

Functional outcomes in adults following corpus callosotomy: A systematic review

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ABSTRACT

Corpus callosotomy is a commonly used surgical procedure for seizure relief in individuals with drug-resistant epilepsy but little is known about the functional outcomes of this surgery in adults. This paper systematically reviews published literature pertaining to post-surgical outcomes across cognitive and non-cognitive functional domains after anterior or total corpus callosotomy. Based on the 15 papers that met our inclusion criteria, our review suggested that praxis and visuoconstructional skills may be especially susceptible to decline after surgery, despite reduced seizure burden, with levels of attention and intellectual functioning often maintained or improving. Non-cognitive functional outcomes (quality of life, independent living, mood and behaviour) generally improved with reduced seizure burden.

1. Introduction

Corpus callosotomy (CC) is one of the earliest palliative procedures devised for surgical control of drug-resistant epilepsy, which involves severing fibres of the corpus callosum [1–4]. Indications for corpus callosotomy include Lennox Gastaut syndrome, atonic seizures, or persistent generalised tonic clonic seizures in the absence of a clear lesion, that are poorly controlled by medication [5,6]. Given the possible complications and the irreversible nature of the procedure, many centres now prefer to use the less invasive vagal nerve stimulation (VNS) surgery to break the generalised nature of epileptiform activity and reduce the frequency of these seizures [7].

In resource poor countries or developing economies such as India however, VNS is not a viable option given the costs and the inconsistent reports of seizure control associated with the procedure [8]. Even in the West, it is not uncommon for individuals to undergo VNS followed by CC [9,10]. Corpus callosotomy may thus be a cost-effective solution for individuals that meet the indication for the same. While non-seizure related outcomes have been extensively studied in the pediatric

population, little is known about these outcomes in adult cohorts. The possibility of a chronic disconnection syndrome is often a deterrent to corpus callosotomy in children [11] as well as adults. Despite this, the long-term outcomes of adults with epilepsy undergoing a corpus callosotomy remain relatively uninvestigated. A thorough understanding of the same is warranted with a view to determining the safety and applicability of this procedure in appropriate adult candidates.

This paper aims to systematically investigate the functional outcomes of corpus callosotomy in adults suffering from drug-resistant epilepsy.

2. Methods

2.1. Search strategy

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) checklist was used to ensure a transparent systematic review of functional outcomes of corpus callosotomy within the adult population [12]. SCOPUS (475), OSF preprints (0), ScienceDirect

Abbreviations: ACC, anterior corpus callosotomy; AVLT, auditory verbal learning test; BVRT, Benton Visual Retention Test; CC, corpus callosotomy; CPS, complex partial seizures; FSIQ, full-scale IQ; GIQ, general intelligence quotient; GT, generalised tonic; GTC, generalised tonic clonic; IQ, intelligence quotient; PIQ, performance intelligence quotient; RCF, Rey Complex Figure; SEEG, stereoelectroencephalography; SLCC, stereotactic laser corpus callosotomy; VIQ, verbal intelligence quotient; VNS, vagus nerve stimulation; VSMS, Vineland's Social Maturity Scale; WISC-R, Wechsler Intelligence Scale for Children-Revised; WMS, Wechsler Memory Scale; QoL, quality of life.

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(994), PubMed (314) and Web of Science (1) were searched from 1990 onwards using the terms “corpus callosotomy AND adult”. Removal of duplicates (62) reduced the total of 1784 hits to 1722 (See Fig. 1). The search was conducted between 11/4/23 and 19/5/23.

2.2. Inclusion criteria

To be included in the review, all of the following criteria needed to be met: (1) the concerned individual be aged 18 or above with a history of epilepsy (2) the only neurosurgical procedure undergone be some form of corpus callosotomy (anterior, posterior or total) (3) functional outcomes (cognitive, behavioural, psychological, every day living related etc.) be reported for the individual at least 6 months post-surgery

(4) the article be published in English (5) the paper be a primary research study.

Papers that made reference to experimental tasks with little bearing on an individual's daily functioning were excluded. Similarly, large studies that looked at functional outcomes but did not clearly indicate the results for post-callosotomy individuals or individuals ≥ 18 years of age were also excluded. Individuals with a comorbid neurological condition (e.g. Downs syndrome, autism), or individuals that underwent any other brain surgery before the CC were also excluded. Studies without pre-operative data for comparison of post-surgery effects were also excluded unless post-operative results were reported in the form of difference scores. Studies reporting on qualitative differences in abilities also formed part of this review.

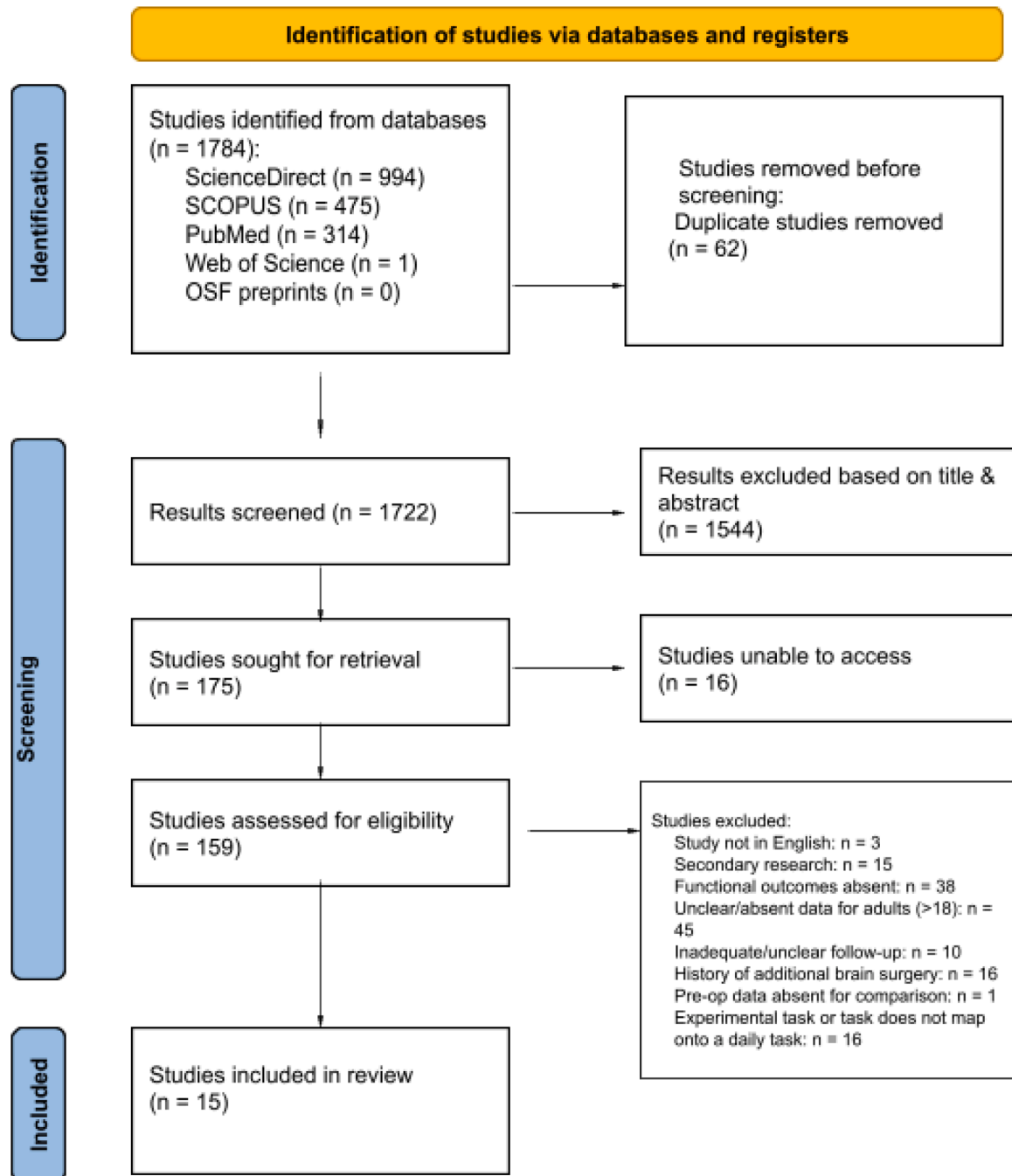


Fig. 1. PRISMA guidelines for selection of studies for review.
Note. The flowchart follows PRISMA 2020 guidelines (Page et al. [12]).

2.3. Data extraction

In cases where individuals aged 18 or over comprised only a few individuals in the reported sample, data pertaining to these specific individuals were extracted. Extracted data included the individual's age, extent of CC they underwent, pre- and post-surgical functional status (or reported difference scores), duration of follow-up and where provided, the extent of seizure relief experienced. For individuals undergoing a two-stage CC, functional outcomes after the first or second surgery are reported, based on the information presented in the original paper and they are categorised under partial or complete CC respectively.

3. Results

A total of 15 articles comprising 73 participants met the inclusion criteria. Outcome measures included intellectual functioning, cognitive functioning (attention, speed of information processing, language, praxis and visuospatial skills, verbal and visual memory, executive functioning), quality of life, daily functioning (independent living and adaptive skills), psychological and behavioural status. There was a great deal of variability across studies with regard to selection of participants, outcome measures used, duration of follow-up as well as level of detail provided pertaining to the participants (see Table 1)

The extent of resections in the anterior CC category varied from < 1/3rd to 2/3rd resection of the corpus callosum anteriorly. Where available, the extent of the resection has been reported. Else, it has simply been termed anterior CC (ACC). There were no studies that made reference to outcomes following a posterior CC that met our inclusion criteria. Both one- and two-stage CC's were grouped together as total CC if outcomes reported occurred six months after the second surgery. There were 11 studies that discussed outcomes for ACC and 9 studies discussing outcomes for total CC.

Given the palliative nature of corpus callosotomy as a procedure, seizure freedom was not expected. Where reported, details pertaining to post-surgical seizure status have been presented with regard to reduction in disabling seizures. However, each individual's outcome is not described as a function of their seizure freedom as complete seizure freedom is relatively low after CC [13]. In the event of a poor outcome however, seizure status is mentioned (where data are available) to determine whether the extent of seizure relief could account for the poor functional outcome.

3.1. Intellectual functioning

Where objective test scores were provided, pre-post test change scores of 15 or greater were considered to be significant to align with a

Table 1
Summary of functional outcomes assessed in selected studies.

Study	Relevant sample	Age range for relevant sample (in years)	Type of epilepsy	Procedure length	Duration of follow-up (general range)	Functional outcome assessed
Andersen et al. [23]	8	23–37	GTC, GT, myoclonic, atonic, absence	Anterior CC: 5 Total CC: 3	19–62 (mean 39 months)	Attention, speech & language, praxis & visuospatial skills, quality of life, daily functioning, independent living and adaptive skills, behavioural & psychological features
Baynes et al. [21]	1	44	Generalised seizures	Total CC (inferior part of the rostrum preserved)	7 years	IQ
Buchanan and Fearnside [25]	3	20–29	Tonic seizures, falls, tonic-clonic seizures	Anterior CC: 1 Complete CC: 3	6 months - 4 years	Attention, quality of life, daily functioning, independent living & adaptive skills
Chandra et al. [19]	1	25	Head drops, tonic clonic, tonic	Total CC (endoscopic)	12 months	IQ, attention, daily functioning, independent living & adaptive skills, behaviour & psychological features
Claverie and Rougier [28]	13	18–42	Tonic or atonic seizures with falls	Anterior 2/3rds	1–8 years	Quality of life, daily functioning, independent living & adaptive skills, behaviour & psychological features
Cohen et al. [17]	2	18	Drug-resistant epilepsy	Anterior 2/3rds	1 year	IQ
Cukiert et al. [15]	11	21–53	Idiopathic Generalized Epilepsy	Total CC (sparing only the splenium)	24–98 months (mean 49 months)	IQ, attention, quality of life
Gilliam et al. [24]	6	22–38	Tonic, atonic	Anterior 2/3rds: 6	7–120 months (mean = 26.2 months)	Attention, daily functioning, independent living & adaptive skills
Mamelak et al. [22]	9	19–31	GTC, atonic, CPS	ACC: 6 Total CC: 3	6–69 months	IQ
Marino et al. [14]	12	19–41	Tonic-clonic, atonic, versive, myoclonic, absence	Anterior 1/2 CC: 2 <1/3 anterior CC: 3 2/3 anterior CC: 5	4–11 years	IQ, attention, praxis & visuo-perceptual skills
Phelps et al. [27]	1	39	–	Total CC: 1 (inferior part of rostrum preserved)	7+ years	Memory
Rathore et al. [16]	1	18	GTCS, tonic seizures, drop attack	Anterior CC: 1	1 year	IQ, attention, behavioural & psychological features
Rich et al. [26]	2	39–49	Focal & tonic-clonic seizures	Anterior SLCC: 1 Total CC: 1	20–24 months	Speech & language, executive functioning
Sass et al. [20]	1	19	Secondary generalized epilepsy	Total CC (two-stage)	40 months	IQ
Sauerwein and Lassonde [18]	2	20–21	–	Total CC	15 months - 1 year	IQ, speed of information processing, speech & language and memory

CPS - Complex Partial Seizures, GTC - generalised tonic clonic, GT - generalised tonic, SLCC - stereotactic laser corpus callosotomy.

one standard deviation change in intellectual functioning. Given that the data spans from 1990 there is some variability in the index scores used to denote intellectual functioning. Where index scores were not presented, author reports of improvement/declines have been presented. Where available, the specific type of intellectual functioning has been specified. Results are presented on the basis of the type of surgery conducted and the type of intellectual functioning under consideration.

3.1.1. General intellectual functioning

One case each of anterior 1/3rd and anterior ½ resection that were untestable pre-surgically could undergo formal evaluation of their intellect post-operatively, suggestive of some improvement [14]. The GIQ of nine individuals in the cohort reported by Marino et al. [14] remained stable after varying levels of anterior CC (< anterior 1/3rd to anterior 2/3rd), with Cukiert et al. [15] reporting similar findings in their 11 cases of anterior CC. There was one case each of unchanged intellectual functioning following an ACC [16] and anterior 2/3rd resection [17].

There were only two reports of a decline in intellectual functioning in cases of anterior CC. One occurred in the context of reduced seizure burden following an anterior 2/3rd resection [17], and one in the context of post-operative complications [18], where details pertaining to post-surgical seizure burden were unclear.

Three individuals that underwent a total CC were reported to have maintained their pre-surgical level of intellectual functioning at the time of post-surgical follow-up [18–20], while one individual was reported to show a decline despite a reduction in seizure burden [21] (Table 2).

3.1.2. Verbal intellectual functioning

All six individuals undergoing anterior CC in the series by Mamelak et al. [22] maintained their pre-surgical level of verbal intellectual functioning, as did an additional eleven [15] and nine [14] individuals across other studies. The single case of decline in VIQ after anterior CC occurred in the context of significant surgical complications [18].

All five individuals undergoing complete CC were reported to show stable VIQ's over time [18,21,22] (Table 3).

3.1.3. Performance based intellectual functioning

As seen in Table 4 one individual in the series by Marino et al. [14] showed an improvement in PIQ, while the remaining eight maintained pre-surgical levels of functioning. All six individuals subjected to anterior CC maintained pre-surgical levels of PIQ [22]. The only reported case of decline, once again presented in the context of post-operative complications which included right hemisphere edema and left-sided hemiplegia [18].

Four cases of complete CC reported stable PIQ at the time of post-surgical follow up [18,22], with reports of a decline in one case [21], despite a reduction in debilitating seizures.

3.2. Cognitive functioning

3.2.1. Attention

A total of nine individuals undergoing varying levels of resection of the anterior CC (two with < 1/3rd resection, three with 1/3rd resection, two with anterior ½ resection and two with 2/3rd resection) showed improved attention on neuropsychological measures [14]. Similarly, qualitative improvements in attention were reported in 11 adults with idiopathic generalised epilepsy after an anterior CC [15]. Parental reports were suggestive of improvements in attention post ACC in an adult with pre-existing intellectual disability [16], one case in the series by Andersen et al. [23] and in six adults following anterior 2/3rd CC [24]. Two individuals with 2/3rd CC resection maintained pre-surgical levels of attention on neuropsychological measures [14] and three parents in the Andersen et al. [23] study felt concentration to be unchanged in their adult child post ACC, despite only one individual experiencing significant seizure reduction.

Table 2
Intellectual functioning as a functional outcome of CC in Adults.

	Procedure	N	Measure	Seizure burden	Outcome
Cohen et al. [17]	Anterior 2/3rd	1	WISC-R IQ	Unchanged: 1	Stable: 1
	Anterior 2/3rd	1	WISC-R IQ	Reduced: 1	Decline: 1
Cukiert et al. [15]	Anterior CC (splenium sparing)	11	IQ	Reduced: 10 Stable: 1	Stable: 11
Marino et al. [14]	< 1/3rd	1	GIQ	Reduced: 1	Stable:1
	1/3rd	2	GIQ	Reduced: 2 [§]	Stable: 2
		1	IQ	Reduced: 1	Improved:1
	Anterior ½	1	GIQ	Reduced: 1	Stable:1
		1	IQ	Reduced: 1	Improved: 1
	Anterior 2/3rd	5	GIQ	Reduced: 5	Stable: 5
Rathore et al. [16]	ACC	1	IQ	Reduced:1	Stable: 1
Sauerwein and Lassonde [18]	Anterior CC (splenium sparing)	1	FSIQ	Not reported	Decline: 1 Post-operative complications affecting the right hemisphere
Total CC Baynes et al. [21]	Total CC	1	FSIQ	Reduced: 1	Decline: 1
Chandra et al. [19]	Total CC (endoscopic)	1	IQ	Unclear:1	Stable: 1
Sass et al. [20]	Two-stage CC	1	IQ	Not clearly stated	Stable: 1
Sauerwein and Lassonde [18]	Total CC	1	FSIQ	Not reported	Stable: 1

*GIQ = general IQ; FSIQ = full-scale IQ; WISC-R = Wechsler Intelligence Scale for Children - Revised. Even though some individuals were assessed with the WISC-R, a test intended for children, the individuals were over 18 years of age and hence these data have been included in the study.
^ Some individuals who could not be administered an IQ test pre-surgically could participate in these assessments post-surgically. Although this does not adhere to the criteria of a 15-point change in performance, this is considered an improvement and reported as such only with regard to GIQ/IQ. Data pertaining to these individuals is not repeated with regard to VIQ and PIQ.
§ One of these individuals experienced an increase in generalised tonic clonic seizures from 1/year to 3/year post-surgery despite a reduction in atonic seizures.

Neuropsychological measures of attention showed a worsening in one case of anterior CC (2/3rd resection) despite significant seizure reduction [14]. Worse concentration in the context of moderately reduced seizure frequency was also noted in parent ratings provided for one operated case [23]. Buchanan and Fearnside [25] report reduced hyperactivity in an individual with an intellectual disability following a two-stage CC. On informal assessment, attention was felt to be unchanged after an endoscopic CC [19]. Andersen et al. [23] also report the case of P18 whose parents reported no change in concentration despite more than 90 % reduction in seizures after a complete CC. Parents of two additional individuals in the same series undergoing the same procedure reported worse concentration post-operatively, in the context of no significant change in seizure frequency (Table 5).

3.2.2. Speed of information processing

Sauerwein and Lassonde [18] noted a decline in psychomotor speed in MP's preferred and non-preferred hands as measured by the finger tapping test (> 1 SD change in scores) following a splenium sparing CC. MP however did experience right hemisphere edema as a complication of her surgery. Conversely, total CC (with no complications) was

Table 3
Verbal Intelligence Quotient (VIQ) outcomes after corpus callosotomy.

	Procedure	N	Measure	Seizure burden	Outcome
Anterior CC Cukiert et al. [15]	Anterior CC (splenium sparing)	11	VIQ	Reduced: 10 Stable: 1	Stable: 11
Mamelak et al. [22]	Anterior ½ CC	2	VIQ	Reduced: 2	Stable: 2
	Anterior ½ - 2/3rd	4	VIQ	Reduced: 3 Not reported: 1	Stable: 4
Marino et al. [14]	< 1/3rd	1	VIQ	Reduced: 1	Stable: 1
	1/3rd	2	VIQ	Reduced: 2 ⁵	Stable: 2
	Anterior 1/2	1	VIQ	Reduced: 1	Stable: 1
	Anterior 2/3rd	5	VIQ	Reduced: 5	Stable: 5
Sauerwein and Lassonde [18]	Anterior CC	1	VIQ	Not reported	Decline: 1 Post-operative complications affecting right hemisphere
Total CC Baynes et al. [21]	Total CC	1	VIQ	Reduced	Stable: 1
Mamelak et al. [22]	Total CC	3	VIQ	Reduced: 1 Unchanged/ Increased: 2	Stable: 3
Sauerwein and Lassonde [18]	Total CC	1	VIQ	Not reported	Stable: 1

Table 4
Performance Intelligence Quotient (PIQ) outcomes after corpus callosotomy.

	Procedure	N	Measure	Seizure burden	Outcome
Anterior CC Mamelak et al. [22]	Anterior ½ CC	2	PIQ	Reduced: 2	Stable: 2
	Anterior ½ - 2/3rd	4	PIQ	Reduced: 3 Not reported: 1	Stable: 4
Marino et al. [14]	< 1/3rd	1	PIQ	Reduced: 1	Stable: 1
	1/3rd	2	PIQ	Reduced: 2 ⁵	Stable: 2
	Anterior 1/2	1	PIQ	Reduced: 2	Improved: 1
	Anterior 2/3rd	5	PIQ	Reduced: 5	Stable: 5
Sauerwein and Lassonde [18]	Anterior CC (splenium sparing)	1	PIQ	Not reported	Decline: 1 Post-operative complications affecting right hemisphere
Total CC Baynes et al. [21]	Total CC	1	PIQ	Reduced: 1	Decline: 1
Mamelak et al. [22]	Total CC	3	PIQ	Reduced: 1 Unchanged/ increased: 2	Stable: 3
Sauerwein and Lassonde [18]	Total CC	1	PIQ	Not reported	Stable: 1

associated with no change in finger-tapping performance across both hands in case FP [18] (Table 6).

3.2.3. Speech and language

There was a great deal of heterogeneity in terms of assessment of speech and language across the studies reviewed. Anterior CC (splenium sparing) was associated with no change in vocabulary, reading or writing grade equivalence in case MP [18], despite significant post-surgical complications affecting the right hemisphere.

Outcomes of total CC included persistent dysarthria in one case (P8) [26] and significant language difficulties (agrammatism, speaking in phrases rather than sentences) in another (P18), despite significant seizure reduction [23] (Table 7).

3.2.4. Praxis

Three individuals in the series reported by Andersen et al. [23] did not show evidence for persistent apraxia after anterior CC. On the other hand, one individual showed mild, non-debilitating apraxia and one showed severe apraxia of the dominant arm. There was significantly reduced seizure burden in both cases.

In the same series, total CC was associated with apraxia in all three cases: mild apraxia of the non-dominant hand in one individual (P18) and severe apraxia of non-dominant upper and lower limbs in two other cases (P13, P15). P13 also developed buccofacial apraxia, while P18 showed significant inter-hemispheric antagonism, resulting in difficulty to learn new bimanual tasks [23] (Table 8).

3.2.5. Visuo-perceptual skills

There was only one study [14] that provided a qualitative commentary on visuoconstructional skills. Two individuals undergoing an ACC (anterior ½ resection) were felt to have shown minor improvements in visuoconstructional abilities. Pre-surgical levels of constructional abilities were maintained in five individuals (one < 1/3rd anterior CC, two with anterior 1/3rd resection, two with anterior 2/3rd resection) with worsening reported in four cases (one with anterior 1/3rd resection, three with anterior 2/3rd resection) [14].

Visuospatial organisation as measured by an object assembly task showed a mild decrease after splenium sparing CC in case MP [18], but remained stable in case FP after a complete CC. Of note, MP experienced significant right-sided post-operative complications. The extent of post-operative seizure burden was not reported in both of these cases (Table 9).

3.2.6. Memory

Memory was investigated using formal measures across all studies.

3.2.6.1. Verbal memory. Verbal memory outcomes were reported in a single case following anterior CC which showed post-surgical improvements in list learning [18].

Complete CC improved delayed word list recall in one individual [18] but was associated with a decline in verbal memory for word pair learning [27] (Table 10)

3.2.6.2. Visual memory. Case MP who underwent an anterior CC showed a decline in picture recall scores for a complex figure [18] but not for simple figures seen in the BVRT.

Total CC was associated with poorer post-operative ability to learn geometrical figures [27]. (Table 10)

3.2.7. Executive functioning

Rich et al. [26] reported subjective worsening in executive functioning 24 months after an anterior SLCC in one individual (P7). Specifics regarding the precise executive function measured were not provided.

Cukiert et al. [15] refer to executive intelligence outcomes after a

Table 5

Attention outcomes following corpus callosotomy.

	Procedure	N	Measure	Seizure burden	Outcome
Anterior CC					
Marino et al. [14]	SEEG guided microsurgical < 1/3rd	2	Neuropsychological measures	Reduced: 2	Improved:2
	1/3rd	3	Neuropsychological measures	Reduced: 3 ^s	Improved:3
	1/2	2	Neuropsychological measures	Reduced: 2	Improved:2
	2/3rd	5	Neuropsychological measures	Reduced: 5	Improved:2 Stable: 2 Declined:1
Gilliam et al. [24]	ACC (2/3rd)	6	Parental report of alertness	Reduced:6	Improved:6
Rathore et al. [16]	ACC	1	Parent ratings	Reduced:1	Improved:1
Andersen et al. [23]	ACC	5	Parent ratings	Reduced:3 Unchanged: 2	Improved:1 Stable: 3 Decline: 1
Cukiert et al. [15]	Anterior CC (splenium sparing)	11	Qualitative assessment	Reduced: 11	Improved:11
Total CC					
Andersen et al. [23]	Total CC	3	Parent ratings	Reduced: 1 Unchanged: 2	Stable:1 Decline: 2
Buchanan and Fearnside [25]	Total CC (two-stage)	1	Qualitative	Reduced: 1	Improved: 1
Chandra et al. [19]	Total CC (endoscopic)	1	Informal assessment	Reduced: 1	Unchanged:1

SEEG - stereoelectroencephalography.

Table 6

Speed of information processing as a function of corpus callosotomy.

	Procedure	N	Measure	Seizure burden	Outcome
Anterior CC					
Sauerwein and Lassonde [18]	Anterior CC (splenium sparing)	1	Finger tapping	Not reported	Decline: 1 Post-operative complications affecting right hemisphere
Total CC					
Sauerwein and Lassonde [18]	Total CC	1	Finger tapping	Not reported	Stable: 1

Table 7

Speech and language outcomes after corpus callosotomy.

	Procedure	N	Measure	Seizure burden	Outcome
Anterior CC					
Sauerwein and Lassonde [18]	Anterior CC	1	Vocabulary; reading, writing grade equivalence	Not reported	Stable: 1 Post-operative complications affecting right hemisphere
Total CC					
Rich et al. [26]	Total CC	1	Speech	Reduced: 1	Decline: 1
Andersen et al. [23]	Total CC	1	Speech and naming	Reduced: 1	Decline: 1

Table 8

Praxis skills after corpus callosotomy.

	Procedure	N	Measure	Seizure burden	Outcome
Anterior CC					
Andersen et al. [23]	ACC	5	Praxis	Reduced: 3 Stable: 2	Stable: 3 Decline: 2
Total CC					
Andersen et al. [23]	Total CC	3	Praxis	Reduced: 1 Unchanged: 2	Decline: 3

Table 9

Visuoperceptual skills after corpus callosotomy.

	Procedure	N	Measure	Seizure burden	Outcome
Anterior CC					
Marino et al. [14]	< 1/3rd CC	1	Visuospatial skills (qualitative)	Reduced: 1	Stable: 1
	Anterior 1/3rd	3	Visuospatial skills (qualitative)	Reduced: 3 ^s	Stable: 2 Decline: 1
	Anterior half	2	Visuospatial skills (qualitative)	Reduced: 2	Improved: 2
	Anterior 2/3	5	Visuospatial skills (qualitative)	Reduced: 5	Stable: 2 Decline: 3
Saurwein and Lassonde [18]	Anterior CC (splenium sparing)	1	Visuospatial organisation	Not reported	Decline: 1 Post-operative complications affecting right hemisphere
Total CC					
Saurwein and Lassonde [18]	Total CC	1	Visuospatial organisation	Not reported	Stable: 1

splenium sparing anterior CC, wherein all 11 individuals were found to show no change in scores at the time of post-surgical follow-up. Case DR in the series by Phelps et al. [27] was reported to show no appreciable change on subtests on mental control and digit span from the WMS after a total CC.

3.3. Non-cognitive outcomes

3.3.1. Quality of life

Table 11

Quality of life (QoL) was measured both formally and informally. A total of 20 individuals were reported to have improved QoL/life comfort following an anterior CC (anterior CC = 3, anterior 2/3rd = 6, splenium sparing CC = 11)[15, 23, 25, 28]. There were no reported changes in quality of life on Likert scale type measures in seven individuals [23,28] (anterior CC = 2, anterior 2/3rd = 5). Three individuals' quality of life was reported to have worsened, one despite reduced seizure burden [23], and two, who experienced increased post-operative seizure burden

Table 10
Memory outcomes after corpus callosotomy.

	Procedure	N	Memory measure	Seizure burden	Outcome
Anterior CC Sauerwein and Lassonde [18]	Anterior CC (splenium sparing)	1	Verbal memory (AVLT)	Not reported	Improved: 1 Post-operative complications affecting right hemisphere
Total CC Sauerwein and Lassonde [18]	Total CC	1	Verbal memory (AVLT)	Not reported	Improved: 1
Phelps et al. [27]	Total CC (inferior part of rostrum preserved)	1	Verbal memory (Russell revision WMS Logical memory, Verbal Paired Associates)	Not reported	Decline: 1
Anterior CC Sauerwein and Lassonde [18]	Anterior CC	1	Visual memory (RCF, BVRT)	Not reported	Decline: 1 Post-operative complications affecting right hemisphere
Total CC Phelps et al. [27]	Total CC (inferior part of rostrum preserved)	1: DR	Visual memory (Russell revision WMS Picture Reproduction)	Not reported	Decline: 1

WMS - Wechsler Memory Scale, AVLT - Auditory Verbal Learning Test, RCF - Rey Complex Figure, BVRT - Benton Visual Retention Test.

Table 11
Quality of life (QoL) after corpus callosotomy.

	Procedure	N	Measure	Seizure burden	Outcome
Anterior CC Andersen et al. [23]	Anterior CC	5	QoL rating on a 5-point Likert scale	Reduced: 3 Stable: 2	Improved: 2 Stable: 2 Decline: 1
Buchanan and Fearnside [25]	Anterior CC	1	Clinician reported QoL	Reduced seizure burden	Improved: 1
Claverie and Rougier [28]	Anterior 2/3rd	13	Physician/educator rated life comfort	Increased burden: 2* No change: 4 Reduced: 7	Improved: 6 Stable: 5 Decline: 2
Cukiert et al. [15]	Anterior CC	11	Clinician reported QoL	Reduced: 10 Unchanged: 1	Improved: 11
Total CC Andersen et al. [23]	Total CC	3	QoL rating on a 5-point Likert scale	Reduced: 1 Unchanged: 2	Stable: 2 Decline: 1
Buchanan and Fearnside [25]	Total CC (two-stage)	2	Clinician reported QoL	Reduced: 2	Improved: 2

* Study reports increased seizure burden but the type of seizures that increased is not specified.

[28]. It was unclear however whether this increase in seizures pertained to debilitating or non-debilitating seizures.

Two individuals undergoing a complete CC were felt to show qualitative improvements in QoL based on professional observation [25]. Conversely, in the series by Andersen et al. [23] two individuals

experienced no change in their QoL measured on a Likert scale while one individual reported a worsening, despite reduced seizure burden (Table 11).

3.3.2. Daily functioning, independent living and adaptive skills

Four individuals in the series by Clavier and Rougier [28] were felt to have experienced a psychosocial benefit and four showed an improvement in independent living status after anterior CC. Of the two individuals (P14 and P18) previously in a state of permanent medical dependence, one now attended a school for handicapped people and one progressed to adapted home-living. Two individuals demonstrated autonomy in the home environment pre-surgically; one of whom gained work in a specialised facility post-operatively and one was able to avail of an adapted part-time job [28]. Similarly, Gilliam et al. [24] reported decreased special care needs in four participants in their study following anterior 2/3rd CC.

Anterior 2/3rd CC however was also associated with no psychosocial benefit ($n = 8$), no change in independent living skills ($n = 8$) [28] and unchanged special care needs ($n = 1$) [24]. One individual in the series by Clavier and Rougier [28] experienced post-operative worsening of seizures along with worsening in psychosocial functioning and independent living.

Outcomes in this regard following a complete CC were just as variable. Two individuals reported an improvement in independent living ability [25]: one no longer required a helmet and a capable, previously unemployed individual was able to gain full time employment post-surgery. Social and adaptive skills were found to be stable in one case [19] with pre-operative SQ of 25, maintained post-surgically (SQ = 19).

There was one report of worsening on the Barthel Index tapping independence in activities of daily living in the context of unchanged seizure burden [23]. Specifically, all daily living activities of this individual were reportedly compromised and they were also no longer able to walk (Table 12).

Table 12
Daily functioning, independent living and adaptive skills as a function of corpus callosotomy.

	Procedure	N		Seizure burden	Outcome
Anterior CC Claverie and Rougier [28]	Anterior 2/3rd	13	Psychosocial benefit	Increased burden: 2* No change: 4 Reduced: 7	Improved: 4 Stable: 8 Decline: 1
		13	Independent living	Increased burden: 2 No change: 4 Reduced: 7	Improved: 4 Stable: 8 Decline: 1
Gilliam et al. [24]	Anterior 2/3rd	5	Special care needs	Reduced: 5	Improved: 4 Stable: 1
Total CC Andersen et al. [23]	Total CC	1	Activities of daily living (Barthel index)	Unchanged: 1	Decline: 1
Buchanan and Fearnside [25]	Total CC (two-stage)	2	Independent living	Reduced: 2	Improved: 2
Chandra et al. [19]	Total CC (endoscopic)	1	Social and adaptive skills (VSMS)	Reduced: 2	Stable: 1

VSMS - Vineland's Social Maturity Scale.

* Study reports increased seizure burden but the type of seizures that increased is not specified.

3.3.3. Behavioural and psychological features

Anterior CC was associated with improvements in behaviour across three cases [16,28], and improved motivation in one of the five cases reported by Andersen et al. [23]. Motivation and interaction remained unchanged in four individuals following anterior CC [23]. Anterior CC was however also associated with a worsening in interaction skills [23] as well as behavioural worsening [28] in one case each despite at least a 40 % seizure reduction in each case.

Complete CC was associated with behavioural improvements in one individual [25], with no change in CBCL ratings in the 25-year-old woman described by Chandra et al. [19]. Similarly, total corpus callosotomy was associated with no impact on motivation and interaction in two individuals, one who showed no improvement in seizure burden (P15) and one who showed significant improvement in seizures (P18) [23]. Another individual (P13) who did not experience any biological benefit from surgery showed less interaction and worse motivation post-operatively [23] (Table 13).

4. Discussion

The 15 papers identified for study inclusion variously investigated intellectual functioning, specific cognitive skills, daily living skills and behaviour as outcome measures. Anterior CC appeared to be the most common surgical procedure ($n = 59$), followed by total CC ($n = 14$).

4.1. Cognitive outcomes

Intellectual functioning (refer to Section 3.1), whether divided into verbal and performance based abilities, or a general IQ, appeared to be largely preserved following varying extents of ACC as well as complete CC, with 27/30 cases across all reviewed studies for GIQ reporting a positive outcome (i.e. stable or improved). Objective improvements in the case of PIQ but not VIQ are understandable given the benefits of improved speed on PIQ measures, likely arising from a reduction of anti-seizure medications. One observed decline in IQ could be attributed to a post-operative complication [18], and the two other cases failed to report objective scores, making it unclear whether the reported 'decline' constituted a reliable, 15-point drop in scores or was a subjective assessment. Most operated cases (29/40, 72.5 %) were reported to show

improved attentional abilities post surgery.

Other specific cognitive outcomes (refer to Section 3.2) were investigated less commonly and relied on small sample sizes. Complete [23] but not anterior CC [18] was associated with worsening of expressive language, particularly articulation and grammar. Praxis outcomes were generally poor with some level of apraxia reported in 62.50 % (5/8) of the cases reported by Andersen et al. [23] that met the inclusion criteria for this review. Further, three of these individuals experienced debilitating apraxia. Likewise, anterior CC showed some association with worsening of visuospatial abilities (5/12), despite reduced seizure burden.

There was very sparse data speaking to memory outcomes (Section 3.2.6). Word list learning was found to improve [18], while memory for word pairs reduced post-operatively [27]. This raises the hypothesis of different memory tasks showing a differential effect post CC and may warrant investigation in future studies.

Visual memory (Section 3.2.6.2) declined in both cases where it was investigated (one anterior CC and one two-stage CC) [18,27]. Albeit stemming from a relatively small sample size, it is possible that underlying difficulties with visuoconstructional skills negatively impacted performance on visual memory tasks. Difficulties observed on memory tasks with complex constructional demands (e.g. Rey Complex Figure) with minimal reported impact on simpler tasks (e.g. Benton Visual Retention Test) [18,27] lends further plausibility to this hypothesis. Concurrent investigation of visuo-perceptual abilities along with visual memory and usage of a recognition format in future studies is recommended to clarify independent effects on both of these outcomes.

4.2. Non-cognitive outcomes

Independent living skills and motivation bore a somewhat clearer relationship with seizure burden, with increased or unchanged seizure burden associated with a worsening in these domains, albeit a limited sample size [23,28]. Similar results were observed with regard to quality of life, social interaction and behaviour, although there were isolated cases where reported quality of life, interaction [23] and behaviour worsened [28] despite reduced seizure burden (refer to Section 3.3).

4.3. Worsening of abilities despite reduced seizure burden

A notable finding of this review pertained to the observed decline in cognitive (and in some cases non-cognitive) functioning despite a reduction in seizure burden. Worsening in the context of a reduction in seizures was more commonly reported with regard to language abilities (2/2), praxis (3/4) and visuospatial skills (4/11), with this being less commonly observed with regard to intellectual functioning (2/25) and attention (2/36). Together, this would suggest that language, praxis and visuospatial abilities may be especially susceptible to a decline following corpus callosotomy, with the impact on these domains being independent of experienced seizure relief. A more detailed analysis of individuals who show worsening in functioning despite reduced seizure burden would help delineate the specific factors contributing to a good/bad functional outcome.

4.4. Extent of lesion effects

Extent of CC resection did not appear to have any clear effects with regard to functional outcomes in adults. Negative outcomes with regard to attention appeared to be more common following a total CC (2/5) than an anterior CC (2/35). In the small sample sizes obtained through this review, expressive language difficulties were only observed after a complete CC. Anterior CC was more commonly associated with dominant limb apraxia, whereas complete CC seemed to affect the non-dominant limb [23]. It would be important to track these functions in individuals undergoing all different types of corpus callosotomies to better understand the implications of the extent of resection on

Table 13
Behavioural and psychological features as a function of corpus callosotomy.

	Procedure	N		Seizure burden	Outcome
Anterior CC					
Andersen et al. [23]	ACC	5	Motivation	Reduced: 3 Unchanged: 2	Stable: 4 Improved: 1
Andersen et al. [23]	ACC	5	Interaction	Reduced: 3 Unchanged: 2	Stable: 4 Decline: 1
Claverie & Rougier [28]	Anterior 2/3rd	3	Behaviour	Reduced: 3	Improved: 2 Decline: 1
Rathore et al. [16]	ACC	1	Behaviour	Reduced: 1	Improved: 1
Total CC					
Andersen et al. [23]	Total	3	Motivation	Reduced: 1 Unchanged: 2	Stable: 2 Decline: 1
Andersen et al. [23]	Total	3	Interaction	Reduced: 1 Unchanged: 2	Stable: 2 Decline: 1
Buchanan and Fearnside [25]	Total CC (two-stage)	1	Behaviour	Reduced: 1	Improved: 1
Chandra et al. [19]	Total CC (endoscopic)	1	Behaviour (CBCL)	Reduced: 1	Stable: 1

functionality.

5. Limitations

Many of the measures used across the reviewed studies were neuropsychological measures or qualitative reports of improvement. Ecologically valid measures in the form of questionnaires or activity checklists may offer a more objective and useful measure of functional outcomes rather than neuropsychological scores or a broad caregiver rating of change in abilities. Neuropsychological measures, when used, should adhere to appropriate guidelines (e.g. reliable change indices or a 1-SD change in scores) to ensure that only reliable changes in performance are categorised as an improvement or decline in functioning, rather than arbitrary interpretations of the same.

Lastly, the present review was restricted to individuals who underwent no other surgical intervention, who had no additional cerebral pathology and no other known neurological condition apart from epilepsy. The impact of CC on functional outcomes in these cases remains to be investigated.

6. Conclusion

CC appears to have a positive effect with regard to attention and intellectual functioning outcomes in adults. Conversely, praxis and visuospatial skills may be particularly likely to decline post-operatively, despite reduced seizure burden, although larger sample sizes are needed to state the same with certainty. Complete CC may be associated with reductions in expressive language. With regard to non-cognitive outcomes, the biological benefit from surgery in the form of seizure reduction appears to be most important in determining positive outcomes. Well-designed, systematic research studies spanning a variety of outcomes are required to comprehensively understand the impact of CC in adults. Detailed investigations of individuals that show post-operative functional deficits despite a significant reduction in seizure burden are also required.

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CRedit authorship contribution statement

Shriya Parekh: Data curation, Investigation, Methodology, Visualization, Writing – original draft, Writing – review & editing. **Deepa Anand Bapat:** Conceptualization, Methodology, Project administration, Supervision, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Supplementary materials

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