunnel states

[a]Probability of response to treatment pooled from INSITE/iMIA/SIFI [1–3] adjusted for proportion of early revisions [4]

[b]Probability of early revision [4]

[c]Probability of late revision [4] converted from 24-month to 3-month probability using methods in [5]

[d]Probability of response to treatment pooled from INSITE/iMIA/ [1–3]

[e]Probability of response to treatment pooled from INSITE/iMIA/SIFI [1–3]

[f]Uses median duration of effect of 3 months

[g]Assumption based on discussions with UK clinicians

[h]Assumption based on discussions with UK clinicians

[i]Probability of response pooled from RFA [6]

[j]Uses median duration of effect. Assumed 7.9 months based on evidence from RFA [7]

To fully explore the uncertainty in the model parameters, the probabilistic sensitivity analysis (PSA) varied all variable model inputs simultaneously, using Excel's random number generator to sample values from the probability distributions for each variable as detailed in Table 2. This was repeated for 1000 iterations using a custom visual basic for applications (VBA) script following an approach outlined by Briggs et al. [35] and was sufficient to achieve stabilization.

3 Results

3.1 Base-Case Results

The results of the base-case analysis are presented in Table 4. After 5 years in the NSM arm, patients on the stepped treatment (strategy 1) had received an average of 0.98 steroid injections, 1.30 courses of physical therapy, and 1.22 RFA procedures. Almost all patients had stopped treatment, and only 4.3% were living with improved pain and function. This contrasts with the MI SIJF arm, where 64.3% remain in the response-to-treatment health state after 5 years, with an associated improvement in pain and physical function. Surgical intervention with MI SIJF accrued total procedure-related and pain-management costs of £8358, while the stepped treatment strategy had total costs of £6880. Over the 5-year time horizon, the model predicts that patients with MI SIJF would have 2.98 QALYs (discounted) compared to strategy 1 with 2.30 QALYs (discounted). This resulted in an incremental cost-effectiveness ratio (ICER) for MI SIJF versus strategy 1 of £2164/QALY gained.

Strategy 2 of the NSM arm had lower costs (£6564) than strategy 1 because there were fewer procedures of all types (0.66 RFA, 0.49 corticosteroid injections, and 0.65 physiotherapy courses), and this resulted in 2.26 QALYs and an ICER of £2468/QALY gained for MI SIJF. Strategy 3 of the NSM arm had lower costs (£6580) than strategy 1 because there were no PTSI procedures and just a slight increase in RFA procedures (1.33 RFA). This resulted in 2.28 QALYs and an ICER of £2518/QALY gained for MI SIJF. MI SIJF results in greater utility gain compared to all non-surgical treatment pathways. Within the NSM arms, the stepped pathway resulted in a higher utility gain than PTSI or RFA alone because patients had the chance for additional treatment having failed the first-line intervention.

3.2 Sensitivity Analyses

The results of the PSA shown in the cost-effectiveness plane (CEP) (Fig. 3a) illustrate that all three treatment strategies are broadly consistent in terms of their results. The majority of simulated ICERs occupy the northeast quadrant of the CEP, where there exists a trade-off between increased cost and increases in QALYs gained. The cost-effectiveness acceptability curve (CEAC) (Fig. 3b) highlights that MI SIJF has a probability of being the dominant treatment of 5%, 4%, and 4% versus strategies 1, 2, and 3, respectively. It is also apparent that at a threshold of £20,000/QALY gained, MI SIJF has a probability of being cost-effective of 96%, 97%, and 91% versus non-surgical treatment for strategies 1, 2, and 3, respectively.

Table 4 Cost-effectiveness results in the base case

	MI SIJF	NSM strategies					
		Strategy 1	Diff.	Strategy 2	Diff.	Strategy 3	Diff.
Treatment outcomes after 5 years							
MI SIJF procedures per patient	1.04						
RFA procedures per patient		1.22		0.66		1.33	
Corticosteroid injections procedures per patient		0.98		0.49			
Physiotherapy courses per patient		1.30		0.65			
Proportion in response	64.3%	4.3%	60.0%	0.6%	63.7%	1.2%	663.1%
Costs after 5 years							
MI SIJF surgery costs	£6322						
PTSI costs		£978		£489			
RFA costs		£1092		£628		£1255	
Pain-management costs	£2037	£4811		£5448		£5325	
Total	£8358	£6880	£1478	£6564	£1794	£6580	£1778
Health outcomes after 5 years							
Life years (discounted)	4.53	4.53	0	4.53	0	4.53	0
QALYs (discounted)	2.98	2.30	0.68	2.26	0.73	2.28	0.71
Life years (undiscounted)	4.96	4.96	0	4.96	0	4.96	0
QALYs (undiscounted)	3.27	2.52	0.75	2.47	0.80	2.49	0.78
ICER after 5 years (MI SIJF vs NSM strategy)		£2164		£2468		£2518	

MI SIJF minimally invasive sacroiliac joint fusion, *NSM* non-surgical management, *ICER* incremental cost-effectiveness ratio, *ODI* Oswestry Disability Index, *PTSI* physical therapy and corticosteroid injections, *QALY* quality-adjusted life year, *RFA* radiofrequency ablation

The results of the DSA shown in the tornado plot (Fig. 4) illustrate that the base-case result for all strategies is most sensitive to the input determining the proportion of patients that achieve a response to treatment with MI SIJF. However, changing this value by 20% in either direction does not change the conclusion that MI SIJF is cost-effective in the medium term.

The effect of the time horizon was explored by extending the model to a patient's lifetime. The results are shown in the electronic supplementary material (Table S1). When comparing all the treatment strategies to MI SIJF, all are dominated, i.e. they are more costly and less effective than the comparator. A further threshold analysis was performed on the model time horizon. Variation of the model time horizon showed that MI SIJF becomes cost-effective at a threshold of £20,000/QALY gained by year 2 and MI SIJF is dominant (cost-saving and has better outcomes) by year 7. An additional threshold analysis showed that the ICER increases when the duration of the effect of the PTSI and RFA is increased; the results show that the ICER is less than £3000 for a duration of effect of up to 24 months for both the PTSI and RFA interventions across all three treatment strategies.

4 Discussion

This analysis demonstrates that for patients with chronic SIJ pain, MI SIJF is cost-effective compared to NSM in an NHS context over a 5-year time horizon. Although the difference in cost between MI SIJF and NSM is relatively small (£8358 vs £6880 for NSM strategy 1), there is a significant difference in QALYs as a result of the superior and durable effect of the surgical intervention (2.98 QALYs vs 2.30 QALYs for NSM strategy 1). At 5 years after MI SIJF, around 64% of patients are expected to maintain a response in terms of reduction in ODI compared to just over 4% of patients in the NSM arm, where treatments are known to provide only temporary relief rather than a long-term pain-management solution. This resulted in an ICER for MI SIJF versus NSM strategy 1 of £2164/QALY gained.

As with all models, the current analysis has limitations imposed by data availability and our structural assumptions. One limitation is the difficulty in modelling the variation in NSM pathways, as there is no accepted standard practice. Feedback from consultants interviewed prior to model development suggested regional variability in practice. Despite limited efficacy data, feedback from consultants interviewed prior to model development suggest that PTSI is a common first-line treatment, and

Fig. 3 a Probabilistic sensitivity analysis: cost-effectiveness plane. The dotted line represents an ICER of £20,000 per QALY gained. **b** Cost-effectiveness acceptability curve for MI SIFJ compared to three non-surgical treatment strategies. *ICER* incremental cost-effectiveness ratio, *MI SIJF* minimally invasive sacroiliac joint fusion, *QALY* quality-adjusted life years, *WTP* willingness to pay
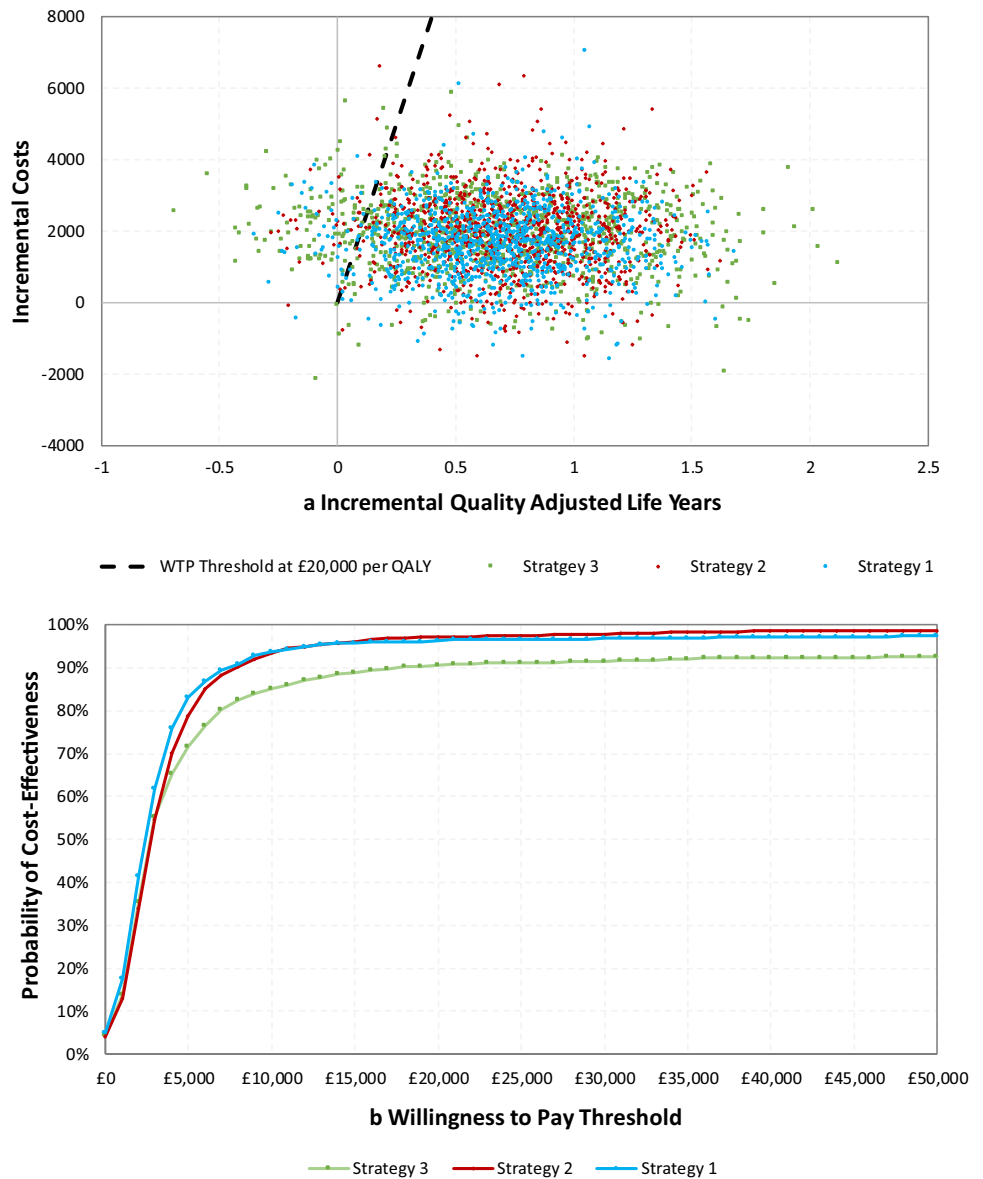
a small proportion of patients may be offered RFA at a later stage. The NICE guidelines [33] on lower back pain recommend RFA of the lumbar facets, but do not address this treatment for SIJ pain. Furthermore, these guidelines explicitly do not recommend repeat corticosteroid injections, due to a lack of robust evidence on their efficacy. Additionally, because of the lack of robust data for the efficacy of corticosteroid injections, it was necessary to group together physical therapy and corticosteroid injections as a treatment (PTSI), which might not be reflective of clinical practice in England. Despite this, by pooling the comparator arms from the two MI SIJF RCTs it meant patients who had an RFA procedure performed as part of the trial were included in the efficacy outcomes; this limitation is conservative in the sense that it should inflate the efficacy of the comparator group. The duration of the

effect of both corticosteroid injections and RFA remains uncertain, but threshold analysis on these values suggested that the assumptions employed were not drivers of the results. One major model driver was the healthcare utilization cost due to pain management in non-responder health states. This cost was derived from a facet joint injection trial that failed to meet enrolment criteria, and thus the indication was not identical to the current study and the number it was based on was small; however, the cost values used were similar to those employed in the NICE MTEP analysis [22].

When considering the generalizability of the analysis, it is important to highlight that it has been conducted from the perspective of a comprehensive healthcare system, namely the NHS in England. Therefore, the resource
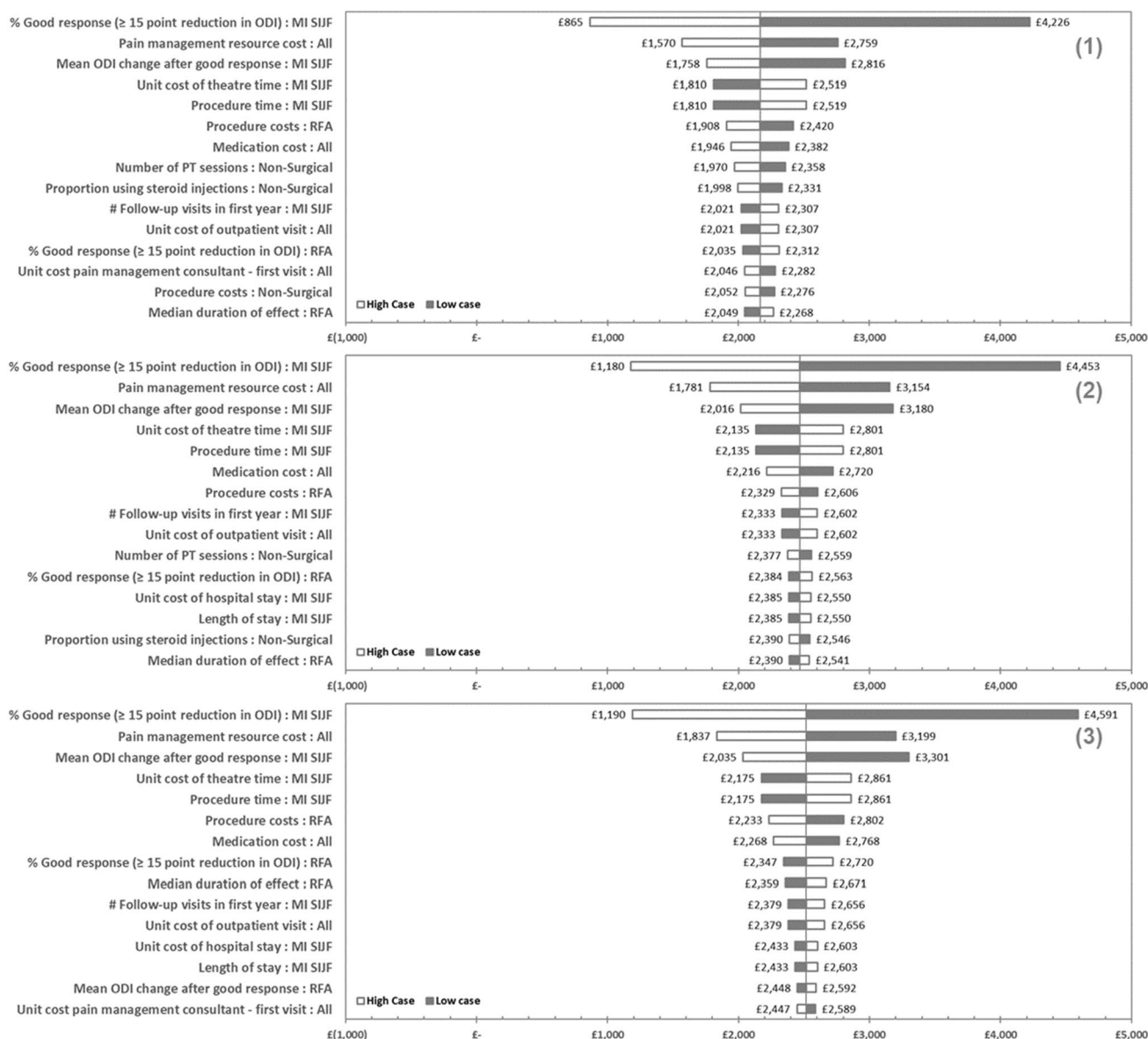
Fig. 4 Deterministic sensitivity analysis showing parameter uncertainty of 20% of the ICER of MI SIJF vs three NSM treatment strategies. *ICER* incremental cost-effectiveness ratio, *MI SIJF* minimally invasive sacroiliac joint fusion, *NSM* non-surgical management, *ODI* Oswestry Disability Index, *PT* physical therapy, *RFA* radiofrequency ablation

utilization and cost data that have been used are not necessarily generalizable to other locations.

Further, the assumptions used in the NSM arm of the model are quite conservative, with a limited number of repeat injections or RFA procedures per patient occurring during the 5 years. This is different from NSM treatment in other geographies, where repeat procedures are more frequent [36, 37].

The iFuse TTIs, the clinical evidence base for which the current model builds, have several unique features, including a triangular cross section, porous surface allowing bone ingrowth/ongrowth, and that the devices are impacted into place rather than screwed into place. For these reasons, the safety and effectiveness of iFuse TTIs are likely not generalizable to other laterally placed devices which are circular in cross section, do not have a porous surface, and are screwed into place. Increased interest in SIJ dysfunction and fusion has generated other devices and allograft products placed dorsally. However, there is limited evidence supporting their safety and effectiveness, and these are not covered within NICE IPG 578 [14].

The results of our analysis align with the conclusions drawn by the NICE EAC team, who reported that MI SIJF resulted in savings of £129 per patient treated by year 8 [22].

This indicates that MI SIJF is likely to dominate NSM over the longer term, findings also backed up in our extended time horizon model (Table S1, see the electronic Supplementary material). More broadly, our results are also similar to other cost-utility analyses which demonstrated MI SIJF are cost-effective compared to non-surgical treatments from US commercial payer and government perspectives [38].

The predicted ICER from our study is in the same range as results from other UK-focused analyses (Table S2, see the electronic Supplementary material) for orthopaedic surgical interventions. Due to different time horizons and modelling approaches, results cannot be directly compared. Nonetheless, our results suggest that MI SIJF represents comparative value when compared to treatments routinely offered within the NHS to treat severe pain and mobility issues, such as knee and hip replacement.

Sensitivity analysis suggests that there is a greater than 90% probability of MI SIJF being considered cost-effective at a threshold of £20,000/QALY compared to NSM across all treatment strategies. When extending the analysis to a lifetime horizon, MI SIJF has better outcomes and is less costly than NSM.

In conclusion, this analysis is complementary to the cost-minimization analysis conducted under the NICE MTEP evaluation and is intended to aid NHS decision makers in evaluating, with a patient-focused perspective, the long-term clinical and economic benefits of MI SIJF.

Declarations

Conflict of interest Rob S. Blissett and Deirdre B. Blissett are directors of MedTech Economics Ltd., a consultancy commissioned by Si-BONE Inc. to perform economic analysis and draft this article. Daniel J. Cher and W. Carlton Reckling are employed by Si-BONE Inc. Matthew P. Newton Ede has received funding from Si-BONE Inc. to provide training unrelated to this article. Philip M. Stott has received funding to lecture on behalf of by Si-BONE Inc. unrelated to this article.

Ethics approval Not applicable.

Consent to participate Not applicable.

Consent for publication Not applicable.

Availability of data and material All data inputs used in the model are available within the article and the electronic supplementary material.

Code availability Not applicable.

Author contributions Conceived and designed the experiments: RSB, DBB, DJC, and WCR. Analysed the data: RSB, DBB, DJC, and WCR. Contributed reagents/materials/analysis tools: RSB, DBB, DJC, and WCR. Wrote the paper: RSB, DBB, DJC, and WCR. Interpretation of the analysis: RSB, DBB, DJC, and WCR. Played a role in the design and the execution of the study and commented on the manuscript: RSB, DBB, DJC, WCR, MPNE, and PMS.

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