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Systematic Review/Meta-Analysis

# Outcomes in surgical treatment for tandem spinal stenosis: systematic literature review

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**Abstract**

**BACKGROUND CONTEXT:** Tandem spinal stenosis (TSS) refers to a narrowing of the spinal canal in distinct, noncontiguous regions. TSS most commonly occurs in the cervical and lumbar regions. Decompressive surgery is indicated for those with cervical myelopathy or persistent symptoms from lumbar stenosis despite conservative management. Surgical management typically involves staged procedures, with cervical decompression taking precedence in most cases, followed by lumbar decompression at a later time. However, several studies have shown favorable outcomes in simultaneous decompression.

**PURPOSE:** The aim of this study is to provide a literature review and compare surgical outcomes in patients undergoing staged vs simultaneous surgery for TSS.

**STUDY DESIGN/SETTING:** Systematic literature review.

**METHODS:** A systematic review using PRISMA guidelines to identify original research articles for tandem spinal stenosis. PubMed, Cochrane, Ovid, Scopus, and Web of Science were used for electronic literature search. Original articles from 2005 to 2021 with more than eight adult patients treated surgically for cervical and lumbar TSS in staged or simultaneous procedures were included. Articles including pediatric patients, primarily thoracic stenosis, stenosis secondary to neoplasm or infectious disease, minimally invasive surgery, and non-English language were excluded. Demographic, perioperative, complications, functional outcome, and neurologic outcome data including mJOA (modified Japanese Orthopaedic Association), Nurick grade (NG), and ODI (Oswestry disability index), were extracted and summarized.

**RESULTS:** A total of 667 articles were initially identified. After preliminary screening, 21 articles underwent full-text screening. Ten articles met our inclusion criteria. A total of 831 patients were included, 571 (68%) of them underwent staged procedures, and 260 (32%) underwent simultaneous procedures for TSS. Mean follow-ups ranged from 12 to 85 months. There was no difference in estimated blood loss (EBL) between staged and simultaneous groups (p=.639). Simultaneous surgeries had shorter surgical time than staged surgeries (p<.001). Mean changes in mJOA, NG, and ODI was comparable between staged and simultaneous groups. Complications were similar between the groups. There were more major complications reported in simultaneous operations, although this was not statistically significant (p=.301).

**CONCLUSION:** Staged and simultaneous surgery for TSS have comparable perioperative, functional, and neurologic outcomes, as well as complication rates. Careful selection of candidates for

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simultaneous surgery may reduce the length of stay and consolidate rehabilitation, thereby reducing hospital-associated costs. 

*Key words:* Cervical spinal stenosis; Lumbar spinal stenosis; Spine; Tandem spinal stenosis

## Introduction

Tandem spinal stenosis (TSS) refers to a narrowing of the spinal canal in more than one distinct, noncontiguous region. TSS typically manifests in the cervical and lumbar regions, with thoracic stenosis being the least common [1]. Patients may present with neurogenic claudication, cervical myelopathy with progressive gait disturbance, or mixed upper and lower extremity symptoms [2]. However, only a reported 5% to 28% of patients are symptomatic at presentation [2,3]. TSS has an estimated prevalence of 5% to 60% in the general population [4−12]. This condition may be related to degenerative changes, congenital stenosis, or a combination of both [13,14]. Incidence of degenerative conditions such as TSS is expected to rise with increasing life expectancy [15]. This anticipated rise in incidence necessitates a reexamination of the methods we use to manage this condition. Currently, there is a lack of consensus on surgical management of TSS. Typically, cervical decompression takes precedence in the setting of cervical cord compression and myelopathic symptoms unless severe claudication dominates. In some cases, both cervical and lumbar surgeries can be performed simultaneously [2,12].

Studies dedicated to those with symptomatic or radiographic TSS are scarce. This suggests that current practice extrapolates from well-established literature on single region stenosis. Isolated regional decompression for single region stenosis is associated with a high success rate and acceptable complication profile [16−18]. The purpose of this study is to systematically review the existing literature on surgical management of TSS to compare neurologic and functional outcomes in staged and simultaneous procedures. Secondly, we seek to determine the safety and efficacy of simultaneous and staged surgeries for symptomatic TSS.

## Methods

A systematic review was performed using Preferred Reporting Items for Systematic Review and Meta-Analyses (PRISMA) guidelines [19] (Fig. 1). In accordance with PRISMA recommendations, our study protocol was registered with the International Prospective Register of Systematic Reviews (PROSPERO) on October 25, 2021 (registration number (CRD42021286511). Institutional review board approval was not required for this study. PubMed, Cochrane, Ovid/Medline, Scopus, and Web of Science were queried for the following terms: ((spinal stenosis[mesh]) OR (spinal stenos*[tiab])) AND (((cervical vertebrae[mesh]) OR (cervical[tiab])) AND ((lumbar vertebrae[mesh]) OR (lumbar[tiab])))) OR (tandem stenos*[tiab])) OR (tandem spinal stenos*[tiab])) OR (concomitant stenos*[tiab])) OR (concomitant spinal stenos*[tiab])) OR (concurrent stenos*[tiab])) OR (concurrent spinal stenos*[tiab])) OR (cervical stenos*[tiab] AND lumbar stenos*[tiab]). Our search did not include newer and minimally invasive methods such as “MILD”, “interspinous spacers”, or “percutaneous arthrodesis”. References from studies selected in our search were screened to identify additional articles for inclusion. One article was identified and added to the final analysis.

The primary outcomes assessed in this study were perioperative parameters and post-operative functional and neurologic status changes. Perioperative parameters consisted of operative time and estimated blood loss (EBL). Functional and neurologic status were measured by changes in modified Japanese Orthopedic Association (mJOA) score, Nurick’s Grade (NG), and Oswestry Disability Index (ODI). Secondary outcomes were intraoperative and post-operative complications. These were classified as major if they affected postoperative outcome, and minor if they did not or were only temporary. Major complications included pulmonary embolism (PE), myocardial infarction (MI), and stroke. Among minor complications were DVT, wound infections and delayed wound healing, urinary tract infections, pneumonia, ileus, reversible nerve palsies, incidental durotomies, gait disturbances, and anemia requiring transfusion. Abstracts were reviewed by three independent reviewers (SS, CP, AK) to determine eligibility for full-text analysis. Full-text review was performed by the same three authors. All conflicts were decided by a fourth arbiter (PA). Duplicates were removed before the screening process based on article title, author, and year of publication.

Inclusion criteria were as follows: (1) English language articles or readily available English language translations, (2) original research articles from 2005 through 2021, (3) Studies with human subjects, (4) Studies that reported our primary and/or secondary outcomes for TSS patients, (4) Adult patients defined as 18 years old or older. Exclusion criteria were as follows (1) Studies with subjects younger than 18 years of age, (2) Studies with primarily thoracic stenosis patients, (3) Case reports and case series of fewer than 8 patients, (4) articles published in non-English languages, (5) systematic literature reviews.

### *Study evaluation*

Three authors (PA, SS, and CP) independently rated each study using the National Institutes of Health (NIH) Quality Assessment Tool, which assess nine distinct criteria [20]. All three authors scored each study from 1 to 9, for a maximum score of 27. Studies were then classified as good

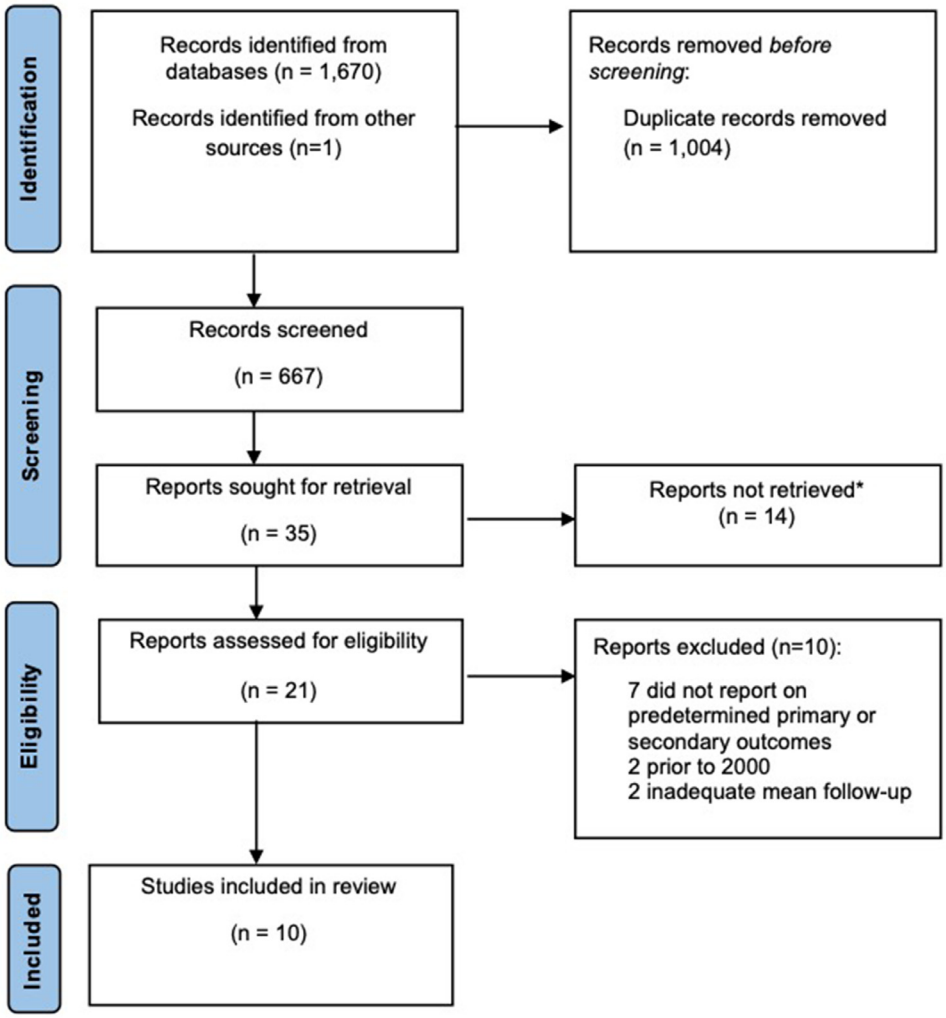


Fig. 1. Flowchart for article selection, which was done in accordance with 2009 preferred reporting items for systematic reviews and Meta-analyses guidelines *13 articles not retrieved due to wrong topic (tendom stenonsis due to atherosclerosis of carotid arteries and 1 duplicate that was not removed initially.

(>66%), fair (33%−66%), or poor (<33%). "Good" studies can be interpreted as having the least risk of bias, "fair" studies as being susceptible to some bias, and "poor" studies as having a significant risk of bias, which could invalidate results (Supplemental Table 1). All participating authors declared no conflicts of interest with regard to manufacturing or materials.

### *Statistical analysis*

Statistical analyses were performed using JMP Pro 16 software (SAS Institute Inc, NC). Continuous variables were reported as weighted means and standard deviations, and categorical variables were reported as proportions. Patient demographics were compared between cohorts with an independent *t* test for continuous variables. Mann-Whitney *U* test was used to relate number of complications to staged or simultaneous procedures. Threshold for statistical significance was established at $p<.05$. Forest plots were used to show the comparison of complications among the included cohorts, with an $I^2$ of 50% to 75% considered moderate heterogeneity and greater than 75% considered high heterogeneity. Proportional meta-analysis using random effects model was performed for complications.

## Results

A total of 667 articles were included in the initial title and abstract screening after removal of duplicates. After preliminary screening, 21 articles met the criteria and underwent full-text review. Ten articles of 21 were selected after full-text review and are summarized in Table 1. Of the 10 included articles, 3 reported outcomes of staged procedures, 4 reported outcomes in simultaneous procedures, and 3 reported both. The 10 studies combined involved 831 TSS patients, 348 (42%) of them are female. The mean age ranged from 29.0 to 92.0 for staged and 43.0 to 88.0 for simultaneous procedures (Table 2). Of the 831 patients, 571

Table 1
Summary of included studies

| Author, year | Study design | N | Mean follow up (months) | Summary of outcomes |
|---|---|---|---|---|
| Aydogan et al., 2007 [29] | Retrospective case series | Staged: 8 | 34.6 | JOA & ODI of all patients improved and was maintained at final follow up |
| Kikuike et al., 2009 [31] | Retrospective case series | Simultaneous: 17 | 69.0 | Improvement in JOA-B, JOA-C, ADL at 6 mo, but symptom deterioration at final follow-up |
| Eskander et al., 2011 [27] | Retrospective cohort study | Staged: 22<br>Simultaneous: 21 | 85.0 | Improvement in JOA, ODI for both staged and simultaneous groups. Age > 68 yr., EBL >400 mL, op time >150 min impacted outcomes and increased complication rate |
| Krishnan et al., 2014 [32] | Retrospective case series | Simultaneous: 53 | 35.8 | Improvement in mJOA, ODI, & NG. Better outcomes in patients < 60 yrs. EBL <400 mL, op time <150 had better outcomes and less complications |
| Li et al., 2017 [23] | Retrospective cohort study | Staged: 222 | 12.0 | JOA & NG improved after prioritized cervical surgery. The lumbar operation rate after prioritized cervical surgery was lower than the cervical operation rate after prioritized lumbar surgery |
| Yamada et al., 2018 [22] | Retrospective cohort study | Staged: 191<br>Simultaneous: 11 | 38.4 | No differences between the TSS and non-TSS patients in pre- and postop L-JOA, and L-JOA recovery rate. Additional cervical surgery improved both C-JOA and L-JOA |
| Singrakhia et al., 2019 [33] | Prospective case series | Simultaneous: 82 | 31.7 | Improvement in mJOA, NG, & ODI. Age, EBL, & op time did not impact complication rate |
| Luo et al., 2019 [24] | Retrospective cohort study | Staged: 47 | Prioritized cervical surgery: 35.0<br>Prioritized lumbar surgery: 36.7 | Cervical stenosis treated first: 67% with complete resolution of symptom. Lumbar stenosis treated first: 91% need cervical operation |
| Cao et al., 2021 [28] | Retrospective cohort study | Staged: 81<br>Simultaneous: 14 | 32.1 | Improvement in JOA-C & JOA-L but ODI decreased. 38.2% of the prioritized cervical group had alleviation of symptoms. 61.8% of the cervical prioritized group had second-stage surgery |
| Abbas et al., 2021 [34] | Retrospective cohort study | Simultaneous: 62 | Study group: 35.2<br>Control group: 36.1 | Mean ODI & mJOA showed significant postop improvement but not at final follow-up. There was no statistical difference in operative time, blood loss, and hospital stay based on age |

Abbreviations: ADL, activities of daily living; EBL, estimated blood loss; op time, operative time; JOA, Japanese Orthopaedic Association (score); JOA-B, JOA-Back; JOA-C, JOA-Cervical; L-JOA, Lumbar-JOA; ODI, Oswestry Disability Index; NG, Nurick's Grade; TSS, Tandem Spinal Stenosis.

Table 2
Summary of demographics reported in included studies

| Author, year | Age, mean (range) (years) | N | Sex |
|---|---|---|---|
| Aydogan et al., 2007 [29] | 68 (51 − 80) | Staged: 8 | 6 M, 2 F |
| Kikuike et al., 2009 [31] | 70.9 ± 10.7 (51 − 86) | Simultaneous: 17 | 12 M, 5 F |
| Eskander et al., 2011 [27] | 66.5 | Staged: 22<br>Simultaneous: 21 | 20M, 23 F |
| Krishnan et al., 2014 [32] | 63.3 (43 − 88) | Simultaneous: 53 | 19 M, 34 F |
| Li et al., 2017 [23] | Prioritized lumbar: 56.3<br>Prioritized cervical:58.3 | Staged: 222 | 119 M, 103 F |
| Yamada et al., 2018 [22] | 72 ± 8.8 (32−92) | Staged: 191<br>Simultaneous: 11 | 106 M 96 F |
| Singrakhia et al., 2019 [33] | 61.8 (29 − 83) | Simultaneous: 82 | 70 M, 12 F |
| Luo et al., 2019 [24] | Prioritized lumbar: 60.0<br>Prioritized cervical: 58.7 | Staged: 47 | 37 M, 10 F |
| Cao et al., 2021 [28] | 62.7 (46 − 79) | Staged: 81<br>Simultaneous: 14 | 81 M, 51 F |
| Abbas et al., 2021 [34][#] | Study group: 71.03 (65 − 89)<br>Control group: 60.13 (50 − 65) | Simultaneous: 62 | 37 M, 25 F |

Abbreviations: M, male; F, Female; [#] Study group was defined as age >/= 65 years and control group as age <65 years.

(68%) underwent staged procedures, and 260 (32%) underwent simultaneous surgery. Of the 571 staged procedures, 260 (46%) had cervical spinal surgery first. The staged procedures group included patients with TSS that had undergone decompression in one region or both at the time of the respective studies. Mean follow-up times ranged from 12 to 85 months.

### *Functional and neurologic status*

Functional and Neurologic outcomes assessed included mJOA score, NG, and ODI. Five studies reported preoperative and postoperative mJOA scores for patients who underwent staged vs simultaneous surgery, represented by 3 and 5 cohorts, respectively. Changes in mJOA for staged procedures ranged from 0.3 to 3.3, with a mean of 1.9±1.5. Changes in mJOA for simultaneous procedures ranged from 0.2 to 4.8, with a mean of 3.2±1.9. There was no difference in change in mJOA between staged and simultaneous groups (p=.134) (Fig. 2). There were not enough cohorts with complete data on mJOA including standard deviation values to compare cervical and lumbar first outcomes directly. Preoperative and postoperative NGs were reported by five studies, represented by four cohorts each. Changes in NG for staged procedures ranged from 0.6 to 1.9, with a mean of 1.3±0.5. Changes in NG for simultaneous procedures were 2.0 to 2.5, with a mean of 2.1±0.4. There was no significant difference in NG between staged and simultaneous procedures (p=.106) (Fig. 3). Preoperative and postoperative ODI were reported in 7 of the 10 studies, represented by 6 cohorts each. Changes in ODI in the staged procedures ranged from 11.54 to 39.71, with a mean of 26.17±11.11. Changes in ODI in the staged procedures ranged from 11.29 to 45.28, with a mean of 32.97±13.00. There was no significant difference in ODI between staged and simultaneous procedures (p=.975) (Fig. 4). The mean change in NG in those that underwent cervical surgery first was 1.6±0.4 compared with 0.4±0.2 in lumbar first subjects (p=.08). The mean change in ODI in cervical first subjects was 27.1±10.0 and 21.1±12.6 in lumbar first subjects (p=.539).

### *Intraoperative parameters*

The perioperative parameters we sought to compare were operative time and EBL. Seven of the 10 studies reported these parameters and are summarized in Table 3. Studies involving staged operations provided the totaled operative times and the EBLs of the two separate procedures. Operative times and EBLs from simultaneous surgeries were reported in six studies with a total of 260 patients, while they were reported in three staged studies for a total of 294 patients. EBLs are comparable between staged and simultaneous procedures (410.5±682.9 vs 388.0±429.2 respectively, p=.639). Staged procedures cumulatively took longer than those of simultaneous procedures (215.1±106.3 vs 168.7±172.0, p<.001).

### *Complications*

All 10 studies reported complications, with a total of 45 complications in the staged procedures and 90 in the simultaneous procedures. There were more major complications in the simultaneous (12) group than in the staged group (4) although this was not statistically significant (p=.301) (Fig. 4). The major complications included PE (4) MI (2) stroke (1), Cauda equina (1), and tracheostomy (1). There was a total of 119 minor complications; 41 after staged procedures and 78 after simultaneous procedures (p=.714) (Fig. 5). There were three reoperations related to the index procedure and 44 reoperations related to major complications including neurological deficit, hematoma, and deep infection. Proportional meta-analysis showed no significant

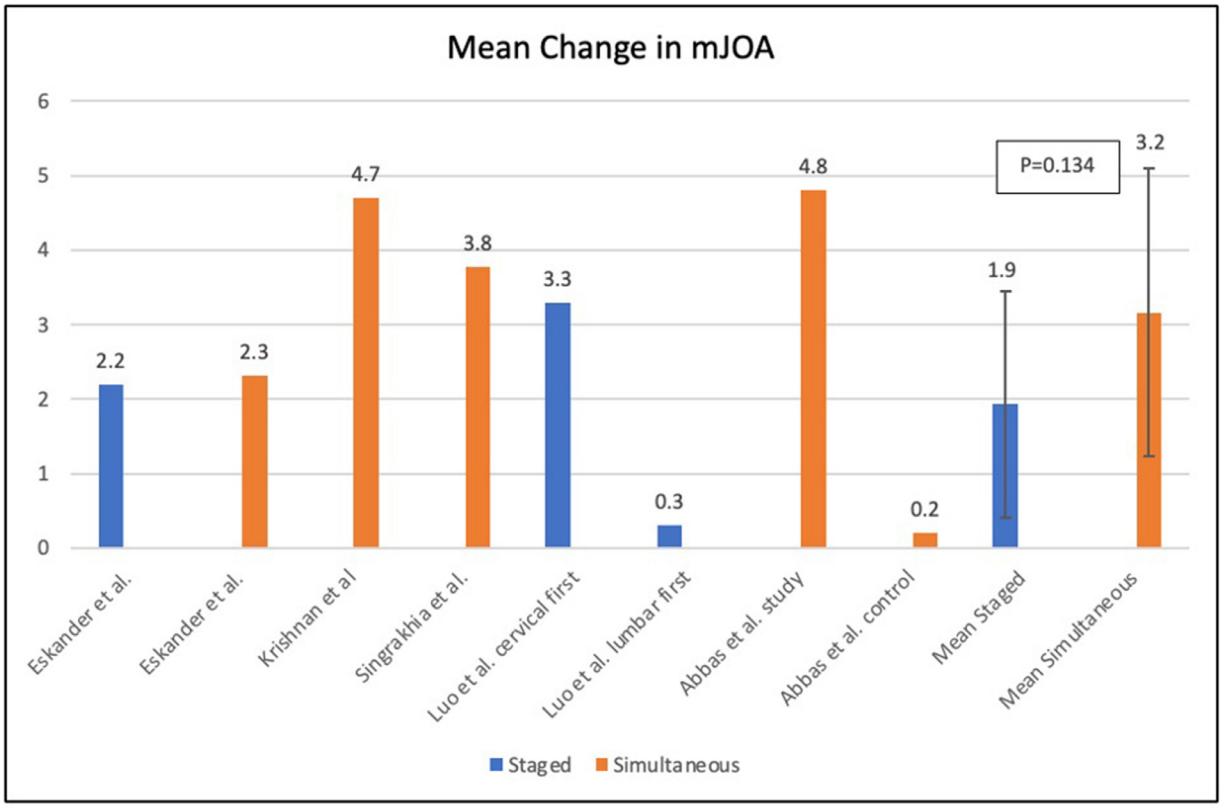


Fig. 2. Change in MJOA for included studies and their respective cohorts and mean change in staged vs simultaneous cohorts. p-value represents difference between mean staged and mean simultaneous cohorts mJOA-modified Japanese Orthopaedic association.

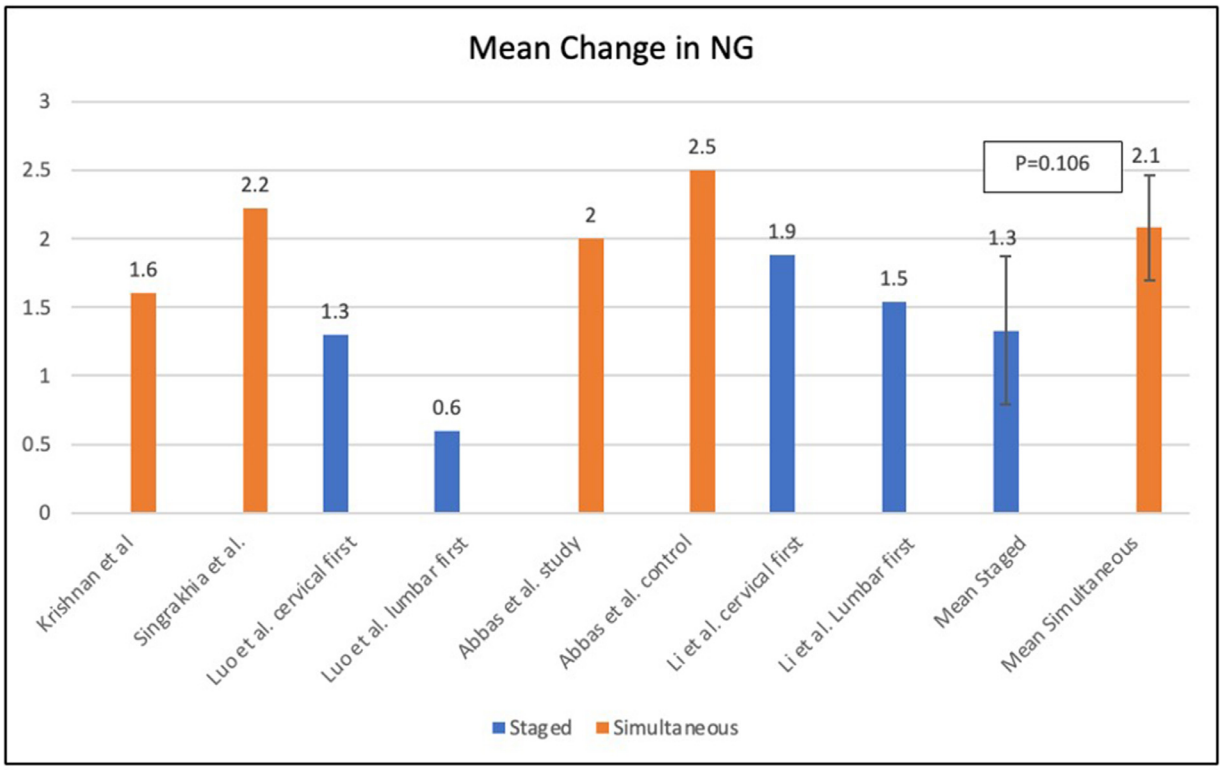


Fig. 3. Change in NG for included studies and their respective cohorts and mean change in stage vs simultaneous cohorts p-value represents difference between mean staged and mean simultaneous cohorts. NG-Nurick's grade#study group consisted of a Cohort of patients above 65 years of age and control group below 65 years of age.

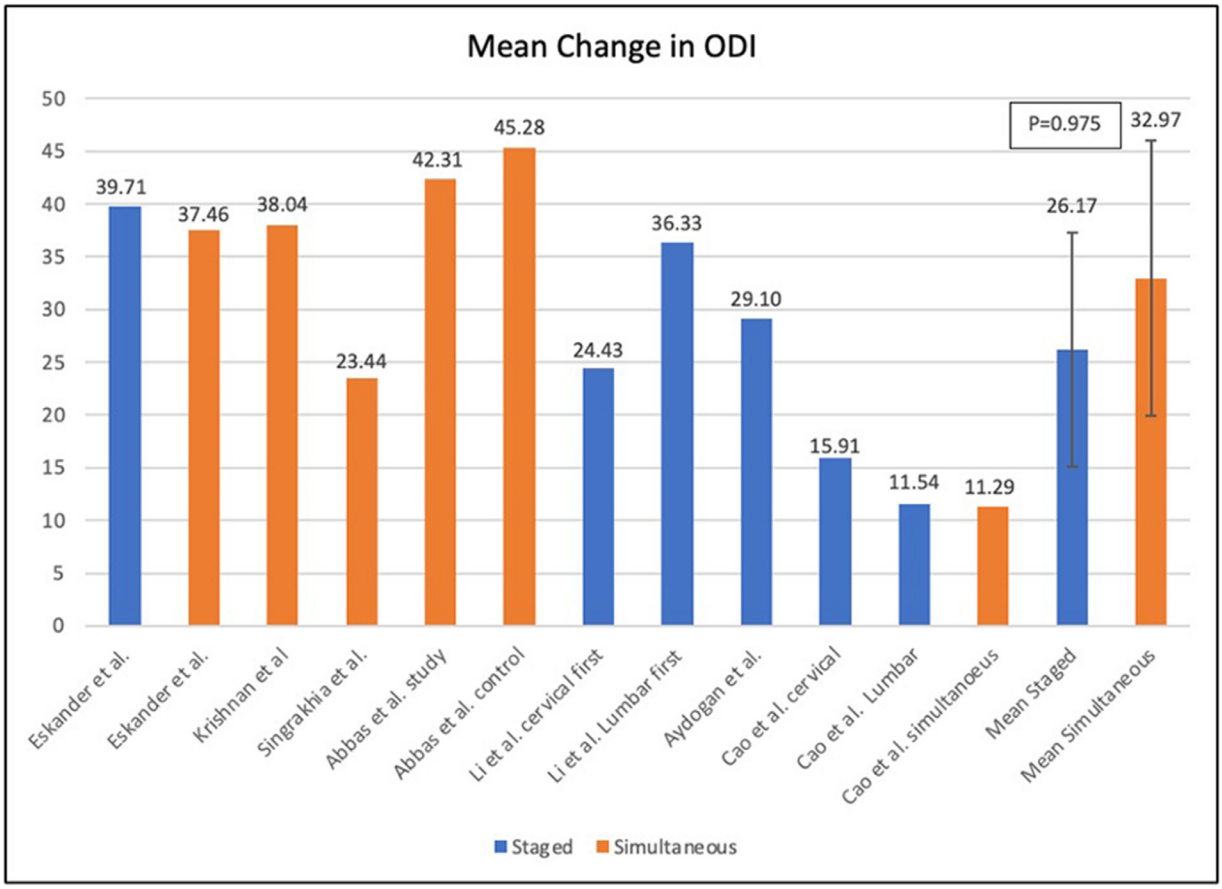


Fig. 4. Change in ODI for included studies and their respective cohorts and mean change in staged vs simultaneous cohorts p-value represents differences between mean staged and mean simultaneous cohorts ODI, Oswestri Disability Index.

Table 3
Summary of reported perioperative parameters for included studies

| | N | EBL, mean (mL) | p value | Operative Time, mean (mins) | p-value |
|---|---|---|---|---|---|
| Kikuike et al., 2009 [31] | Simultaneous: 17 | 440.0 ± 330.0 | - | 189.0 ± 49.0 | NR |
| Eskander et al., 2011 [27] | Staged: 22 | Staged: 405.0 | 0.02 | Staged: 185.0 | <.001 |
| | Simultaneous: 21 | Simultaneous: 557.0 | | Simultaneous: 128.0 | |
| Krishnan et al., 2014 [32] | Simultaneous: 53 | 394.71 ± 131.14 | - | 171.3 ± 48.1 | - |
| Yamada et al., 2018 [22] | Staged: 191 | Staged: 372.8 ± 478.0 | NR | Staged: 218.8 ± 108.3 | NR |
| | Simultaneous: 11 | Simultaneous:432.3 ± 486.6 | | Simultaneous: 257.6 ± 134.1 | |
| Singrakhia et al., 2019 [33] | Simultaneous: 82 | 353.4 ± 92.9 | - | 173.7 ± 39.3 | - |
| Cao et al., 2021 [28]·* | Staged: 81 | | 0.116 | | .138 |
| | Cervical first: 55 | Cervical first: 489.0 ± 91.2 | | Cervical first: 209.6 ± 32.3 | |
| | Lumbar first: 26 | Lumbar first: 525.8 ± 63.7 | | Lumbar first: 224.4 ± 55.4 | |
| | Simultaneous: 14 | Simultaneous: 478.6 ± 73.6 | | Simultaneous: 199.3 ± 35.4 | |
| Abbas et al., 2021 [34]·# | Simultaneous: 62 | | NR | | NR |
| | Study group: 32 | Study group: 350.5 | | Study group: 154.8 | |
| | Control group: 30 | Control group: 304.2 | | Control group: 135.7 | |
| Total | Staged: 294 | Staged: 410.5 ± 682.9 | 0.639 | Staged: 215.1 ± 106.3 | <.001 |
| | Simultaneous: 260 | Simultaneous: 388.0 ± 429.2 | | Simultaneous: 168.7 ± 172.0 | |

Abbreviations: EBL, estimated blood loss; NR, not reported.
* Those with TSS that did not undergo both surgeries were excluded.
# Study group consisted of a cohort of patients above 65 years of age and control group below 65 years of age.

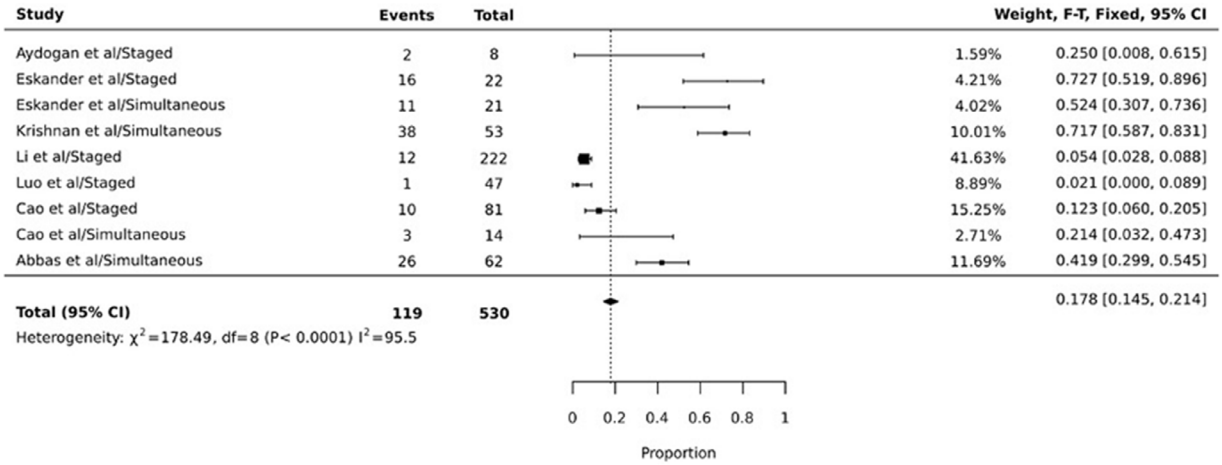


Fig. 5. Forest Plot showing minor complications.

difference in major and minor complications between staged and simultaneous cohorts. Overall heterogeneity was significant for major ($I^2$ − 95.5%, p<.001) and minor complications ($I^2$ − 67.2%, p=.016). (Figs. 5 and 6).

## Discussion

Our review has found no significant differences functional and neurologic outcomes in staged and simultaneous decompressions for TSS. Similarly, there were no significant differences in complication rates between the two groups. Although EBL was comparable, cumulative operative time was significantly less in simultaneous procedures. To our knowledge, there have only been a few studies conducted on TSS outcomes and complications.

### *Incidence of TSS*

The incidence of degenerative spinal stenosis is anticipated to continue to rise as life expectancy steadily increases. The true prevalence in the general population is currently not well defined [4−11]. In a cadaveric study by Lee et al., the presence of cervical stenosis was associated with lumbar stenosis, suggesting the prevalence of TSS is higher than estimated in those with spinal stenosis [14]. Congenital stenosis also contributes significantly to the prevalence of TSS [14,21]. A large cadaveric study by Bajwa et al. established a positive correlation between congenital stenosis of the cervical spine and congenital stenosis of the lumbar spine [21]. According to these cadaveric studies, congenital stenosis has an estimated prevalence of 2% to 5% in the general population [14,21]. Degenerative changes associated with advanced age can contribute to and combine with congenital stenosis can lead to TSS. Cervical decompression usually takes precedence over lumbar decompression, although some studies suggest that decompressive surgery should be prioritized for the more symptomatic region [22−27]. Yet other studies have shown that simultaneous procedures have comparable outcomes to staged procedures for TSS [2,26,28]. Our review of available literature reveals that staged and simultaneous have comparable outcomes and complications Table 4.

### *Prioritizing cervical or lumbar decompression for TSS*

There is a lack of available literature on surgical outcomes in patients with TSS owing to the relative rarity of this condition. Of the available studies, outcomes on staged

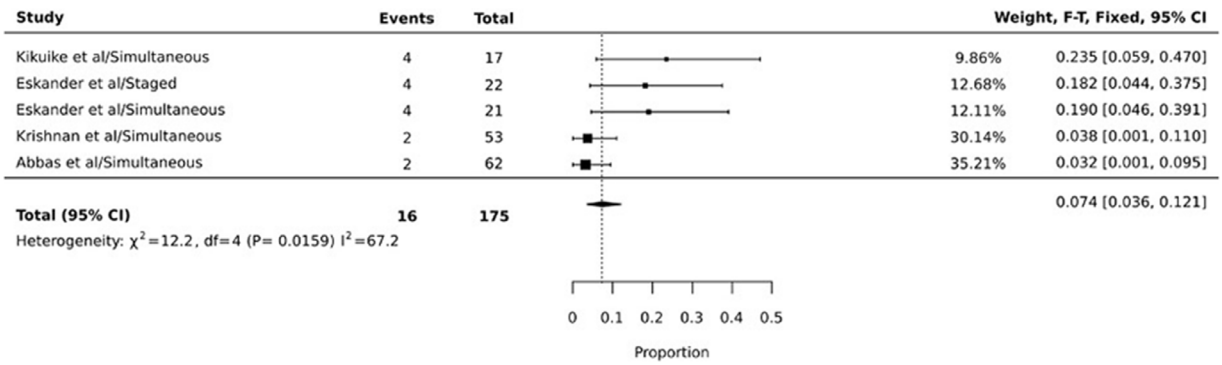


Fig. 6. Forest Plot showing major complications.

Table 4
Reported complications from included studies

| | N | Staged/Simultaneous | Major complications | Minor complications | Complications |
|---|---|---|---|---|---|
| Aydogan et al., 2007 [29] | Staged: 8 | Both | 0 | 2 | Incidental durotomy, DVT |
| Kikuike et al., 2009 [31] | Simultaneous: 17 | Simultaneous | 4 | 0 | 2 reoperations and 2 operations related to complications. Deep wound infection, compressive hematoma |
| Eskander et al., 2011 [27] | Staged: 22<br>Simultaneous: 21 | Both | Staged: 4<br>Simultaneous: 4 | Staged: 16<br>Simultaneous: 11 | 1 reoperation and 2 operations related to complications: 3 PE, 2 MI, 1 deep infection, 1 cauda equina, 1 tracheostomy and "27 minor complications" |
| Krishnan et al., 2014 [32] | Simultaneous: 53 | Simultaneous | 2 | 38 | Septicemia, PE, DVT (2), reversible palsy (5), hyponatremia (8), transient renal function alteration (4), incidental durotomy (3), wound gaping (2), superficial infection (1), paralytic ileus (8), UTI (5) |
| Li et al., 2017 [23] | Staged: 222 | Staged | 0 | 12 | Reversible palsy (3), gait disturbances (6), infection (3) |
| Yamada et al., 2018 [22] | Staged: 191<br>Simultaneous: 11 | Both | 39 | NR | 39 operations related to complications (Not Specified). |
| Singrakhia et al., 2019 [33] | Simultaneous: 82 | Simultaneous | NR | NR | 16 complications (Not Specified) |
| Luo et al., 2019 [24] | Staged: 47 | Staged | 0 | 1 | Wound healing complication (1) |
| Cao et al., 2021 [28] | Staged: 81<br>Simultaneous: 14 | Both | Staged: 0<br>Simultaneous: 0 | Staged: 10<br>Simultaneous: 3 | Anemia (5), DVT (4), pneumonia (1), UTI (3) |
| Abbas et al., 2021 [34] | Simultaneous: 62 | Simultaneous | 2 | 26 | 1 operation for complication; incidental durotomy (2), reversible palsy (2), superficial wound infection (4), deep wound infection (2), UTI (5), ARDS (1), Prolonged catheterization (13), DVT (1), Reversible nerve palsy (3) |

procedures specifically for TSS are relatively less common possibly due to the reliance on well-established literature on isolated regional stenosis. Despite this, staged operations are still the mainstay of surgical management in TSS. Generally, cervical decompression is the priority, although some studies have concluded that the more symptomatic region should take precedence. Li and colleagues showed that cervical decompression first is superior to lumbar first at improving both cervical and lumbar symptoms [23]. In their study, 144 underwent cervical first surgery with 22.9% needing subsequent lumbar operation, while 78 had lumbar first surgery with 57.7% needing subsequent cervical surgery. JOA, NG, and ODI significantly improved after prioritized cervical surgery, but JOA and NG did not significantly improve after prioritized lumbar surgery. Yamada et al. found that after lumbar surgery, additional cervical surgery improved both cervical-JOA (C-JOA) from 10.3±2.8 to 12.1±3.0 (p=.030) and lumbar-JOA (L-JOA) from 14.8±7.3 to 19.9±5.0 points (p=.033)21.[22] Additionally, in a study of 47 patients treated by staged procedures, Luo et al. found cervical surgery first lowers the need for second stage surgery [24]. Eleven of 36 patients (31%) required second stage surgery in those treated for cervical stenosis first. This is in contrast to 10 of 11 (91%) patients treated for lumbar stenosis first who required second stage surgery. If lumbar surgery was performed first, there was a significant worsening of mJOA and NG. Cao et al. also concluded that cervical surgery first significantly reduces the need for second-stage surgery [28]. In their cohort, 61.8% of those that had cervical surgery first required second-stage surgery while 89.6% who had lumbar first surgery required second-stage surgery. Other studies by Aydogen et al. and Dagi et al. did not document any impact of cervical decompression on lumbar stenosis symptoms [2,29]. On the other hand, a study investigating Quality of Life (QoL) outcomes by Pennington et al. found that 19.6% of their total 803 patients that received lumbar decompression alone had significantly improved Visual Analogue Scale (VAS), Pain Disability Questionnaire (PDQ) and EuroQOL-5 Dimensions (EQ- 5D) [30]. This represents a minority of the literature that suggests lumbar decompression alone for TSS can improve overall symptoms.

### *Staged vs simultaneous operations for TSS*

Currently, there is no consensus on surgical management for symptomatic TSS. Staged operations, which are generally more supported in the literature, are less invasive and more familiar and thus relatively favored. Tsutsumimoto et al. conducted a study on the natural course of patients with cervical myelopathy and coincident asymptomatic lumbar canal stenosis [6]. In this study, only 17.9% patients developed lower extremity symptoms after cervical decompression. This led to the conclusion that prophylactic lumbar decompression was unwarranted in asymptomatic patients who undergo cervical surgery. Moreover, Li et al.

found that the rate of subsequent lumbar surgery after prioritizing cervical surgery was 22.91% [23]. Inoue and colleagues conducted a retrospective study of 64 patients with TSS wherein 69% had improvement of lumbar symptoms after cervical decompression alone [25]. However, lumbar symptoms relapsed in 30 of the 44 cases within a mean follow-up time of 6.3 months, prompting additional surgery in 28 patients. A total of 50 (78%) had additional surgery after initial lumbar surgery due to worsening of symptoms or no improvement after initial decompression. Only 22% of patients maintained improvement at final follow-up.

Functional and neurologic outcomes of staged and simultaneous procedures for TSS have rarely been compared in the literature. Eskander et al. directly compared outcomes in TSS patients; 22 of whom underwent staged procedures and 21 simultaneous procedures [27]. The authors of this study showed that both groups with similar demographics had postoperative improvement in JOA and ODI. Cao et al. compare 14 single-stage operations with those that underwent staged procedures and found no significant difference in Neck Disability Index (NDI), Cervical-JOA (C-JOA), and ODI [28]. Despite a lack of data supporting the direct comparison with staged surgeries, there have been a number of studies that show promising functional and neurologic outcomes in simultaneous operations for TSS. Kikuike et al. found improvement in B-JOA (back-JOA) (from 14.4 to 21.9), C-JOA (from 12.5 to 14.5), and Activities of daily living (ADL) scores 6 months after surgery [31]. However, there was significant deterioration at final follow-up in 42% of patients, which the authors attributed to patient-specific factors such as systemic comorbidities. The results of this study were supportive of simultaneous surgeries although there were rather limited by the size of the cohort. In a larger study, Krishnan et al. studied 53 patients that had simultaneous surgeries for TSS [32]. The mJOA and ODI improved at 12 months (from 8.86 to 13.00 and from 68.15 to 30.11, respectively) and further at final follow-up (14.52 and 24.03 respectively). In the largest study to date, Singrakhia and colleagues prospectively planned 82 single-stage surgeries for TSS [33]. mJOA, NG, and ODI all had significant improvement at 12 months postoperatively and further improvement at final follow-up. Abbas et al evaluated 62 patients with TSS for differences in clinical outcomes based on age [34]. They found no significant difference based on age in Visual Analog Scale (VAS), mJOA, NG, and ODI. The authors concluded that with personalized optimization for every patient, age is not a significant factor in determining outcomes for single-stage surgery for TSS. Similarly, Aiwale et al. compared 45 single staged-surgery patients older than 60 years of age to those younger [35]. ODI and NGs had no significant difference when analyzed by age group. Their findings indicated that despite advanced age and comorbidities, single staged surgery with good outcomes is feasible. Simultaneous procedures for TSS have been compared with other procedures that are routinely carried out concurrently such as bilateral total knee or bilateral total hip replacements. These procedures have been proven to have comparable perioperative complication rates with their unilateral staged versions while reducing anesthesia events and hospital stay and thereby improving overall cost for the patient [36,37]. TSS has also been likened to Double Crush syndrome, impingement of a peripheral nerve in two or more distinct locations. Optimal results for this condition, which is mechanistically similar to TSS, are achieved when decompression is done on both levels simultaneously [38].

### *Perioperative parameters*

Potential disadvantages of simultaneous surgery for TSS include increased operative time and increased EBL. Increased operative time and increased blood loss have been associated with higher rates of complications. Eskander et al. showed that operative time above 150 minutes and EBL above 400 mL do significantly impact complications [27]. Krishnan et al. report that operative time below 150 minutes reduces average number of complications but has no significant effect on the outcome [32]. Nevertheless, Singrakhia et al. found no correlation between increased operative time, EBL and complication rates with a larger cohort [33]. Abbas et al. had similar findings with a more comorbid patient cohort [34]. Their non-control study cohort was older (mean age 71.03 vs 60.13 years) and had more serious comorbidities (more than 20 patients with more than 2 comorbidities). Whether simultaneous operations have longer operative times and EBLs is also a matter of contention. Cao et al. reported shorter operative times and lower EBLs for their simultaneous cohort compared with their staged [28]. However, their simultaneous surgery cohort was limited by a small sample size of 14 patients. Additionally, their patients were carefully selected to minimize age and comorbidities. Perioperative parameters are likely more important in the immediate postoperative period but have less bearing on the final surgical outcome than other factors such as duration and severity of symptoms at presentation. Adequate decompression and fixation are likely better predictors of long-term outcomes of surgery. Optimal decompression and fixation are attainable in either staged or simultaneous operations. Therefore, it is no surprise that the outcomes of both methods are generally comparable. However, the postoperative period when operative time and EBL are most likely to have an impact coincides with the time common medical complications are more likely to occur. In our review of the literature, we found operative time to be shorter in simultaneous procedures. However, none of the studies reported operative time or anesthesia time separate from total operative time. Increased operative times in staged procedures are likely due to two distinct additional prep and anesthesia times. Whether simultaneous surgeries have higher operative times and higher EBLs is still unclear as results have been conflicting so far. It is clear however, that preoperative

optimization and careful patient selection leads to good outcomes and lessens complications.

### *Complications*

Complications are perhaps the greatest potential drawback to simultaneous surgery in TSS. Classification systems such as Clavien-Dindo categorize complications based on severity. However, our categorization of complications as major and minor was defined by effect on final outcome. This definition was used in order to remain consistent with the studies included herein. Among the included studies, three define major and minor complications and the rest of the studies simply report them without clear definitions. As such, three studies define DVTs as minor complications, and the other cohorts in which DVTs occurred only reported their occurrence.

Most complications are surgical complications, such as incidental durotomy and reversible palsy. However, a considerable number of complications such as DVT, PE, MI or stroke are related to health comorbidities. Staged procedures are more familiar, and surgeons understand the complications well. In a direct comparison of staged and simultaneous procedures, Eskander et al. found no significant differences between the two groups with respect to complications [27]. Age was the major factor that contributed to complications. Patients above 68, regardless of surgical treatment approach had significantly more major and minor complications. Krishnan et al. found that minor complications were more likely in patients older than 60 years of age [32]. In addition, Abbas et al. included 18 patients above the age of 65 and 11 below the age of 65 years of age [34]. They found that despite older age, single-stage surgery for TSS was safe and efficacious given preoperative optimization.

### *Limitations*

The relative lack of literature reporting specifically on clinical outcomes of TSS led to several limitations in the interpretation of these findings. First, of the existent studies, there is a skew toward reporting on simultaneous operations given that staged operations rely on isolated region stenosis data. Additionally, there is probably a bias in patient selection as healthier patients are more likely to be considered to undergo simultaneous surgery, therefore complication rates appear similar. If patients were randomized to each group, results may be different. Furthermore, there is great heterogeneity in the reporting of the data from the available studies which limited data extraction. For instance, grading of stenosis was not widely reported within each study. This may be reflected in the differences in functional and neurologic scores as well as improvements in such scores reported among the included studies. Additionally, complications reported in these studies mainly focused on events that occurred during the postoperative period. Since patient follow up in these studies ranged from 12 to 85 months, we can only acknowledge the complications during this time point. Future studies looking at long-term follow-up of these patients will help us understand any long-term sequela such as changes in functional and neurological status, incidence of adjacent level disease, hardware failure or nonunion requiring revision surgery. Although we recognize that any recommendation based on these data is weak, we have made comparisons that allow, for limited conclusions based on a systematic comprehensive compilation of the relevant available data.

## Conclusions

The lack of clear consensus on surgical management of TSS specifically underscores the importance of re-evaluating current practices. Although the literature overall is limited, there are abundant studies from which conclusions can be drawn on surgical outcomes after staged and simultaneous operations. If electing for staged operations, cervical decompression should precede lumbar operation in those with symptoms of cervical myelopathy or severe cervical stenosis and cord compression. This optimizes the functional and neurologic outcomes, and it may eliminate or defer the need for second-stage lumbar surgery in certain cases. Simultaneous surgery is also an option for carefully selected patients. Perioperative outcomes and functional and neurologic outcomes have so far been comparable between staged and simultaneous procedures. Complication profiles are also similar and are not pronounced in simultaneous decompressions when compared with staged decompressions. Overall, the strategies appear to yield similar outcomes although more data is necessary. These findings are meaningful in the context of increasingly common surgical management of degenerative conditions of the spine. Consolidating procedures in carefully selected patients might curtail costs associated with spine surgery.

## Declaration of competing interest

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors. We have no conflicts of interest or conflict of interest-associated biases to report.

## Supplementary materials

Supplementary material associated with this article can be found in the online version at https://doi.org/10.1016/j.spinee.2022.07.088.

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