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REVIEW ARTICLE

IMPROVING WALKING CAPACITY BY SURGICAL CORRECTION OF EQUINOVARUS FOOT DEFORMITY IN ADULT PATIENTS WITH STROKE OR TRAUMATIC BRAIN INJURY: A SYSTEMATIC REVIEW

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Objective: **Equinovarus foot deformity following stroke or traumatic brain injury compromises walking capacity, interfering with activities of daily living. In soft-tissue surgery the imbalanced muscles responsible for the deviant position of the ankle and foot are lengthened, released and/or transferred. However, knowledge about the effectiveness of surgical correction is limited. The aim of the present study was to carry out a systematic review of the literature to assess the effects of surgical correction of equinovarus foot deformity in patients with stroke or traumatic brain injury.**

Methods: **A systematic search of full-length articles in the English, German or Dutch languages published from 1965 to March 2011 was performed in PubMed, EMBASE, CINAHL, Cochrane and CIRRIE. The identified studies were analysed following the International Classification of Functioning, Disability and Health criteria.**

Results: **A total of 15 case series, case control and historically controlled studies (CEBM level 4) were identified, suggesting that surgical correction of equinovarus foot deformity is a safe procedure that is effective in terms of re-obtaining a balanced foot position, improving walking capacity and diminishing the need for orthotic use.**

Discussion: **Further validation of surgical correction of equinovarus foot deformity following stroke or traumatic brain injury is required, using higher level study designs with validated assessment tools. Comparing surgical techniques with other interventions is necessary to generate evidence upon which treatment algorithms could be based.**

Key words: equinovarus; foot deformity; stroke; traumatic brain injury; orthopaedic surgery; adult.

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INTRODUCTION

Patients with an upper motor neuron lesion, such as in stroke and traumatic brain injury (TBI), often experience disruption of the functional balance between agonistic and antagonistic muscle activity. In the affected lower extremity, such muscular imbalance often causes deformities of the ankle and foot. Although different types of acquired ankle and foot deformity following stroke and TBI have been described, equinovarus deformity is most characteristic and most frequently seen (1, 2). In the lower limb, involuntary activity of the plantar flexors and invertors of the ankle and foot, combined with paresis of the dorsal flexors and evertors, may explain the dynamics in the development of equinovarus foot deformity (3, 4).

Impaired walking capacity is a well-known consequence of stroke and TBI, and regaining independent gait is considered to be a primary goal in the rehabilitation of these patients (5, 6). Previous prospective cohort studies have shown that 60–80% of stroke survivors are able to walk independently at 6 months post-stroke (7–9). Available data, albeit limited, regarding walking capacity have shown that up to 70% of TBI survivors will also re-gain independent gait within the first 6 months (6, 10). Besides the fact that independent gait is highly related to independence in activities of daily living (ADL) (5), a number of studies have shown that the extent of gait recovery also differentiates patients who are housebound from those who are unlimited community walkers (11–13).

Equinovarus foot deformity compromises several prerequisites of walking (14). It interferes with foot clearance in the swing phase, with appropriate prepositioning of the foot at the end of the swing phase, with loading of the stance leg and with ankle stability (and postural balance) during the stance phase. As a result, these patients experience an increased risk of falling and are frequently unable to walk either unassisted or without orthotic devices (15).

A number of non-invasive and invasive options to treat equinovarus foot deformity following stroke or TBI have been proposed in the literature. These treatment options include orthotics (16), chemical denervation (17–19), neurosurgical denervation (20), functional electrical stimulation (21, 22) and soft-tissue surgery. All these interventions aim to correct the deviant position of the ankle and foot.

In soft-tissue surgery the imbalanced muscles responsible for plantar flexion and inversion of the ankle and foot are length-

ened, released and/or transferred. As a result, the muscle forces that act on the ankle–foot complex are balanced and equinovarus deformity is corrected (23, 24). However, in evidence-based rehabilitation guidelines the surgical correction of equinovarus deformity is not commonly addressed (25, 26). Indeed, in the average rehabilitation setting, ankle–foot orthoses and orthopaedic footwear often constitute the first choice of treatment. It is an important question whether this preference is based on convenience or on clinical evidence (27).

To our knowledge the effect of surgical correction of equinovarus foot deformity following stroke or TBI is indistinct. In addition, the criteria for selecting patients for soft-tissue surgery are heterogeneous, hindering optimal clinical decision-making (28).

Hence, the aim of the present study was to carry out a systematic review of the literature to assess the effects of surgical correction of equinovarus foot deformity in patients with stroke or TBI. Subsequently, recommendations with respect to selecting patients with equinovarus foot deformity are given to support the clinical decision-making process in patients with equinovarus foot deformity who are eligible for surgical correction.

METHODS

Definitions

- *Stroke* is defined as "an acute neurological dysfunction of vascular origin with sudden (within seconds) or at least rapid (within hours) occurrence of symptoms and signs corresponding to the involvement of focal areas of the brain" (29).
- *Traumatic brain injury* is defined as "damage to brain tissue caused by an external mechanical force as evidenced by medically documented loss of consciousness or post-traumatic amnesia due to brain trauma or by objective neurological findings that can be reasonably attributed to TBI on physical examination or mental status examination" (30).
- *Equinovarus foot deformity* is defined as "a combination of a plantarflexed, inverted and adducted foot, (either dynamic or structural), acquired after stroke or TBI with possibly various degrees of severity of the different components".
- *Walking capacity* is defined as "the degree of autonomy in walking, with or without the aid of appropriate assistive devices (such as canes or walkers), safely and sufficiently to carry out mobility-related activities of daily living".
- *Capacity,* according to the World Health Organization (WHO) International Classification of Functioning Disability and Health (ICF), is a "qualifier" that describes a patient's ability to execute a task or action, but *does not* qualify what a patient does in his or her current environment (performance) (31).

Study identification

A systematic search was conducted of articles published in PubMed, EMBASE, CINAHL, Cochrane Controlled Trials (Rehabilitation and Related Therapies), Center for International Rehabilitation Research Information and Exchange (CIRRIE, http://cirrie.buffalo.edu/), and National Rehabilitation Information Center for Independence REHABDATA (http://www.naric.com) databases between 1965 and March 2011. REHABDATA was consulted for rehabilitation research conducted within the USA. CIRRIE includes research from all areas of rehabilitation conducted outside the USA, starting in 1990. The following MeSH headings and key words were used: "equinus, equinovarus, foot deformity, foot deformities, hemiplegia, hemiparesis, stroke, cerebrovascular disorders, head injury, traumatic brain injury, upper motor neuron, orthopedics, neurorehabilitation, surgery". The search strategy that was used for PubMed and other electronic databases is available on request from the corresponding author. In addition, the references of the selected articles were checked and the search was extended within cited references. Study selection and methodological screening was independently performed by two authors (GJR, JHB). In the case of disagreement, a third reviewer was consulted (AVN).

Selection criteria

As case series are probably the most frequent type of surgical report in the literature (32), it was decided not to restrict the selection to a specific study design. As a consequence, studies were included if they used either within-group pre-post treatment comparisons or between-groups comparisons in a (randomized) controlled design.

In addition, studies were required to meet the following inclusion criteria: (*i*) investigating stroke and/or TBI in adults (irrespective of the phase of recovery); (*ii*) investigating the efficacy of surgical correction of equinovarus foot deformity (lengthening, release and/or transferring of muscles and/or tendons); (*iii*) being written as a full-length article in the English, German or Dutch languages and being published in a peer-reviewed journal between 1965 and March 2011. If two or more papers were published by the same group, and if (within these papers) aetiology of equinovarus foot deformity was comparable, only the study with the highest number of patients was included.

Methodological quality assessment

The Oxford CEBM levels of evidence were used to grade the selected studies (33). The Index for Non-Randomized Studies (MINORS) was applied to further assess the quality of each study (34). Few validated instruments are available to assess the methodological quality of observational or non-randomized studies. MINORS is a validated list designed to assess the methodological quality of non-randomized (surgical) studies (either comparative or non-comparative) which comprises 12 items, of which the last 4 items apply only to comparative studies. Items are scored as 0 (not reported), 1 (reported but inadequate) or 2 (reported and adequate). The maximum score is 16 for non-comparative studies and 24 for comparative studies.

Data extraction

Because no (randomized) controlled trials were identified, no pooling of data was allowed, either in a meta-analysis or in a best-evidence synthesis. The selected articles were analysed following the WHO ICF (available from: www.who.int/icidh, 2001). The ICF is a classification of health and health-related domains at both individual and population level, commonly used within the field of rehabilitation medicine. It shifts the focus from cause to impact by describing how a disease can influence body structure and function, activity and participation.

RESULTS

Study selection

Fig. 1 shows the study selection process as a flow chart. The initial systematic search strategy in PubMed identified 320 relevant citations (on request available from the corresponding author).The search in the other databases did not yield additional articles. On the basis of the title, 228 studies were excluded. Another 46 studies were excluded based on their abstracts. Important reasons for exclusion were the use of interventions that did not fit within our definition, and the use of patient populations with an aetiology other than stroke or TBI. Full texts of the remaining 46 studies were examined. Screening the references of these studies revealed 4 additional articles (23, 35–37). From these 50 initially selected studies, 35 had to be excluded in second instance because they: (*i*) were

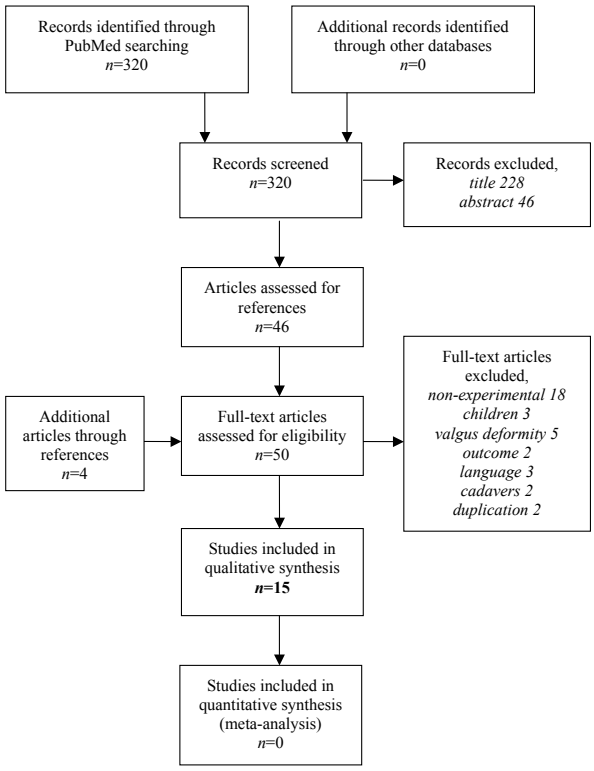

Fig. 1. Study selection process.

non-experimental (narrative reviews) ($n=18$), (*ii*) included only children ($n=3$), (*iii*) focused on equinus or equinovalgus deformity ($n=5$), (*iv*) evaluated outcome other than surgical efficacy ($n=2$) (37, 38), (*v*) were published in a language other than English, Dutch or German ($n=3$), or (*vi*) investigated cadavers ($n=2$). Two other studies were excluded because they were part of larger studies published by the same group (39, 40). Ultimately, 15 studies met all inclusion criteria and were further analysed (35, 36, 41–53).

Methodological quality

Table I shows the methodological characteristics of the 15 studies included in the present review. Within our search limits, the earliest report regarding outcome of surgical correction of equinovarus foot deformity in patients with stroke or TBI dated from 1969 (45). All studies used a within-group design with pre-post treatment comparisons and were classified as case series (35, 36, 41, 43, 45, 47, 48, 50–53), case control (49), or historically controlled studies (42, 44, 46). Two studies (44, 49) used a prospective study design, whereas the other studies were conducted retrospectively. Only one study incorporated a group of healthy controls (49). All included studies were considered to be of the same, relatively low, level of methodological quality. They were scored as level 4 according to the definition of the Oxford Centre for Evidence-based Medicine. MINORS scores ranged from 4 to 14, emphasizing the methodological heterogeneity amongst the case-series designs (34).

Surgical techniques and comparisons

None of the studies compared surgical intervention with an alternative treatment. Three studies compared (uncontrolled, non-blinded) two techniques of surgical intervention; (*i*) Hosalkar et al. (42) differentiated two fixation techniques into the cuboid bone for split anterior tibialis tendon transfer (SPLATT), favouring the lateromedial over the dorsoplantar routing; (*ii*) Keenan et al. (44) compared toe flexor release with long toe flexor transfer to the calcaneus (to improve calf muscle strength), favouring the latter approach; and (*iii*) Morita et al. (46) compared long toe flexor transfer (to the fourth metatarsal bone on the dorsum of the foot) with whole anterior tibial tendon transfer (to the third cuneiform bone), favouring the first approach i.e. the use of long toe flexor transfer in dorsiflexion support. In one study, two groups were differentiated, based on (ab)normal electrical activity of the posterior tibial muscle in the stance phase, through which it was decided whether or not to lengthen this muscle. There were no differences in functional outcomes between both groups (49). In all but one study (53) the surgical procedures through which muscles and tendons were lengthened, released and/or transferred were described in detail.

Patient selection

The inclusion criteria in 13 studies were dominated by their retrospective nature. Patients were enrolled simply because they had had a surgical correction of equinovarus foot deformity. As a result, the original indication for this correction (i.e. the severity of the equinovarus foot deformity, additional impairments and/or the impact on activities of daily living) could not be properly traced in most studies. Some authors included only structural equinovarus deformity (36, 41), whereas others included only dynamic equinovarus deformity (47, 49). Four authors assigned surgery when extensive physiotherapy, nerve blocks and/or orthoses failed to correct the deviant equinovarus position (35, 45, 46, 49). In 4 studies regaining the ability to walk barefoot (i.e. without orthoses or orthopaedic footwear) was mentioned as a primary goal for surgery (46, 48, 51, 53). In 12 studies functional recovery of motor control after stroke (minimum of 6 months post-stroke) or TBI (minimum of 12 months post-TBI) was awaited before surgical correction was performed. In the remaining 3 studies information about the time since brain injury was lacking (35, 44, 45).

Gait assessment

The applied methods of gait assessment in the 15 studies are presented in Table II. Pre-operative instrumented gait analysis was used to assist in the surgical decision-making in 6 studies (41, 42, 44, 47, 49, 50), whereas 2 studies (36, 43) used only dynamic electromyography data for this purpose. The remaining 7 studies, all conducted before 1999, used qualitative (clinical) data in the pre-operative assessment. Only 3 studies used instrumented gait analysis in both the pre- and the postoperative assessments (41, 44, 49).

Table I. *Methodological characteristics of the included studies*

Authors	Study design	Minors score	Number of subjects	Age, years Mean [range]	Diagnosis	Time since injury, months Mean [range]	Intervention	Follow-up, months Mean [range]
Carda et al., 2009 (41)	Case series; uncontrolled; retrospective; single centre; non-blinded	13	177	50 [SD 14]	177 stroke	67 [no data]	135 a–l; 9 g–l; 32 gs–l; 174 fdl–r or fdl–l; 4 tp–l; 33 splatt; 71 ehl–t; 13 fhl–t; 11 fdl–t	12 [constant]
Edwards et al., 1993 (36)	Case series; uncontrolled; retrospective; single centre; non-blinded	9	21 (24 feet)	41 [18–67]	9 stroke, 9 TBI, 2 other	34 [no data]	23 a–l+splatt+tf–r; 2 tp–l; 3 tp–r; 3 fp–r; 4 fhl–t; (2 triple arthrodesis)	39 [12–79]
Hosalkar et al., 2008 (42)	Historically controlled; retrospective; single centre; non-blinded (comparing surgical techniques)	13	I: 17 II: 30	I: 46 [32–61] II: 42 [29–67]	47 TBI	18 [11–48]	I: 17 splatt; dorso plantar fixation II: 30 splatt; latero medial fixation note: additional procedures in both groups – not specified	I: 51 [37–84] II: 29 [24–48]
Keenan et al., 1984 (43)	Case series; uncontrolled; retrospective; single centre; non-blinded	10	54 (59 feet)	25 [14–50]	54 TBI	35 [SD 26]	53 a–l; 1 tp–l; 52 fdl–r; 34 fhl–r; 59 splatt; 18 fhl–t	49 [SD 23]
Keenan et al., 1999 (44)	Historically controlled; prospective; single centre; non-blinded (comparing surgical techniques)	14	I: 25 (31 feet) II: 30 (36 feet)	I: 40 [11–80] II: 36 [21–69]	I: 12 stroke, 11 TBI, 2 other II: 10 stroke, 17 TBI, 3 other	no data	I: 31 a–l+tf–r+splatt; 3 ehl–l; 13 tp–l II: 36 a–l+tf–r+fdl/fhl–t+splatt; 9 ehl–l; 15 tp–l note: additional proximal procedures in both groups	I: 41 [17–53] II: 24 [19–32]
Mooney et al., 1969 (45)	Case series; uncontrolled; retrospective; single centre; non-blinded	4	194	55 [17–84]	194 stroke	no data	122 a–l; 122 tf–r; 82 splatt note: study includes description of proximal procedures	>6
Morita et al., 1998 (46)	Historically controlled; retrospective; single centre; non-blinded (comparing surgical techniques)	11	I: 110 II: 15	57 [32–78]	125 stroke	23 [6–132]	I: 110 g–l+fdl–t+fhl–t; 8 tp–l; 15 fdb–r+fhb–r II: 15 g–l+ta–t+fdl–r+fhl–r; 3 fdb–r +fhb–r	33 [24–74]
Namdari et al., 2009 (47)	Case series; uncontrolled; retrospective; single centre; non-blinded	12	64	54 [24–74]	64 stroke	66 [17–523]	58 a–l; 30 tp–l; 7 ehl–l; 56 fp–r; 64 splatt; 61 fdl–t; 39 ehl–t	12 [3–42]
Ono et al., 1980 (48)	Case series; uncontrolled; retrospective; single centre; non-blinded	8	39	[18–76]	32 stroke, 1 TBI, 6 other	>12 [no data]	39 g–l+dl–t+fhl–t note: in the same study 39 adult and 17 children	[46–98]

Table I. *Contd.*

Authors	Study design	Minors score	Number of subjects	Age, years Mean [range]	Diagnosis	Time since injury, months Mean [range]	Intervention	Follow-up, months Mean [range]
Pinzur et al., 1986 (49)	Case controlled; prospective; single centre; non-blinded (comparing surgical techniques)	13	I: 42 II: 12 (30 healthy controls)	stroke 57 [17–77] TBI 30 [18–51]	36 stroke, 16 TBI, 2 other	38 [12–204]	I: 42 a–l+fhl–r+fhb–r+fdl–r+ta II: 12 a–l+tp–l+fhl–l+fdl–r+ta	30 [24–62]
Reddy et al., 2008 (50)	Case series; uncontrolled; retrospective; single centre; non-blinded	12	26	55 [23–72]	26 stroke	75 [no data]	26 a–l+fhl–r+fdl–t+splatt; ? tp–l; ? ehl–t	18 [6–48]
Roper et al., 1978 (35)	Case series; uncontrolled; retrospective; single centre; non-blinded	6	50	43 [18–72]	stroke or TBI	no data	37 a–l; 13 tf–r; 8 tp–r; 23 splatt note: additional proximal procedures	no data
Tracy et al., 1976 (51)	Case series; uncontrolled; retrospective; single centre; non-blinded	6	35	40 [18–62]	22 stroke, 7 TBI, 6 other	36 [no data]	35 a–l+tp–l+tf–r+splatt	32 [4–73]
Vogt et al., 1998 (52)	Case series; uncontrolled; retrospective; single centre; non-blinded	12	69 (73 feet)	47 [8–79]	42 stroke, 15 TBI, 12 other	50 [no data]	49 a–l+fdl–r+fhl–r+splatt 9 a–l+splatt 6 fdl–r+fhl–r+splatt 9 splatt	44 [12–168]
Yamamoto et al., 1992 (53)	Case series; uncontrolled; retrospective; single centre; non-blinded	9	75	57 [no data]	75 stroke	18 [no data]	41 g–l+fdl–t+fhl–t 16 g–l+tf–r 3 g–l+tp–t 5 g–l+ta 5 g–l 5 tf–r	77 [no data]

SD: standard deviation; TBI: traumatic brain injury.

–l: lengthening; –r: release; –t: transfer; a: Achilles tendon; g: gastrocnemius; gs: gastrocnemius and soleus; tf: toe flexor (intrinsic and extrinsic); fdl: flexor digitorum longus; fdb: flexor digitorum brevis; fhl: flexor hallucis longus; fhb: flexor hallucis brevis; tp: tibialis posterior ta: tibialis anterior (whole tendon); splatt: split anterior tibial tendon transfer; edl: extensor digitorum longus; ehl: extensor hallucis longus; fp: fascia plantaris.

Outcomes

Outcome measures were categorized according to the ICF and are presented in Table II. In almost every study an improvement of the foot position following surgery was reported; however, only one study (41) statistically quantified this improvement. Walking speed was measured in 4 studies (41, 44, 46, 53), of which 2 reported a significant effect; in the study by Carda et al. (41) walking speed improved from 0.32 (m/s) prior to surgery to 0.40 m/s after surgery ($p < 0.001$); Keenan et al. (44) found an improvement in walking speed from 0.36 m/s before to 0.5 m/s after surgery ($p < 0.053$). Although improvement in walking speed appeared to be similar in two other studies (46, 53), the statistical significance of these findings was not supported. Both Carda et al. and Yamamoto et al. (41, 53) positively correlated improvement in walking speed with improvement in walking capacity. Again, only Carda et al. (41) statistically supported this correlation.

Orthotic use was reported in all 15 studies. In 14 studies the need for orthoses decreased post-operatively. In the study by Keenan et al. (43) the increase in post-operative orthotic use was explained by regaining walking capacity in the (formerly) non-ambulatory group. Three studies reported on the significance of decrease in orthotic use (44, 47, 52). Keenan et al. (44) found a significant difference in the need of orthoses after surgery favouring the group in which the long toe flexors were transferred to the calcaneus ($p = 0.025$).

Nine studies (36, 41–44, 46, 47, 50, 52) selected walking capacity as a primary outcome measure, whereas 4 studies did not report on walking capacity (48, 49, 51, 53) and 2 studies merely made a brief comment (35, 45). In these 9 studies, walking capacity was operationalized by ambulation categories ranging from non-ambulatory to unlimited community walker. Only 4 out of these 9 studies used a validated ambulation scale, i.e. the Walking Handicap Score (12) (41) and the Viosca score (54) (42, 47, 50). Although walking capacity seemed to improve in all studies, only 4 reported a statistically significant effect (41, 47, 50, 52). One other study suggested statistical significance, but no supporting data were presented (42).

In general, adverse effects and medical complications were rare, as were recurrences of foot deformities (Table III). Morita et al. (46) discussed the relatively high recurrence rates of hammer-toe and varus deformity in their study. When indicated, they now release the short toe flexors and lengthen the posterior tibial tendon, and report diminished recurrences of foot deformities.

Table II. *Assessment and outcomes of surgical correction of equinovarus foot deformity in the included studies according to the International Classification of Functioning*

	Assessment of gait		Body structures and functions				Activities		Participation	
			Foot position		Walking	Spatiotemporal	Orthotic	Walking	Patient	
Authors	Pre-	post-operative	Stance	swing	speed	parameters	use	capacity	satisfaction	Others
Carda et al., 2009 (41)	GA	GA	↑*	↑*	↑*	↑*	↓	↑*	NT	Propulsion ↑* Gait stability ↑*
Edwards et al., 1993 (36)	EMG	QA	↑	NT	NT	↑	Ø	↑	NT	
Hosalkar et al., 2008 (42)	I: GA	QA	↑	NT	NT	NT	↓	↑	NT	
	II:GA	QA	↑	NT	NT	NT	↓	↑	NT	
Keenan et al., 1984 (43)	EMG	QA	↑	NT	NT	NT	Ø	↑	NT	
Keenan et al., 1999 (44)	I: GA	QA	↑	↑	NT	NT	Ø	Ø	NT	
	II:GA	GA	↑	↑	↑*	↑	↓	↑	NT	
Mooney et al., 1969 (45)	QA	QA	↑	NT	NT	NT	Ø	↑	NT	
Morita et al., 1998 (46)	I: QA	QA/GA	↑	NT	↑	↑	↓	↑	NT	Propulsion ↑* Shift body weight ↑*
	II:QA	QA	↑	NT	NT	NT	↓	Ø	NT	
Namdari et al., 2009 (47)	GA	QA	↑	↑	NT	NT	↓*	↑*	NT	
Ono et al., 1980 (48)	QA	QA	↑	NT	NT	NT	Ø	NT	↑	
Pinzur et al., 1986 (49)	I: GA	GA	↑	↑	NT	↑	↓	NT	↑	Knee recurvation ↓
	II:GA	GA	↑	↑	NT	↑	↓	NT	↑	Knee recurvation ↓
Reddy et al., 2008 (50)	GA	QA	NT	NT	NT	NT	↓	↑*	NT	Use of non-operative therapy ↓
Roper et al., 1978 (35)	QA	QA	↑	NT	NT	NT	↓	Ø	NT	Knee recurvation ↓
Tracy et al., 1976 (51)	QA	QA	↑	↑	NT	NT	↓	NT	NT	
Vogt, 1998 (52)	QA	QA	↑	↑	NT	NT	↓*	↑*	↑	
Yamamoto et al., 1992 (53)	QA	QA	NT	NT	↑	NT	↓	↑	↑	

↑*: statistically significant improvement; ↓* statistically significant deterioration; ↑: improvement in more than 50% of the patients (no statistical analysis); ↓: deterioration in more than 50% of the patients (no statistical analysis); Ø: no statistical difference or modification for less than 50% of the patients (no statistical analysis); NT: not tested; GA: instrumented gait analysis, including electromyography during walking; QA: qualitative assessment.

Table III. *Adverse effects reported in the included studies*

Author	Subjects *n*	Medical complications	Residual or recurrent deformities
Carda et al., 2009 (41)	177	3 deep vein thrombosis 4 wound infection 1 haematoma	3 toe curling
Edwards et al., 1993 (36)	21 (23 feet)	1 wound infection 1 tendon rupture	2 varus 1 toe curling
Hosalkar et al., 2008 (42)	I: 17 II: 30	3 screw pullout none	none none
Keenan et al., 1984 (43)	54 (59 feet)	1 wound infection with skin necrosis	none
Keenan et al., 1999 (44)	I: 25 (31 feet)	no data	none
	II: 30 (36 feet)	no data	2 equinus
Mooney et al., 1969 (45)	194	6 wound infection 2 Achilles tendon rupture 1 death due to hepatitis	6 varus (15 valgus)
Morita et al., 1998 (46)	I: 110	1 wound infection	17 equinovarus, 21 toe curling
	II: 15	none	2 equinovarus, 6 toe curling
Namdari et al., 2009 (47)	64	no data	no data
Ono et al., 1980 (48)	39	no data	few toe curling
Pinzur et al., 1986 (49)	54	2 wound infection 2 tendon pullout	none
Reddy et al., 2008 (50)	26	none	no data
Roper et al., 1978 (35)	50	none	none
Tracy et al., 1976 (51)	35	1 chronic ulcer	3 equinovarus 3 toe curling
Vogt et al., 1998 (52)	69 (73 feet)	5 wound infection 5 tendon rupture 2 reflex dystrophy	3 equinovarus 6 toe curling
Yamamoto et al., 1992 (53)	75	no data	6 equinovarus 3 equinus 5 toe curling

DISCUSSION

This systematic review was conducted to gain insight into the available evidence on the effects of soft-tissue surgery to correct equinovarus foot deformity following stroke or TBI. The rationale for this review was that, despite a paucity of well-conducted studies, clinical experience shows that surgical correction should be considered as a valuable treatment option. Several papers on the management of equinovarus foot deformity have been published (1–4, 55–57), but, as far as we are aware, there is no synthesis of experimental studies on surgical correction. The methodology of a systematic review offered the most objective approach (58).

The results of this review suggest that surgical correction of equinovarus foot deformity can be effective in re-obtaining a balanced foot position after stroke or TBI, which can improve walking capacity and diminish the need for an ankle–foot orthosis. However, the scientific evidence supporting surgical correction of equinovarus foot deformity is limited. All included studies were case series, scoring "level 4" evidence according to the definition of the Oxford Centre for Evidence-based Medicine (Grade C recommendation) (33). Indeed, the surgical procedures reported in this review have all been evaluated in non-controlled studies. In general, it is estimated that randomized controlled trials (RCTs) account for less than 10% of the evidence base for surgical interventions (59). Nevertheless, despite the inherent difficulties in conducting RCTs, well-controlled studies are also essential in proving the effects of surgical procedures, for instance by using a control group that will receive the studied intervention in a later stage. In the present review, all but two of the included studies were retrospective, which implies that the data had been collected before stating an hypothesis in the context of a scientific study. As a consequence these data are highly subjective to information bias, which compromises the internal validity of the studies. On the other hand, in observational studies such as case series, the investigator does not purposely control which patients are selected and what intervention they receive, which implies that the results are probably closer to routine clinical practice and, therefore, have a relatively high external validity. In addition, depending on their methodological quality, observational studies can make valid statements about the safety of surgical intervention (60). All studies in this review showed that adverse effects and medical complications were rare, which makes it fair to conclude that surgical correction of equinovarus foot deformity following stroke or TBI can be safely performed.

An adequate *selection* of patients suitable for surgical equinovarus foot correction after stroke or TBI should be the first challenge in future research. Due to methodological shortcomings and poor description, criteria for selecting the most suitable patients cannot be derived from the present review. In current rehabilitation practice, surgical correction often seems to be an afterthought in treatment options. Patients with a structural equinovarus deformity or those with severe spasticity who failed to respond to alternative treatment (such as an orthosis or chemodenervation) will eventually be considered eligible for surgery. Surgical correction might, however, be considered in an earlier stage. In addition, based on this review, patients with dynamic equinovarus foot deformity should also be considered for surgical intervention. Indeed, one of the major advantages of surgical correction of equinovarus foot deformity is that patients regain the opportunity to walk barefoot, which is essential when getting out of bed during the night, when taking a shower, or during leisure activities. During such activities, many patients wish to be more independent of, for example, orthosis, which is often neglected by rehabilitation professionals. The advantage of walking barefoot favours surgical correction over orthotics, even if the effectiveness of these different interventions on walking capacity and gait velocity would be comparable. This review showed that recurrences of foot deformity after surgery are rare, which is equally important because it indicates that in many patients surgical correction is not only a safe, but also a permanent,

treatment option. Another aspect of patient *selection* is the timing of surgery post-stroke or post-TBI. Neurological recovery is believed to continue up to 6–9 months after stroke and up to 12–18 months after TBI, which is why surgical correction of equinovarus foot deformity is often postponed until after this recovery period (see Table I). However, the benefits or consequences of postponing surgery have never been formally investigated. Recent evidence, showing that within 3 weeks post-stroke muscle activation patterns in the affected leg are more or less established, seems to support the notion of earlier surgical intervention post-stroke, which may prevent unnecessary development of compensatory gait strategies (61). Of course, it should be kept in mind that surgical correction of equinovarus foot deformity is an elective procedure. Patients with poor vascularization, or other conditions that pose risks to the operation should be excluded.

The second challenge for future research is standardization of *preoperative planning*. From the selected studies a tendency towards thorough (instrumented) gait assessment prior to surgical planning can be determined (Table II). Developing evidence-based guidelines regarding the surgical correction of equinovarus foot deformity will depend on a structured approach. Equinovarus foot deformity can result from a variety of imbalanced muscle forces for which a single, best operation is not available. Thus, surgical correction should, pre-eminently, be patient tailored. Instrumented gait analysis offers the possibility to collect objective and repeatable data on the severity and dynamics of the equinovarus deformity and its consequences for walking capacity (62). Gait analysis, at present, is probably the most powerful instrument to assist clinicians in surgical decision-making and to assess the outcome of surgery (63, 64). Because the activation pattern of most operated muscles alters very little (38), pre-operative gait analysis (including electromyography during gait) is essential in determining the appropriate surgical plan, since it is a good indication of the type of muscle activity to expect post-operatively. Fuller et al. (37) demonstrated that instrumented gait analysis altered the surgical planning for patients with equinovarus foot deformity and produced a higher agreement among surgeons. Introducing instrumented gait analysis as a gold standard not only enables clinicians (and researchers) to exchange reliable and detailed information about patients, but also creates the opportunity to (remotely) consult colleagues or other experts to determine the suitability of an individual patient for a specific surgical procedure (65).

The third challenge concerns uniformity in *outcome measures*. Preferably, all domains of the ICF (functions and structures, activities and participation) should be assessed (Table II). Outcome measures should evaluate the desired treatment effect, but also allow for comparing effectiveness of treatment alternatives. The psychometric properties (reliability, validity, responsiveness) of outcome measures are important criteria for selection (66–68). Instrumented gait analysis produces reliable and repeatable data on spatiotemporal, kinetic and kinematic gait characteristics. By objectively quantifying underlying impairments, gait analysis is not only essential in preoperative planning, but also in evaluating the effect of surgical correction on the deviant ankle–foot position and on the intended improvement of walking capacity. Furthermore, gait analysis allows for detailed comparison with treatment alternatives, such as ankle–foot orthotics, chemodenervation and functional electrical stimulation (63, 69, 70). Of the included studies, only 3 used instrumented gait analysis in both the pre- and post-operative assessment (Table II).

As equinovarus deformity compromises (barefooted) walking, regaining walking capacity will be the first objective of all interventions that aim to correct equinovarus deformity, including surgical correction. Therefore, outcome measures should at least incorporate validated measures of walking capacity. Such measures were used by only 4 studies included in this review. Based on their psychometric properties, the Six-Minute Walk Test (6MWT) (71) and the Functional Ambulation Categories (FAC) (72, 73) appear to be suitable to measure walking capacity. Walking speed can additionally be regarded as a simple and valid parameter of gait, since it is highly correlated with walking capacity (74). Walking speed can, for instance, be measured accurately with the Ten-Meter Comfortable Walk Test (10MCWT) (75). It should be acknowledged, however, that these capacity measures only provide information about what patients *are able to do*, but not about their actual performance (i.e. activities) in daily life. In addition, most clinical outcome measures are unable to quantify the quality of performance while executing meaningful tasks, such as gait. In this perspective, it seems essential to assess the total ambulation time over a representative time period. In addition, validated questionnaires on societal participation will give insight into which activities patients are involved in and provide a more or less complete picture of the benefits of the (surgical) intervention as experienced by individual patients.

A second major objective of surgical intervention is to eliminate (or at least reduce) the need for an ankle–foot orthosis for walking. All studies included in this review reported on the pre- and post-treatment need for orthoses. None of these studies, however, quantitatively compared the effect of an ankle–foot orthosis with that of the surgical correction. In our opinion, recommending a surgical correction would be appropriate only if the expected effect on walking capacity is at least comparable to the effect of an orthosis.

In conclusion, despite the methodological shortcomings of the included studies, it seems fair to state that surgical correction of equinovarus foot deformity following stroke or TBI is a safe and more or less "permanent" treatment option with a good chance of improving walking capacity and of diminishing the need for orthotic use. However, the level of evidence of the selected studies was low and used outcome measures were heterogeneous. It was not possible to conduct a quantitative analysis (i.e. meta-analysis) of the collected results. Further validation of surgical correction of equinovarus foot deformity following stroke or TBI is required, using higher-level study designs (prospective cohort, RCT) with validated assessment tools. Studies that incorporate control groups are necessary to compare surgical techniques with other interventions, with the aim of generating evidence upon which treatment algorithms can be based.

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