Applied Health Economics and Health Policy (2023) 21:467–475
https://doi.org/10.1007/s40258-023-00799-4

SYSTEMATIC REVIEW

Use of Decision-Analytic Modelling to Assess the Cost-Effectiveness of Diagnostic Imaging of the Spine, Shoulder, and Knee: A Scoping Review

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Accepted: 23 February 2023 / Published online: 20 March 2023

Abstract

Background Limited evidence is available on the cost-effectiveness of diagnostic imaging for back, neck, knee, and shoulder complaints. Decision analytic modelling may be an appropriate method to synthesise evidence from multiple sources, and overcomes issues with trial-based economic evaluations.

Objective The aim was to describe the reporting of methods and objectives utilised in existing decision analytic modelling studies that assess the cost-effectiveness of diagnostic imaging for back, neck, knee, and shoulder complaints.

Methods Decision analytic modelling studies investigating the use of any imaging modality for people of any age with back, neck, knee, or shoulder complaints were included. No restrictions on comparators were applied, and included studies were required to estimate both costs and benefits. A systematic search (5 January 2023) of four databases was conducted with no date limits imposed. Methodological and knowledge gaps were identified through a narrative summary.

Results Eighteen studies were included. Methodological issues were identified relating to the poor reporting of methods, and measures of effectiveness did not incorporate changes in quantity and/or quality of life (cost-utility analysis in only ten of 18 studies). Included studies, particularly those investigating back or neck complaints, focused on conditions that were of low prevalence but have a serious impact on health (i.e. cervical spine trauma, cancer-related back pain).

Conclusions Future models should pay particular attention to the identified methodological and knowledge gaps. Investment in the health technology assessment of these commonly utilised diagnostic imaging services is needed to justify the current level of utilisation and ensure that these services represent value for money.

Key Points for Decision Makers

There is a paucity of high-quality modelling studies investigating the cost-effectiveness of diagnostic imaging for common musculoskeletal complaints despite its widespread use.

There are few high-quality modelling studies that adhere to modelling guidelines, limiting our understanding of whether diagnostic imaging for back, neck, knee, and shoulder complaints represent value for money.

1 Introduction

Diagnostic imaging is performed to aid diagnosis and therapeutic decision-making with the aim of improving patient outcomes. A large proportion of imaging requests

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by general practitioners are for musculoskeletal problems such as back, neck, knee, and shoulder pain [1]. Clinicians may request imaging to rule in or out serious pathology (e.g. malignancy, infection) and/or to identify conditions that might require specific treatment (e.g. fracture). Yet, a substantial proportion of tests are performed without an appropriate clinical indication and, therefore, provide little benefit to the patient and may cause harm [1–3]. Despite their frequent use, diagnostic imaging for these common musculoskeletal problems have not been subjected to rigorous processes of health technology assessment like emerging drugs or surgical procedures [4].

The value of diagnostic imaging can be assessed within clinical trials where patients undergo either a new or existing test, and patient-reported health outcomes and costs of the consequent management are measured [5, 6]. The benefit of these test-treatment trials is that they capture all aspects of value generated by a diagnostic test. However, diagnostic imaging has a small indirect effect on patient outcomes that is influenced by the prevalence of the condition and the marginal difference in diagnostic accuracy [7, 8]. In a clinical trial that is comparing two diagnostic tests for example, only 4% of the sample population will be affected by the new test when the prevalence of the disease is 20% and the marginal difference in sensitivity is 20% [8]. Clinical trials would need to recruit a prohibitively large sample size to overcome this dilution effect and provide an effect estimate for patient-reported health outcomes with adequate precision [8, 9]. Further, clinical trials are typically underpowered for cost-effectiveness analyses to report differences in effect and costs [9]. Alternative methods are needed to ascertain the cost-effectiveness of diagnostic imaging.

Decision analytic modelling is one method to estimate the cost-effectiveness of diagnostic tests [6, 10]. This technique synthesises available data on the characteristics of a diagnostic test (i.e. diagnostic accuracy, changes in diagnosis, changes in treatment modality) and its subsequent impact on outcomes and costs, to ascertain whether its use represents value for money to the healthcare system and society [11]. High-quality decision analytic models can aid policy-makers in answering resource allocation questions.

The objective of this scoping review was to describe the methods used in existing decision analytic models that investigate the cost-effectiveness of diagnostic imaging for back, neck, knee, and shoulder complaints. We also aimed to describe the objectives of these studies in terms of the clinical conditions of interest, resource allocation questions addressed, test-treatment pathway, and the incorporation of safety issues. The methodological and knowledge gaps identified in this review will identify opportunities for future research that aim to improve the use of diagnostic imaging for back, neck, knee, and shoulder complaints.

2 Methods

This scoping review was conducted according to the methodology proposed by Levac et al. [12] and Peters et al. [13]. The review methods and results are reported according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) Extension for Scoping Reviews (PRISMA-ScR) [14].

Decision analytic models that investigated the use of diagnostic imaging for people of any age with back, neck, shoulder, or knee pain were included. There was no restriction on type of imaging modality that was being investigated. However, studies that investigated diagnostic imaging screening programmes of healthy individuals (e.g. use of dual-energy x-ray absorptiometry to screen for osteoporosis) or studies in which imaging was part of an intervention (e.g. ultrasound-guided injections) were excluded. There was no restriction on comparators. Studies that undertook cost-effectiveness, cost-utility, or cost-benefit analyses were included irrespective of the type of decision analytic modelling undertaken (e.g. decision tree, Markov modelling including Markov microsimulations, and discrete event simulation). There were no restrictions based upon health outcomes (e.g. quality-adjusted life years [QALYs], cases detected). We excluded conference proceedings and abstracts, and non-English language studies.

2.1 Search Methods

The search strategy was developed in consultation with a medical librarian. We performed database searches of MEDLINE (OVID), Embase (OVID), NHS Economic Evaluation Database, and the Health Technology Assessment database. All databases were searched from inception to 2nd of July 2021 and updated on the 5th of January 2023. The search strategy is outlined in Appendix A (see the electronic supplementary material).

2.2 Data Selection

Titles and abstracts of records retrieved from searches were screened for eligibility by two independent reviewers (SD, CB). The same two reviewers then independently determined eligibility from the full-text reports of potentially eligible studies. Discrepancies were resolved through discussion or via consultation with a third review author (LG).

2.3 Data Charting and Synthesis

We developed a data charting sheet to extract the relevant information from the included studies. The development of this data charting sheet was based on best practice methodological guidelines for economic evaluations [15] and decision analytic models [16] and an iterative process where the data charting sheet was updated to ensure that the data extracted were consistent with the research question and purpose [12]. Data were extracted by two authors (SD, CB), and any disagreements were resolved through discussion or with a third review author (RB) as required. The following study characteristics were charted:

- *Details of study:* Study aims, decision analytic method, type of economic analysis, intervention and comparator, perspective, country, setting, time horizon, cycle length (if appropriate), discounting (if appropriate), funding, and competing interests of study authors.
- *Participants:* Site of complaint investigated, condition of interest, and demographic information of the clinical scenario.
- *Model characteristics:* Assumptions used for model structure, imaging modality/techniques investigated, interventions based on test outcomes, key health states, model inputs and source of these inputs (i.e. prevalence of condition, diagnostic accuracy of imaging, resource use, utility values, or other outcome measures), and cycle length (if appropriate).
- *Results*: Costs and outcomes of each arm, incremental cost-effectiveness ratio for all comparisons (e.g. cost per QALY, cost per extra case detected, etc.), and results of sensitivity analyses if performed to identify predictors of costs and effects.

2.4 Summary of Findings

The study methods and modelling techniques were summarised for all included studies. The objectives and aims of all included studies were mapped within four broad themes identified by the iterative process of data charting: (1) the condition investigated (e.g. non-specific diagnoses, conditions of low prevalence); (2) the resource allocation question addressed (e.g. imaging A vs. imaging B, imaging vs. no imaging); (3) test-treatment pathway (e.g. surgery, palliative care); and (4) the assessment of safety issues related to the use of diagnostic imaging (e.g. radiation, risk of litigation). The outcomes from these themes were described for all included studies and separately for each of the sites of clinical complaints. A methodological appraisal was not conducted as this is beyond the scope of scoping reviews [17].

3 Results

Of the 5772 studies screened for potential eligibility, 18 studies satisfied the eligibility criteria (Fig. 1). Six investigated the use of diagnostic imaging for back complaints,

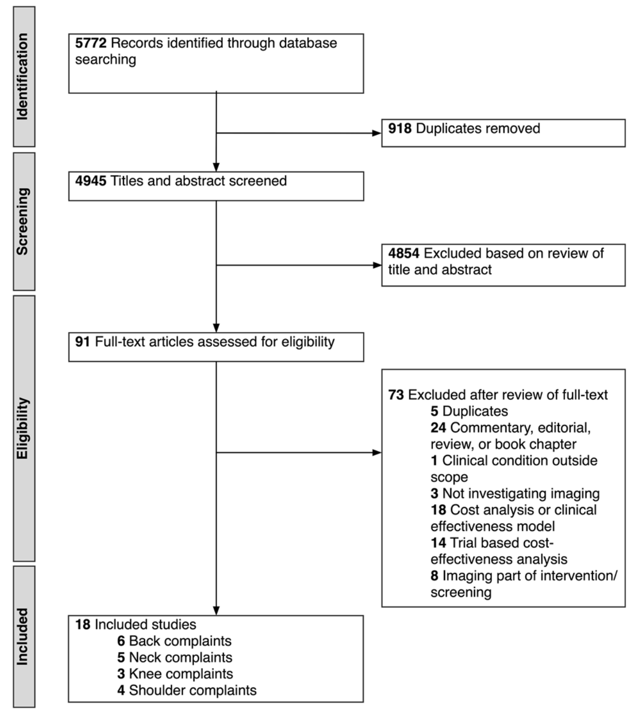

Fig. 1 PRISMA flowchart of included studies. *PRISMA* Preferred Reporting Items for Systematic Reviews and Meta-Analyses

five were for neck complaints, three were for the knee, and four were for the shoulder (Fig. 1).

Seven studies were published within the last 5 years (2018–2022), three were published in the preceding 5 years (2013–2017), and the remaining eight studies were published more than a decade ago (before 2012) (Table 1). Most studies were performed in the United States ($n = 15$, 83.3%), two were from Canada and one was from Australia. The clinical setting of included studies was distributed across primary care [18–22], outpatient orthopaedic clinics [21, 23–29], and emergency departments [30–34], with one study set in a rheumatology clinic [35].

Magnetic resonance imaging (MRI) was most commonly investigated ($n = 13$, 72.2%), including three studies for back complaints [18, 25, 35], three studies for neck complaints [31, 33, 34], and seven studies for knee [21, 23, 27] and shoulder [24, 26, 28, 29] complaints. Computed tomography and x-ray were only investigated in studies of back and neck complaints [18–20, 22, 25, 30, 32, 35]. Two studies focused on ultrasound [24, 28] and two studies on arthrography [26, 29] for shoulder complaints.

3.1 Summary of Study Methods

Reporting of methods was poor in some studies, which limits replication and the generalisability of research findings (Table 2). Issues included absence of the reporting model

Table 1 Summary of descriptive details of included studies

	All studies (*n* = 18)
Year published	***n* (%)**
Earlier than 2002	4 (22.2)
2003–2007	2 (11.1)
2008–2012	2 (11.1)
2013–2017	3 (16.7)
2018–2022	7 (38.9)
Clinical setting[a]	
Primary care	5 (27.8)
Orthopaedic/outpatient clinic	8 (44.4)
Rheumatology clinic	1 (5.6)
Emergency department	5 (27.8)
Imaging modality investigated of interest[a]	
X-ray	6 (33.3)
Ultrasound	2 (11.1)
Computed tomography	4 (22.2)
Arthrography	2 (11.1)
Magnetic resonance imaging	13 (72.2)

[a]Cumulative percentages may be greater than 100% as a single study may contribute to multiple categories

Table 2 Summary of modelling methods of included studies

Model type	*n* (%)
Decision tree	12 (66.7)
Markov model	4 (22.2)
Not stated	2 (11.1)
Perspective[a]	
Societal	6 (33.3)
Health care system	9 (50)
University Level I urban trauma centre	3 (16.7)
Not reported	2 (11.1)
Type of analysis[a]	
Cost-utility	10 (55.6)
Cost-effectiveness	8 (44.4)
Cost-benefit	1 (5.6)
Time horizon[a]	
Less than 12 months	1 (5.6)
1–5 years	8 (44.4)
6–10 years	1 (5.6)
Lifetime	5 (27.8)
Not reported	4 (22.2)
Discounting	
Discounting applied, unclear whether on cost and/or benefits	2 (11.1)
Both cost and benefit	7 (38.9)
Discounting not applied	1 (5.6)
Not required	1 (5.6)
Not reported	7 (38.9)

[a]Cumulative percentages may be greater than 100% as a single study may contribute to multiple categories

structure (two studies [20, 35]), time horizon (four studies [19, 25–27]), discount rate (six studies [19, 21, 25–27, 31]), and cycle length for Markov models (three of four Markov models [23, 33, 34]).

Six studies conducted their analysis from a societal perspective [21, 27, 30, 32–34], four of which investigated the cost-effectiveness of diagnostic imaging for traumatic cervical spine injuries [30, 32–34]. Nine considered a healthcare perspective with some slight variations applied [18, 19, 23, 24, 27–29, 31, 35]. For instance, Ertel et al. [31] modified their perspective to include the costs of litigation following a missed diagnosis. Two studies did not report the perspective taken [20, 26]; however, based on the type of included costs, it can be assumed both took a healthcare perspective.

There were also a wide range of time horizons employed when stated. A lifetime horizon was employed by five studies [30–34], all of which investigated the cost-effectiveness of diagnostic imaging for traumatic cervical spine injuries. Time horizons for the remaining studies ranged from 8 weeks to 10 years.

3.2 Summary of Study Objectives

Figure 2 shows the number of studies categorised within the four broad themes for all included studies and across each of the symptomatic anatomical sites. Within the clinical condition of interest theme, eight studies (44.4%) investigated conditions that have a low prevalence within the relevant setting, but when present have a significant long-term health impact. These studies investigated cervical spine trauma [30–34], cancer-related low back pain [18, 19], and axial spondyloarthritis [35]. Three studies [20, 22, 25], all of which investigated neck or back complaints, investigated non-specific presentations (i.e. acute low back pain, non-emergent spinal disorders). All studies investigating conditions of the knee and shoulder focused on imaging findings that are commonly present in asymptomatic individuals (i.e. meniscal injuries, rotator cuff tears, labral tears).

Within the resource allocation question addressed by the study theme, the majority of studies (*n* = 9) investigated the comparative effectiveness of a range of diagnostic modalities [18, 23, 24, 26, 28–30, 32, 35] or compared diagnostic imaging to no imaging [20, 21, 27, 28, 31, 33, 34]. Interventions aimed at reducing unnecessary imaging were assessed in two studies [22, 25].

For the third theme, a clear test-surgery pathway was outlined in eight studies [21, 23–29], including all seven studies for knee and shoulder complaints. Four studies did not specify the treatment that was provided following the imaging test yet included patient health outcomes

Fig. 2 Synthesis of research questions addressed by the included studies. Note, the total number of studies within a theme may be greater than the number of included studies, as a single study may cross multiple categories

[20, 30–32]. Three decision analytic models, all for neck or back complaints, solely incorporated palliative care to manage symptoms and maintain a level of quality of life rather than treat the conditions (e.g. radiotherapy and chemotherapy for cancer-related back pain, standard care following tetraplegia) [18, 33, 34].

Safety issues related to the use of diagnostic imaging were incorporated in five decision analytic models, all of which focused on neck or back complaints [18, 22, 31, 32, 36]. The increased risk of cancer due to radiation from X-ray or computed tomography (CT) imaging was most commonly considered either by incorporating the probability, costs, and consequence of radiation-induced malignancy [18, 32] or as an outcome measure for interventions that aimed to reduce unnecessary imaging [22, 36]. The probability and cost of litigation following a missed diagnosis were considered in two studies, both of which were assessing the use of imaging to detect cervical spine injury following trauma [31, 32]. One study considered the probability, costs, and consequences of adverse events related to diagnostic imaging itself, such as complications in transport to, or patient positioning in, the MRI scanner [31].

A summary of results from included studies is included in Appendix B (see the electronic supplementary material).

4 Discussion

This review identified several methodological issues and knowledge gaps in the application of decision analytic modelling to investigate the cost-effectiveness of diagnostic imaging for common musculoskeletal conditions. Limitations in the economic analysis performed and perspective taken were identified. Further, knowledge gaps were identified with eight of the 18 studies published over 10 years ago and a focus on clinical conditions that are rare within the clinical setting of interest. The results of this scoping review identify opportunities for future research that address critical evidence gaps.

Ten of the 18 included studies (55.6%) conducted a cost-utility analysis, which is comparatively lower than that reported in a systematic review summarising decision analytic modelling studies of diagnostic tests for various other health conditions. Yang et al. [10] found that a cost-utility analysis had been conducted in 95% of studies. However, this high proportion may be because they confined their search to Health Technology Assessment reports within the UK National Institute for Health Research that are generally considered of good quality.

Cost-utility evaluations are preferred as they quantify the benefit of interventions in terms of the quantity and quality of life, generally expressed as QALYs. This allows findings to be compared across populations and conditions, and enables decision-makers to weigh the opportunity cost of implementing competing interventions [37]—for example, CT imaging for people with low back pain compared to CT imaging for those with respiratory issues. Willingness-to-pay thresholds are also available for cost-utility analyses in multiple countries, which enable decision-makers to identify interventions that represent value for money [38]. Only two studies included in this review stated the absence of cost-utility analysis as a limitation [19, 27], with Suarez-Almazor et al. [27] justifying the exclusion of this type of analysis due to an absence of data. The methodological quality of decision analytic models can be improved by ensuring that the benefit of diagnostic imaging is valued using QALYs instead of focusing on outcomes related to the diagnostic process [39].

Cost-effectiveness analyses identified in this review primarily focused on the number of cases detected. These studies are limited as they overestimate the benefit of imaging in detecting a condition and disregard any harms that may occur [40]. Individuals with a false positive diagnosis may undergo further testing (e.g. invasive biopsy of cancerous lesion) and/or receive unnecessary treatment. Harms due to overdiagnosis (detection of abnormalities that generate a diagnosis that does not result in patient benefit or may cause harm [41]) will also impact the cost-effectiveness of diagnostic imaging [42, 43]. It is critical that future models incorporate all downstream consequences following imaging to accurately estimate the costs and benefits.

While productivity losses are commonly associated with musculoskeletal complaints [44–47], few included studies assessed costs and benefits from a societal perspective [48]. Decision-makers and Health Technology Assessment organisations (e.g. Medicare Services Advisory Committee in Australia, National Institute for Health Research Health Technology Assessment programme in the United Kingdom) prefer economic evaluations from a healthcare perspective [49] as their role is allocating finite healthcare resources. However, the Second Panel on Cost-Effectiveness in Health and Medicine recommended that economic evaluations include both a healthcare and societal perspective reference case to assess how interventions may effect non-health related costs (e.g. productivity, unpaid caregiver time costs) [48]. Diagnostic imaging may impact these non-health-related costs and effect cost-effectiveness ratios. For example, Suarez-Almazor et al. [27] compared the cost-effectiveness of MRI to knee arthroscopy for internal knee derangement from both a healthcare and societal perspective. The incremental cost-effectiveness ratio for MRI was reported to be US$41 per arthroscopy avoided from a healthcare perspective and cost-saving (US$201) when analysed from a societal perspective. Regardless of what perspective is chosen, future studies need to ensure that the relevant information, including costs, is included based on the chosen perspective. Two studies inappropriately excluded productivity losses when taking a societal perspective [21, 30], and costs from litigation due to a missed diagnosis were included in a healthcare perspective [31]. Reporting cost information relevant to the study perspective is important to ensure that cost-effectiveness ratios can be compared between studies.

Imaging requests for common musculoskeletal complaints are increasing and suggest the inappropriate use of imaging [1, 50]. Concerns for the sustainability of diagnostic imaging expenditure have led health systems to seek interventions that reduce inappropriate imaging [51, 52]. Our review included only two studies, both in low back pain, that assessed the cost-effectiveness of interventions addressing inappropriate imaging, and neither included patient health outcomes [22, 25]. An absence of primary studies that assess patient outcomes may have contributed to this knowledge gap [53, 54]. Well-designed models can aid policy-makers in improving the efficient use of diagnostic imaging, and the exploration of uncertainties in model inputs can help direct future research (i.e. sensitivity and value of information analyses [55]).

The current applicability of decision analytic models that have investigated the cost-effectiveness of diagnostic imaging for knee and shoulder complaints are questionable. All seven studies outlined a clear test-treatment pathway where surgery was performed in positive cases [21, 23, 24, 26, 27]. These positive cases were based on pathoanatomical abnormalities observed on imaging that are frequently observed in asymptomatic individuals [56, 57]. Further, surgery for these conditions has been shown to be ineffective [58–61] and contrary to current clinical practice guidelines [62, 63]. This indicates that decision analytic models may need to be updated to accepted test-treatment pathways outlined in clinical practice guidelines.

A strength of this review was the broad search strategy that ensured a comprehensive summary of the published literature to identify methodological and knowledge gaps. A limitation of this review was that we did not formally assess the methodological quality of the included studies as this is not standard practice for scoping reviews. However, we did summarise the reporting of critical methods. There are aspects of methodological quality that are relevant, such as the use of confounding data in Markov models [64], but have not been assessed in the current review. Further, we did not assess the appropriateness and quality of source inputs used in the included studies. In future, a formal assessment of model inputs may be useful to identify areas requiring further research.

5 Conclusion

We found a paucity of high-quality decision analytic modelling studies investigating the cost-effectiveness of diagnostic imaging for common musculoskeletal complaints. The identified methodological flaws and knowledge gaps can be used to inform future studies. With increased scrutiny of the rising cost of healthcare and the need to identify strategies that improve its efficiency, investment in health technology assessments of diagnostic imaging services using decision analytic modelling may aid in research prioritisation and may provide useful insights for decision-makers [65]. However, it is critical that future investigations adhere to modelling guidelines [15, 66] to produce high-quality evidence that aids decision-makers in efficiently allocating diagnostic imaging resources.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s40258-023-00799-4.

Acknowledgements The authors would like to acknowledge and thank Diane Horrigan for her assistance in developing the search strategy.

Funding Open Access funding enabled and organized by CAUL and its Member Institutions.

Declarations

Author contribution SD, LG, and RB conceived the idea for the article, SD and CB performed the literature search and data analysis, and all authors drafted and critically revised the work.

Funding This research did not receive any specific funding.

Conflict of interest All authors declare that they have no conflicts of interest.

Ethics approval Not applicable.

Consent to participate Not applicable.

Consent for publication Not applicable.

Availability of data and material The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

Code availability Not applicable.

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