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THE POST-STROKE HEMIPLEGIC PATIENT

I. *A Method for Evaluation of Physical Performance*

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ABSTRACT. A system for evaluation of motor function, balance, some sensation qualities and joint function in hemiplegic patients is described in detail. The system applies a cumulative numerical score. A series of hemiplegic patients has been followed from within one week post-stroke and throughout one year. When initially nearly flaccid hemiparalysis prevails, the motor recovery, if any occurs, follows a definable course. The findings in this study substantiate the validity of ontogenetic principles as applicable to the assessment of motor behaviour in hemiplegic patients, and focus the importance of early therapeutic measures against contractures.

The motor behaviour in patients who have sustained a cerebrovascular accident with motor-involvement may, when flaccid paralysis does not prevail, be characterized by disorganization of complex reflex mechanisms which are the background for the highly selective voluntary motor performance (i.e., skill) occurring in normal man (33, 40, 53). Secondary to the sensory-motor deficit, decreased passive joint motion and joint pain frequently occur and in their return may influence the motor behaviour (cf. 19, 25).

The aim of this paper is to present a cumulative numerical score system for assessment of the development of motor function and balance in patients who have sustained a cerebrovascular injury leading to hemiparesis/hemiparalysis. A method for simple numerical evaluation of the joint function is also described.

The paper may logically be divided into two parts: (A) A thorough description of the methods of evaluation, and (B) a follow-up study of a series of post-stroke hemiplegic patients.

Twitchell (49) found that if the motor function in hemiplegic patients recovered, the common course of recovery showed regularity in sequence, changes in reflexes being associated with increase in ability for willed movement. Bard and Hirschberg (3) observed that, in the hemiplegic arm, the prognosis for recovery was dependent on the early development of motor function.

Based on empirical observations, Reynolds et al. (45) and later Brunnström (8, 9) described a method for following the recovery of motor function in hemiplegic patients. These authors pointed out that in evaluating the movement in hemiplegic man, conventional testing of muscle strength (12, 38) is inadequate, as the motor function in the hemiplegic patient is often dependent on synergies. The findings of Vallbo (50) that even in normal man α and γ secondary motor neurons are simultaneously activated during static muscle contraction may further substantiate this.

Bobath (5) underlines the relation between the hemiplegic's postural situation and his ability to perform selective voluntary muscle action. This postural background for selective voluntary muscle activity in hemiplegia has recently been further elucidated by the observations of Fugl-Meyer (20, 21) who found that in hemiplegic and hemiparetic patients the postural situation determines the selective voluntary activation of some muscles in the leg and also the reflexly elicited activity in their antagonists. This phenomenon does not occur at all (or only partly) when phasic and/or tonic hyperreflexia does not prevail.

Treatment approaches, such as those described by Bobath (5, 39) Brunnström (9), Kabat & Knotts (44, 51) and Rood (24, 48) all base their treatment on the interaction of postural and voluntary muscle function, and aim to restore optimum functional performance through specific choice of treatment stimuli and careful patient positioning. The importance of assessing the potentialities of the patients before and during treatment procedures is also stressed in these methods.

However, the assessment method applied by the advocates for the different methods all lack numerical score and it is consequently difficult to assess the efficacy of treatment. With few exceptions (3, 8) authors who have investigated the functional capacity of hemiplegics have abstained from describing the neuromuscular capacity *per se* and apply specially designed ADL-performance testing (1, 10, 14, 26, 43). Also standardized, not specifically hemiplegia-oriented forms for ADL-testing with numerical scoring have been applied (7, 15, 47, 52). Others have used more specific methods such as MTM-technique (11) and handwriting (29). The common denominator of the mentioned methods of assessment is absence of standardization of the patient's posture and motor performance and allowance for varying degrees of compensatory mechanisms on account of the patient.

PART A: A Description of Assessment Methods

The evaluation comprises three different but interdependent parts:

I. Motor function and balance
II. Some sensation qualities
III. Passive range of motion and occurrence of joint pain.

MOTOR FUNCTION

An ordinal-scale is applied for grading of the details. The scale includes only three grades, with 0 as minimum and 2 as maximum, as we have found in a pilot study that scales consisting of 5 or 7 steps were likely to elicit less reliable judgements, while the 3-graded scale gave a good degree of reliability.

Basically the methods described by Brunnström (8) are applied. The test form for this procedure is shown in Fig. 1*a* and *b*. For definition of joint motion, the standards of the American Academy of Orthopaedic Surgeons (2) are used.

The form has been constructed following the hypothesis that the restoration of motor function in hemiplegic patients follows a definable stepwise course. Thus, for a patient with hemiparalysis, recurrence of reflexes always precedes volitional motor action. Thereafter, through initial dependence on synergies, the active motion will become successively less dependent upon the primitive reflexes and reactions, and finally complete voluntary motor function with normal muscle reflexes may be regained. As the motor function of the wrist and hand may recover somewhat independently of that of the arm, these functions are tested separately.

For each of the steps (I–V) a maximum score can be attained, the scores for the different steps can be totalled both for the arm and for the leg, and a maximum motor score for the affected side can thus be expressed.

Upper Extremity

Shoulder/Elbow/Forearm (A)

I. *Reflex activity can be elicited.* The biceps-, triceps-, and finger-flexor reflexes are elicited.

Scores: 0: no reflex activity. 2: reflex activity can be elicited in flexors and/or the extensor.
Maximum score 4.

II. *Volitional movement can be performed within the dynamic flexor and/or extensor synergies:* As in all other performance tests using this method, the patients must be meticulously instructed, and it may often be an advantage to use mime as well as verbal means of instruction in order to minimize perceptual difficulties (17). It may often facilitate the evaluation procedure if the patient initially performs the required manoeuvre with the non-affected arm.

(*a*) *Flexor synergy:* The seated patient is instructed by voluntary action of the muscles of the affected arm to bring his forearm fully supinated to the ear of the affected side, the elbow fully flexed, the shoulder abducted to at least 90°, outwards rotated, retracted and elevated.

Scores: 0: the specific detail (cf. Fig. 1*a*) cannot be performed at all. 1: the detail can be performed only partly. 2: the detail is performed faultlessly.

(*b*) *Extensor synergy:* The seated patient is instructed to adduct/internally rotate the shoulder,

UPPER EXTREMITY

A SHOULDER / ELBOW / FOREARM

I	Reflex-activity		Flexors Extensors
II	a	Shoulder	Retraction Elevation Abduction Outwards rotation
		Elbow	Flexion
		Forearm	Supination
	b	Shoulder	Add-/Inw.rotation
		Elbow	Extension
		Forearm	Pronation
III		Hand to lumbar spine	
		Shoulder	Flexion 0°-90°
		Elbow 90°	Pro-/Supination
IV		Shoulder	Abduction 0°-90° Flexion 90°-180°
		Elbow 0°	Pro-/Supination
V	Normal reflex-activity		

B WRIST

Elbow 90° Wrist-stability
Elbow 90° Wrist-flexion/extension
Elbow 0° Wrist-stability
Elbow 0° Wrist flexion/extension
Circumduction

C HAND

Fingers Massflexion
Fingers Massextension
Grasp a
Grasp b
Grasp c
Grasp d
Grasp e

D COORDINATION/SPEED

Tremor
Dysmetria
Time

Fig. 1 a. Test form for assessment of the motor function of the upper extremity in hemiplegia.

extend his arm towards the unaffected knee, forearm pronated. The starting position should be that of full flexor synergy. If the patient cannot actively attain this position, the arm may be passively "placed" therein. Care should be taken to avoid letting the patient substitute gravitational help for muscle activity. Some patients, eager to cooperate, may for instance rotate the thorax or pendulate the affected arm. To assess if the motion is actively performed by the patient, it may now and then be necessary to palpate the pectoralis major and/or the triceps brachii tendons. The criteria for scoring are identical to those listed above.

As 9 details in all are evaluated, maximum score for stage II is 18.

III. *Volitional motion performed mixing the dynamic flexor and extensor synergies:* The seated patient is instructed to perform three separate actions.

(i) Actively position the affected hand on the lumbar spine.

Scores: the requirements to obtain a score of 1 is that the hand should, without any gravitational tricks, pass the anterior–superior iliac spine. 0 and 2 as previously described.

(ii) Flex the shoulder to 90° in a pure flexion motion. The elbow must be fully extended throughout the total required range of motion, the forearm in the midposition between pro- and supination. If, at the start of the motion, the arm is immediately abducted or the elbow flexed, the patient scores: 0. If, in later phases of the motion, shoulder abduction and/or elbow flexion occurs: 1.

(iii) Pronation–supination of the forearm, the elbow joint actively flexed to about 90°, the shoulder joint at 0° (all degrees of freedom).

Scores: 0: if the correct position of the shoulder and the elbow can not be obtained by the patient and/or pro-supination can not be performed at all. The patient scores 1 if active pro-supination can be performed even within a very limited range of motion and at the same time the shoulder and the elbow joints are correctly positioned.

Three details included: maximum score 6.

IV. *Volitional movements are performed with little or no synergy dependence:* The seated patient is instructed to: (i) Abduct the shoulder to 90° in a pure abduction motion. The elbow fully extended (0°) and the forearm pronated. To score more than 0, no initial flexion of the elbow should be tolerated nor should any deviation from the pronated forearm position be allowed. 1 point is scored if the motion can be performed only partly or if, during the motion, the elbow is flexed or the forearm can not be kept in the pronated position.

(ii) Flex the shoulder in a pure flexion motion from 90° to 180°, the principles for scoring as in stage III flexion from 0° to 90°.

(iii) Pronate–supinate the forearm, the elbow fully extended (0°). The shoulder must be kept in a position between at least 30° and not more than 90° flexion. The principles for scoring follows those of stage III (pronation–supination). The three actions tested give a maximum score of 6.

V. *Normal reflex activity:* Muscle reflexes (cf. I) are elicited.

Scoring: 0: at least 2 of the 3 phasic reflexes are markedly hyperactive. 1: one reflex markedly hyperactive *or* at least 2 reflexes lively. 2: no more than one reflex lively and no reflexes markedly hyperactive.

This stage, which can render the patient a maximum score of 2, is included only if the patient has a score of 6 points in stage IV.

The total maximum score for the upper part (A) of the arm is: 36 points.

Wrist (B)

Three different functions of the wrist muscles are assessed. Two of these functions are evaluated in different postural situations of the elbow joint (cf. Fig. 1 *a*).

Wrist stability in approximately 15° dorsal flexion is tested with the shoulder in 0° (all degrees of freedom), the elbow in 90° and the forearm fully pronated. If the elbow cannot by volitional muscle actively be brought to and kept in the required position, the examiner may assist the patient.

Scores: 0: the patient can not dorsiflex the wrist to the required position. 1: dorsiflexion can be performed but no resistance can be taken. 2: the position can be maintained against some (slight) resistance.

The patient is instructed to perform repeated smooth alternating movements from maximum dorsiflexion to maximum volar flexion with the fingers somewhat flexed. The position of the shoulder-, elbow-, and radio-ulnar joints as in the foregoing manoeuvre. The examiner may support the elbow in the required position if needed.

0: volitional movements do not occur. 1: the patient cannot actively move the wrist joint throughout the total passive range-of-motion.

Wrist stability is next tested with the shoulder joint somewhat flexed and/or abducted, the elbow joint in the 0° position, the fore-arm pronated (the examiner may, if needed, support the arm in this position).

Scores as when testing wrist stability described above.

Alternate the dorsi- and volarflexions as previously described but with the shoulder joint somewhat flexed and/or abducted. The elbow fully extended (support if needed).

Scores as above.

Circumduction of the wrist: The quality of the movement is evaluated as follows: 0: circumduction cannot be performed. 1: jerky motion or incomplete circumduction.

As each detail fully and adequately performed can render 2 points, the maximum score of wrist motor function (B) is 10.

Hand (C)

Seven details are evaluated. Of these, five are grasps with different types of muscular co-contractions. The examiner may, if necessary, support the elbow in the 90° position; no support may be given for the wrist.

Mass flexion: The patient is instructed to flex his fingers. Score: 0: no flexion occurs. 1: some, but not full active finger flexion. 2: full active flexion (compared with unaffected hand).

Mass extension: from the position of full active or passive finger flexion, the patient is required to extend all fingers. Scoring as above with the modification that the patient scores 1 if he can release an active mass flexion grasp.

Grasp A: The patient is instructed to extend the metacarpophalangeal joints of digits II–V and flex the proximal and distal interphalangeal joints. The grasp is tested against resistance. 0: the required position cannot be acquired. 1: the grasp is weak. 2: the grasp can be maintained against relatively great resistance.

Grasp B: The patient should perform a pure thumb adduction, the first carpometacarpophalangeal- and interphalangeal joints in the 0° position. 0: the function as such can not be performed. 1: a scrap of paper interposed between the thumb and the second metacarpals can be kept in place but not against a slight tug. 2: a scrap of paper is held well against a tug.

Grasp C: The patient opposes his thumb pulpa against the pulpa of the second finger. A pencil is interposed. Scoring principles as for grasp B.

LOWER EXTREMITY

E HIP/KNEE/ANCLE

I	Reflex-activity		Flexors Extensors
II	a	Hip Knee Ancle	Flexion Flexion Dorsi-flexion
	b	Hip Knee Ancle	Extension Adduction Extension Plantarflexion
III		Knee Ancle	Flexion Dorsi-flexion
IV		Knee Ancle	Flexion Dorsi-flexion
V	Normal reflex-activity		

F COORDINATION/SPEED

Tremor
Dysmetria
Time

G BALANCE

Sit without support
Protective reaction non-affected side
Protective reaction affective side
Stand with support
Stand without support
Stand on non-affected leg
Stand on affected leg

Fig. 1 b. Test form for recording the lower extremity motor function and balance in hemiplegia.

Grasp D: The patient should grasp a cylinder-shaped object (small can), the volar surface of the first and second fingers against each other. Scoring principles as grasp B.

Grasp E: A spherical grasp. The patient grasps a tennis ball or is instructed to place his fingers in a position with abduction position of the thumb and abduction flexion of the second, third, fourth and fifth fingers. Scoring principles as for grasp B.

The total score of the seven evaluated details (C): 14 points.

Coordination/Speed (D)

Very often patients with nearly normal motor function of the upper extremity will complain of slight dyscoordination and a sluggishness in the movements. Therefore, a combined coordination/swiftness of motion test is included for both the upper and the lower extremity.

For the upper extremity, a finger-to-nose test is applied. The patient is instructed to put the tip of his index finger to his nose blind-folded, five times in as rapid succession as he can. The following details are assessed:

Tremor: 0: marked tremor; 1: slight tremor; 2: no tremor.

Dysmetria: 0: pronounced or unsystematic dysmetria; 1: slight and systematic dysmetria; 2: no dysmetria.

Speed: The swiftness of motion is compared with that of the unaffected side: 0: the finger-to-nose manoeuvre repeated 5 times is at least 6 seconds slower on the affected than on the unaffected side; 1: 2 to 5 seconds slower on the affected side; 2: less than 2 seconds difference. Three details evaluated give a maximum sum of 6 points.

The total motor score of the upper extremity: 66 points.

Lower Extremity (E)

I. With the patient in the supine position patellar, knee flexor and achilles reflexes are evaluated. Principles for scoring as in stage I for the upper part of the arm.

Maximum score: 4.

II. This and the following stages are defined as the corresponding stages for the upper extremity.

Flexor synergy: The patient in supine position is instructed to flex his hip-, knee-, and ankle joints maximally. Usually at the same time the hip will be abducted and outwards rotated (Fig. 1*b*). During this motion the distal tendons of the knee flexors should be palpated in order to ascertain that active flexion of the knee occurs.

Scores: 0: the specific detail cannot be performed; 1: the detail can be performed only partly; 2: the detail is performed throughout the total range of motion of each of the three joints.

Extensor synergy: From the "end points" of the flexor synergy the patient should extend his hip-, knee-, and ankle joints, resistance being exerted in order to eliminate gravitational facilitation of the manoeuvre. Hip adduction against resistance is also performed. (The hip adduction may be evaluated in combination with hip extension.)

Scores: 0: the specific detail cannot be performed; 1: some little strength; 2: normal or nearly normal strength (compared with unaffected limb).

Maximum score: 14.

III. The patient in the sitting position, knees free of the bedside of the edge of the chair, is asked to:

Flex his knee beyond 90°. 0: no active motion; 1: from a somewhat extended position, the knee can actively be flexed towards but not beyond 90° (simultaneously the tendons of the hamstrings are palpated); 2: the knee can be flexed beyond 90°.

Dorsiflex his ankle. 0: cannot; 1: impaired active flexion; 2: normal dorsiflexion (compared with unaffected side).

Maximum score: 4.

IV. The standing patient is instructed to flex his knee to at least 90°, the hip at 0° or further extended.

Scores: 0: the knee can not at all be flexed if the hip is not simultaneously flexed; 1: the knee can not be flexed fully to 90° and/or the hip is flexed during the performance of this motion.

Dorsiflex the ankle joint. For recording 1 or 2 points the active motion of the ankle joint is compared with the unaffected side.

Maximum score: 4.

V. The normality of muscle reflexes is recorded according to the principles of E: I, scoring as A: V.

Maximum score: 4.

Coordination/Speed (F)

The patient in the supine position is instructed to bring his heel to the knee cap of the opposite leg 5 times in as rapid succession as possible.

Tremor, dysmetria, swiftness of motion are recorded, applying the principles described for the upper extremity (B).

Maximum score for motor function of the lower extremity: 34 points.

Total score motor function (A–F): 100 points.

Balance (G)

Seven details are evaluated, 3 in the sitting and 4 in the standing patient.

Sit without support: Scores: 0: The patient cannot maintain the sitting position without massive support, i.e., leans heavily towards the back of the chair, cushions have to be placed around him, or he has to be supported in the sitting position with a belt. 1: can sit only for a short while on a stool or on the bed, legs hanging. 2: can sit at least 5 minutes without any support, thus regulating the postural motor function of the body in relation to gravity.

Parachute reaction in non-affected side: The sitting patient, blindfolded, is pushed with a firm push against the non-affected side.

Scoring: 0: does not abduct his shoulder, extend his elbow to avoid falling; 1: impaired parachute reaction; 2: normal parachute reaction.

Parachute reaction, affected side: Starting position, procedure and scoring as for the unaffected side.

Supported standing: Scoring: 0: cannot stand at all; 1: standing demands massive support from other persons; 2: can stand erect for at least one minute with slight (or symbolic) support from other person.

Stand without support: Score: 0: cannot stand without support; 1: can stand erect for less than one minute or can stand for a longer time but somewhat swaying; 2: good standing balance, can maintain the balance for more than one minute without insecurity.

Stand on non-affected side: Score: 0: the position cannot be maintained for more than a few, reeling seconds; 1: can stand in a balanced position between 4 and 9 seconds; 2: can maintain a balanced position for more than 10 seconds.

Stand on affected leg: Scoring as above.

Maximum sum (G): 14.

Sensation (H)

The sensation for light touch is roughly estimated (Fig. 2). Thus, the patient is asked whether he feels that light touch on both arms, the palmar surface of the hands, both legs and the footsoles gave the same qualitative and quantitative impression.

Scoring: 0: anaesthesia; 1: hypaesthesia/dysaesthesia; 2: normaesthesia.

Total score: 8.

The position sense of the joints is tested for the thumb (interphalangeal joint), the wrist, the elbow and the gleno-humeral joint. Very small alterations in the position are accomplished by the examiner who also takes care to place his fingers and his hand

H SENSATION

a	Light touch	Arm
		Vola
		Leg
		Plantar
b	Positon	Shoulder
		Elbow
		Wrist
		Thumb
		Hip
		Knee
		Ancle
		Toes

J PASSIVE JOINT MOTION/JOINT PAIN

Shoulder	Flexion
	Abduction → 90°
	Outw. rotation
	Inw. rotation
Elbow	Flexion
	Extension
Forearm	Pronation
	Supination
Wrist	Flexion
	Extension
Fingers	Flexion
	Extension
Hip	Flexion
	Abduction
	Outw. rotation
	Inw. rotation
Knee	Flexion
	Extension
Ancle	Dorsi-flexion
	Plantar-flexion
Foot	Pronation
	Supination

Fig. 2. Test form for assessment of some sensation qualities, passive range of motion and occurrence of joint pain in hemiplegia.

so that other qualities of sensation than the position sense of the joints do not lead the patients to conclusions. The examiner should also take care to avoid excitation of the primary ending when altering the joint position, as the patient may detect changes in position through I a gamma-fibres. The patients, who should be blindfolded, should answer either verbally or by positioning of the corresponding joint on the unaffected side indicate the positions.

In the lower limb, position sense is tested for the great toe, the ankle joint, the knee and the hip.

Score: 0: absence of sensation; 1: considerable difference in sensation compared with the joint on the unaffected side, but at least 3/4 of the answers correct; 2: all answers correct, little or no difference comparing unaffected with affected limb.

Position sense total score: 16.

Sensation maximum score: 24;

Joint Motion and Joint Pain (J)

Evaluation of passive joint motion and occurence of joint pain during and at the end of the passive motion of a joint performed for most joints of the affected limbs (Fig. 3). Joint motion is compared with the non-affected extremity. It may often be advantageous to evaluate joint motion and joint pain before assessing the motor function, as dysfunction of a joint *per se* should be disregarded when evaluating the motor function.

Scoring: Passive joint motion: 0: only few degrees of range-of-motion; 1: decreased passive range-of-motion; 2: normal passive range-of-motion.

Occurrence of joint pain: 0: pronounced pain during all the movement of very marked pain at the end of the actual range of motion; 1: some pain; 2: no pain.

Total score range-of-motion: 44.

Total score occurrence of joint pain: 44.

As it is felt that the examiner should be able to evaluate joint motion/joint pain on a bedridden patient, the abduction of the shoulder is performed only to 90° and the extension of the hip to 0°.

PART B: A Follow-up Study of a Series of Post-stroke Hemiplegic Patients

MATERIAL

For selecting the hemiplegic patients included in this study we collaborated with the stroke register in Göteborg. Defining stroke as rapidly developed clinical signs of focal (and/or global) disturbances of the cerebral function of presumed vascular origin and more than a few minutes' duration, the stroke team studies epidemiological factors concerning cerebral vascular accidents (31).

Sahlgren's Hospital is a university hospital serving a population of nearly half a million. The hospital serves nearly all cases of acute disease in the city. All patients

Table I. *Some characteristics of 28 patients with stroke and hemiplegia of at least 24 hours' duration*

The classification numbers according to the International Classification of Diseases (ICD) are given in parentheses

Diagnosis	Affected side Right	Left	Sex ♂	♀	Mean age (years)
Intracerebral hemorrhage (431)	3	3	3	3	60
Thrombo-embolic lesions					
(432)	2	1	3	0	54
(433)	2	1	3	0	45
(434)	0	2	2	0	61
Unspecified cerebrovascular lesion (436)	8	6	10	4	58
Total	15	13	21	7	57

aged 65 years and younger admitted to the hospital with a manifest or suspect stroke were seen by a member of the stroke team within a few days. The more exact diagnosis was, for the surviving patients, usually established at a 3-week follow-up examination (30). A control study of the reliability of the stroke-register has shown that more than 92% of the admitted stroke cases were registered. Through the stroke-register our group was notified about stroke patients admitted to the hospital during two periods in 1971 (February–March: 6 weeks, and September–October: 7 weeks). As soon as possible after notification, one of our group evaluated the patient. The average interval between admission and first examination was 4 days and, with two exceptions, all patients were seen within one week after the admission. Initially, we were notified about 80 patients. However, after reduction of the material because of death, within hours to a few days after the stroke, 28 patients fitted this stratification:

A: The patient should not have sustained cerebrovascular accident previous to the actual stroke, nor should he previously have suffered disease or trauma resulting in physical or mental handicap.

B: The patient should have had signs of hemiplegia/hemiparesis lasting at least 24 hours.

C: The patient should, when the stroke-diagnosis was definitely established, belong to one of the diagnostic categories given in Table I, where some physical data are also shown. Patients with cerebral damage due to neoplasm, truma and also subarachnoid haemorrhage were excluded.

METHODS

All subjects were evaluated at least once using the system for assessment previously described. (Coordination and swiftness of motion and protective reactions in the sitting position were, however, not evaluated. Also, the evaluation of joint function did not include evaluation of those joints which in hemiplegia are rarely affected by contracture and pain (cf. 37).

If, at the first evaluation, the motor function showed any appreciable deficit, the patient was re-examined at regular intervals for a period of 6 weeks and thereafter once a month until half a year post-stroke. Finally, in most subjects, a one year follow-up examination was performed. In 8 patients where the motor behaviour was found to be normal or nearly normal at the first examination, no regular follow-up was done, though 4 were re-examined one year post-stroke and at that time had no motor deficit.

Within one year after the stroke, 3 patients died and 2 had iterated stroke resulting in further physical disability. Thus, 15 patients remained to be followed through at least half a year and most of them for one year.

RESULTS

Four patients had, at the first examination, only signs of motor deficit in the lower limb and/or sensory dysfunction. The motor function of these 4 patients recovered nearly completely within half a year.

The detailed scores of all the 20 hemiparetic/paralytic patients are shown in Table II. Ten of these patients were initially in stage I. The development of the motor-behaviour in these ten originally nearly paralytic patients is displayed in Fig. 3 where the motor score is calculated as a percentage of the maximum obtainable score for the shoulder-arm and lower extremity systems, respectively.

Three of the patients (K. E., G. J. and G. L.) recovered little motorfunction in the shoulder–arm, and one of these (K. E., a poorly cooperative, hospitalized and bedridden patient) also obtained very low scores in the lower extremity. However, in most patients, successive restoration of the motor function was observed. The recovery was not limited to the first weeks or months but, especially concerning the shoulder–arm system, in several patients continued during the total follow-up. Only one of the patients, however, recovered fully normal motor behaviour in both the shoulder–arm and in the lower limb. With the exception of patient K. E., lack of cooperation did not seem to correlate to the restoration of motor function in this analysis.

Applying a paired-differences regression analysis, the motor development of the shoulder–arm system as compared with that of the lower extremity was analysed in the 9 patients who were followed one year and who showed development of

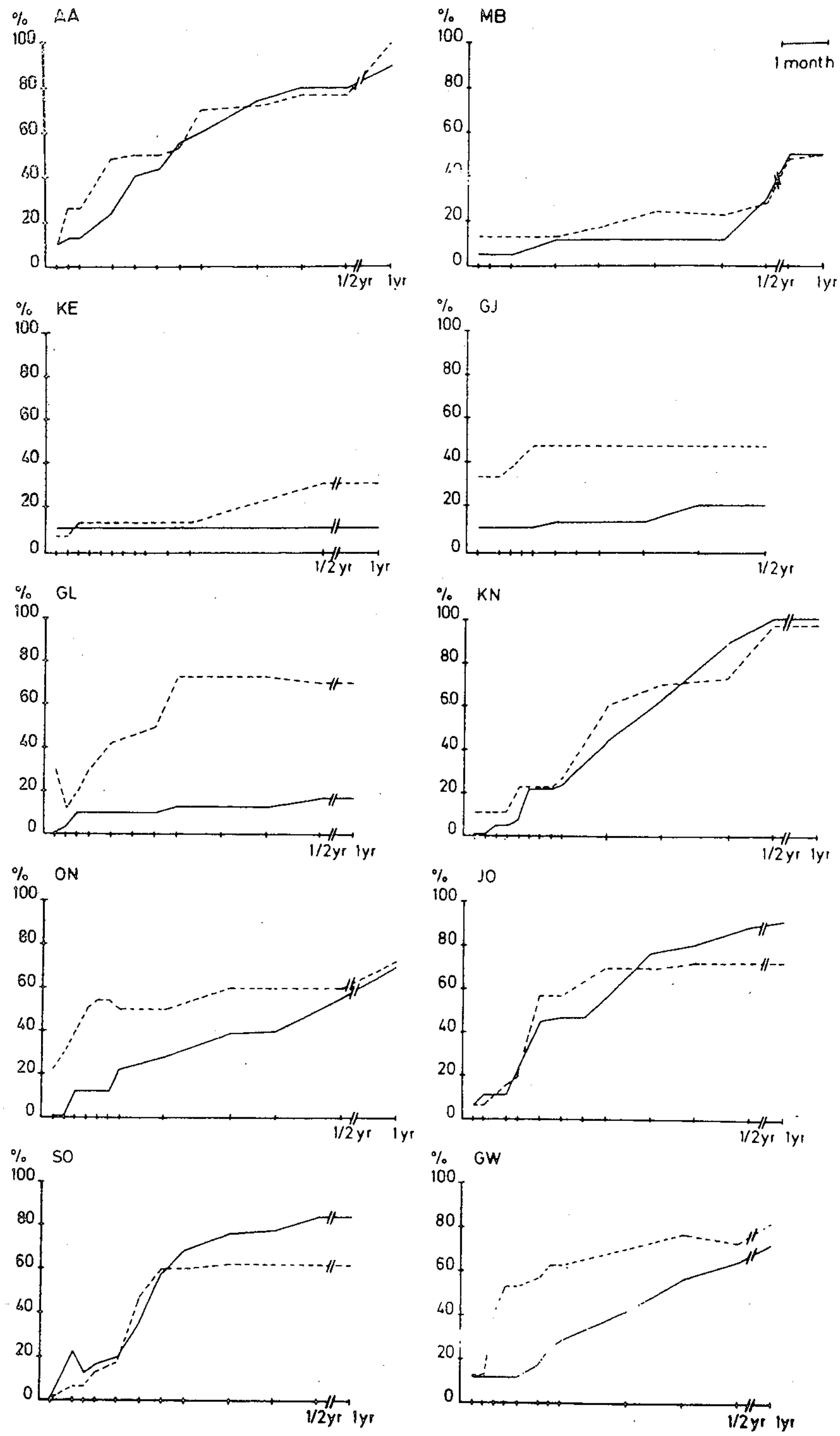

Fig. 3. Recovery of motor behaviour in the shoulder-arm and the lower extremity. The 10 hemiplegic patients are arranged alphabetically. —, Shoulder–arm function; - - -, lower extremity function. The intervals between follow-up investigations are indicated on the X-axis. All measured qualities are given as percent of maximum obtainable scores.

Table II. *Individual scores in various evaluated details for 20 hemiplegic patients during a one-year post-stroke follow-up*

1 =first evaluation; 2=second evaluation; 3=two months follow-up; 4=½ year follow-up; 5=one year follow-up

Initials	Motor behaviour: Shoulder–arm (max: 36)					Motor behaviour: Lower limb (max: 30)					Wrist and hand (max: 24)					Balance (max: 10)				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
A. A.	4	5	19	29	33	3	8	15	23	30	2	2	5	23	23	0	2	8	9	10
M. B.	2	2	4	11	18	4	4	4	10	15	0	0	0	0	0	0	0	3	8	8
K. E.	4	4	4	4	4	2	2	4	9	9	0	0	0	0	0	0	0	0	0	0
H. G.	26	27		29	28	23	26		27	25	24	24		24	22	8	8		8	8
G. J.	4	4	5	7	–	10	10	14	14	–	0	0	0	0	–	4	4	8	8	–
G. L.	0	2	4	6	6	9	4	15	21	21	0	0	0	0	0	0	0	8	8	8
K. N.	0	0	9	32	36	4	4	8	22	26	0	0	10	23	24	0	0	1	4	7
O. N.	0	0	10	20	25	7	9	15	18	22	0	0	0	15	18	1	4	6	9	9
J. O.	2	4	17	32	33	2	2	17	22	22	0	0	16	23	21	0	0	5	7	7
S. O.	0	8	13	30	30	0	2	14	19	19	0	4	3	18	18	4	4	5	8	7
G. W.	4	4	10	23	25	4	4	19	22	25	0	0	1	9	18	0	0	8	8	8
M. C.	0	4	**			4	4	**			0	0	**			0	0	**		
A. J.	2	4	**			4	5	**			0	0	**			0	0	**		
R. S.	2	4	4	**		2	4	4	**		0	0	0	**		0	4	4	**	
N. S.	33	36	*			25	25	*			21	24	*			10	10	*		
G. B.	33	33	–	36	36	21	22	–	30	30	22	22	–	24	24	8	8	–	10	10
A. D.	36	36	36	36	36	23	23	26	30	30	24	24	24	24	24	8	8	9	9	9
J. H.	36	36	–	33	*	30	30	–	30	*	24	24	–	24	*	10	10	–	10	*
J. N.	36	36	36	36	36	12	20	27	30	30	24	24	24	24	24	0	4	10	10	10
A. R.	36	36	36	36	36	18	21	30	30	30	14	20	24	24	24	6	7	10	10	10

*=iterated stroke; **=dead; ***=rheumatoid arthritis.
–=not evaluated/unreliable response.

both systems (Table III). When the analysis for each individual was done along the same time-base line, all except one patient showed significant co-variation between the two systems, with a mean correlation coefficient of 0.88. The maximum correlation coefficients were also computed, i.e., the regression analysis was performed without regard to time but instead comparing to the two systems when the slopes of the two curves were optimally coinciding. This gave a still higher mean correlation coefficient (0.90). In 4 patients the maximum correlation was identical with the simultaneous correlation, while in 4 patients the motor development of the leg was approximately one week ahead of that of the shoulder–arm.

In the 5 patients (Fig. 4) where development of the wrist's motor function could be followed, the order of restoration may indicate that the functions performed with the elbow flexed (i.e., performed with the elbow as a key-point in the flexor synergy (5)) develop earlier than those performed with the elbow in the extensor synergy.

In the 6 patients where restoration of the hand's motor function occurred successively (Fig. 5) the developmental order varied somewhat interindividually. However, high demands for co-contraction and coordination between flexors and extensors seemed to cause delay or absence in recovery of the specific function.

The wrist–hand motor function was not recovered at all in 4 of the 11 patients. No (or only slight) restoration of function of the hand seemed to take place when the motor behaviour of the shoulder–arm did not attain 40% or better of the obtainable maximum (Fig. 6), while the wrist's motor function more closely followed that of the more proximal parts of the upper extremity.

In Figs. 7 and 8, the separate scores of the sequential stages II, III, and IV are plotted. It can be seen that stage II, in all cases where the development of motor behaviour could be followed, started to develop before stage III which, in its turn, preceded stage IV.

In the shoulder–arm, the average percentage score for stage II before stage III started to develop was 61% (range: 50–72); the corresponding score for stage III in relation to the first development of stage IV was 60% (range: 33–100). In the lower

Sensation (max: 24)					Joint pain (max: 24)					Joint motion (max: 24)				
1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
13	21	24	24	24	22	24	22	17	24	23	24	22	20	23
16	16	18	20	20	24	24	16	20	21	24	24	17	21	23
–	–	–	–	–	24	24	14	13	19	24	24	21	14	20
23	24		24	24	***	***	***	***	***	***	***	***	***	***
19	19	22	24	–	24	24	22	20	–	24	24	24	22	–
24	24	24	24	24	24	24	18	15	15	24	24	23	18	19
–	–	4	5	5	24	24	22	22	24	24	24	24	24	24
10	12	18	20	21	21	22	19	17	20	23	24	21	17	22
–	–	24	24	24	24	24	21	24	24	24	24	23	23	23
4	4	9	8	8	24	24	20	18	20	24	24	22	20	21
2	3	9	9	9	24	24	20	22	23	24	24	20	22	24
0	3	**			24	24	**			24	24	**		
–	–	**			24	23	**			23	23	**		
–	–	–	**		24	24	24	**		24	24	24	**	
18	19	*			24	24	*			24	24	*		
22	22	–	24	24	24	21	–	24	24	24	24	–	24	24
24	24	24	24	24	24	24	24	24	24	24	24	24	24	24
22	22	–	22	*	24	24	–	24	*	24	24	–	24	*
22	22	22	24	24	24	24	20	24	24	24	24	22	24	24
22	24	24	24	24	22	22	24	24	24	24	24	24	24	24

extremity the equivalent scores (in per cent) were 76% (range: 50–93) and 79% (range: 50–100).

The balance (Fig. 9) did not necessarily follow the restoration of motor function in the limbs. However, full recovery of balance only occurred in patients with complete recovery of motor function in the lower extremity.

The sensory qualities measured in this study could be correlated neither to the maximum motor behaviour finally achieved nor to the steepness of the individual's motor development curves (Table II and Figs. 3 and 6). However, the sensory qualities could not be evaluated reliably when the total level of cooperation was low or if impressive dysphasia occurred.

Joint motion and pain

None of the patients who had normal or nearly normal motor behaviour in the upper extremity at the first evaluation developed joint pain or reduced passive range-of-motion in the upper extremity joints (Table II). Joint pain and reduced passive joint motion (Fig. 10) commonly occurred in patients who, initially, had poor motor function. Development of contractures was, however, not a constant companion to reduced voluntary muscle activity. Rather, the type of care may be a determi-

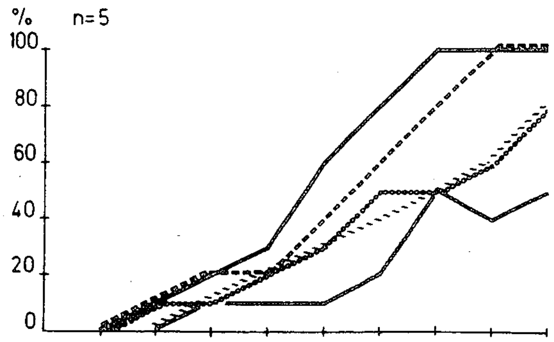

Fig. 4. Development of the 5 different measured wrist-motor functions in 5 hemiplegic patients in whom such development occurred. Values are expressed as mean percentage of the maximum obtainable scores (Y-axis) for all patients at each indicated separate measurement. Nine measurements are included (X-axis) ▬▬: stable wrist, elbow 90° flexed; ▬ ▬: wrist flexion-extension, elbow 90° flexed; ●●●: stable wrist, elbow extended; ▚▚▚: wrist flexion-extension, elbow extended; ▦▦▦: wrist circumduction.

Table III. *Correlations between recovery of motor behaviour in the shoulder–arm and in the lower extremity in nine hemiplegic patients where motor development was observed in both*

Simultaneous: analyses performed with regard to the time-base line
Maximum: analyses performed with regard to the optimum coincidence of the lines of motor recovery of the shoulder–arm and the lower extremity

Subjects	Correlation coefficients: Simultaneous	Correlation coefficients: Maximum	Time difference for maximum correlation (weeks)
A. A.	0.952	0.968	+1
M. B.	0.958	0.958	±0
H. G.	0.902	0.902	±0
G. L.	0.680	0.826	−1
K. N.	0.977	0.979	+1
O. N.	0.822	0.822	±0
J. O.	0.941	0.941	±0
S. O.	0.956	0.977	+1
G. W.	0.724	0.767	+1
Mean:	0.879	0.901	–

nant for the occurrence of contracture. An example: the patient M. B. was initially admitted to a department of internal medicine but was transferred, within 4 weeks, to a department for chronically disabled. When next seen, he scored considerably lower in the joint motion and pain variables. This development towards painful contractures continued for some months. About 3½ months post-stroke he was admitted to a rehabilitation department, and at the first re-evaluation after this transferral the curve had turned in the upward direction. For several of the other patients the danger of development of contracture seemed to be most imminent when passing through stages II and III characterized by dominance of reflex synergies.

Another feature was that joint pain always preceded development of reduced passive range-of-motion. However, when the decrease in joint motion had prevailed for some months the discrepancy between these two details tended to diminish.

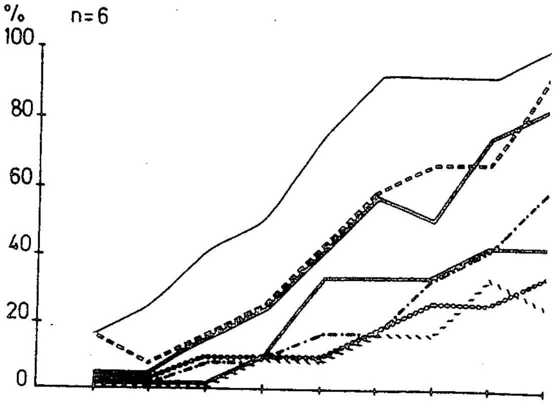

Fig. 5. Development of the 7 different measured hand–finger functions in 6 hemiplegic patients in whom such development occurred. Average values are expressed as percent of the maximum obtainable score (Y-axis), for all patients at each indicated separate measurement for each function. Nine measurements are included (X-axis). —: mass flexion; ▬ ▬: mass extension; ▬▬▬: hook grasp; ▦▦▦: cylinder grasp; ⊕▬⊕: opposition grasp; ⊛⊛⊛: radial grasp; ⧅⧅⧅: spherical grasp.

DISCUSSION

When vascular damage to the central nervous system occurs, a multiplicity of disturbances distorting the normal coordinated muscular answer to sensory feedback and cortical demands must be considered. At the spinal level, simple reflex mechanisms (cf. 28, 35, 41) may be facilitated or released from inhibition. A typical example of such a phenomenon is the occurrence of phasic hyperreflexia based on secondary α- and γ-motor neuron hyperactivity (16, 33, 40); this depends either on direct loss of cerebral inhibition to the spinal motor neuron or on loss of cerebral facilitatory influence on inhibitory inter-neurons. At successively higher levels within the central nervous system, coordinated reflexes (=reactions) may play a more or less pronounced role in the hemiplegic patients' motor behaviour. Thus, depending on the site and size of the vascular lesion, different sub-cortical areas may dominate the patient's motor function. It is well known to most clinicians treating hemiplegic patients that the pontine reflexes: the positive and negative support reactions, the tonic neck and the tonic labyrinthine reflexes, may be clearly discernible after a cerebrovascular accident (4). Also somewhat less defined reflex mechanisms, such as irradiation (20, 21, 32, 46), the righting and the equilibrium reactions, may be released from adequate cortical control and thus either dominate the motor behaviour or be absent (4, 13, 22, 42). Furthermore, sensory information, including information on joint motion and position (18, 19, 23, 25) is essential for skilled motor performance.

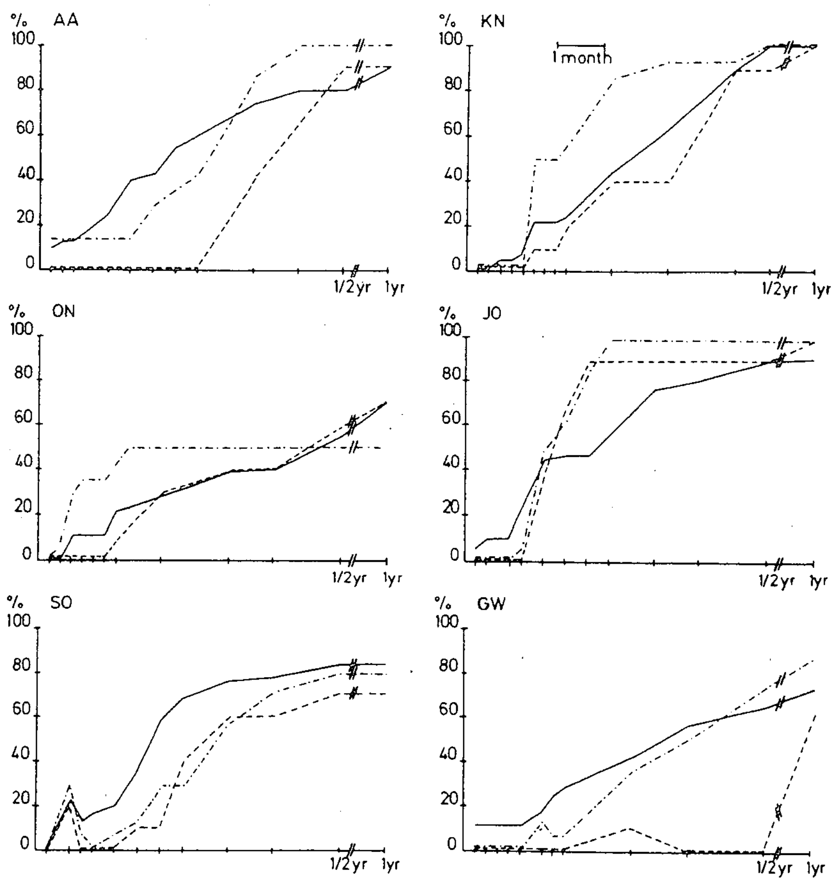

Fig. 6. The motor recovery in the shoulder–arm, wrist and hand in 6 hemiplegic patients in whom development of motor function in the wrist and hand occurred. —: shoulder–arm; ·–·: wrist; –––: hand. The measured qualities are calculated as percent of maximum obtainable scores. Along the X-axis the follow-up investigations are indicated.

Hence, disturbances within both the afferent and the efferent pathways may, in different ways and at different levels of the central nervous system, afflict the motor behaviour of the hemiplegic patients, ultimately leading to absent or incomplete control of the α-γ-linkage (27). The result will be that flaccidity or hyperreflexia, phasic and/or tonic, and irradiative phenomena, often posturally dependent (20), characterize the motor behaviour of the affected limbs of the hemiplegic patient and render it impossible for most patients to perform isolated muscular contractions. Therefore, only the functional strength and not the real strength can be measured. Testing methods using dynamometers and measurements of force by electronic strain-gauges (36) and the like have, in pilot studies (20), also proved to be of very dubious value when hyperreflexia prevails.

Two basic requirements in a method for the evaluation of patients are: (1) reliability, and (2) validity. (1) The finding that this follow-up of a series of patients displayed very small divergences in testing, both item-by-item and in toto, might indicate that the rigidly standardized procedures and the chosen scales allow of little chance error, and thus that the procedures are reliable.

The well known phenomenon that intercurrent diseases, such as infections, may lead to enhanced reflex-hyperactivity in patients with spasticity is elucidated by cases G. L. and S. O. Both these patients had intercurrent lung complications about 2–3 weeks post-stroke, and subsequently their already poor motor behaviour was, for a while, further impoverished (cf. Fig. 3).

(2) Does the applied method really describe that which it is intended to describe? Evidence strongly supporting the internal validity of the findings of Twitchell (49) are here presented in the form of a

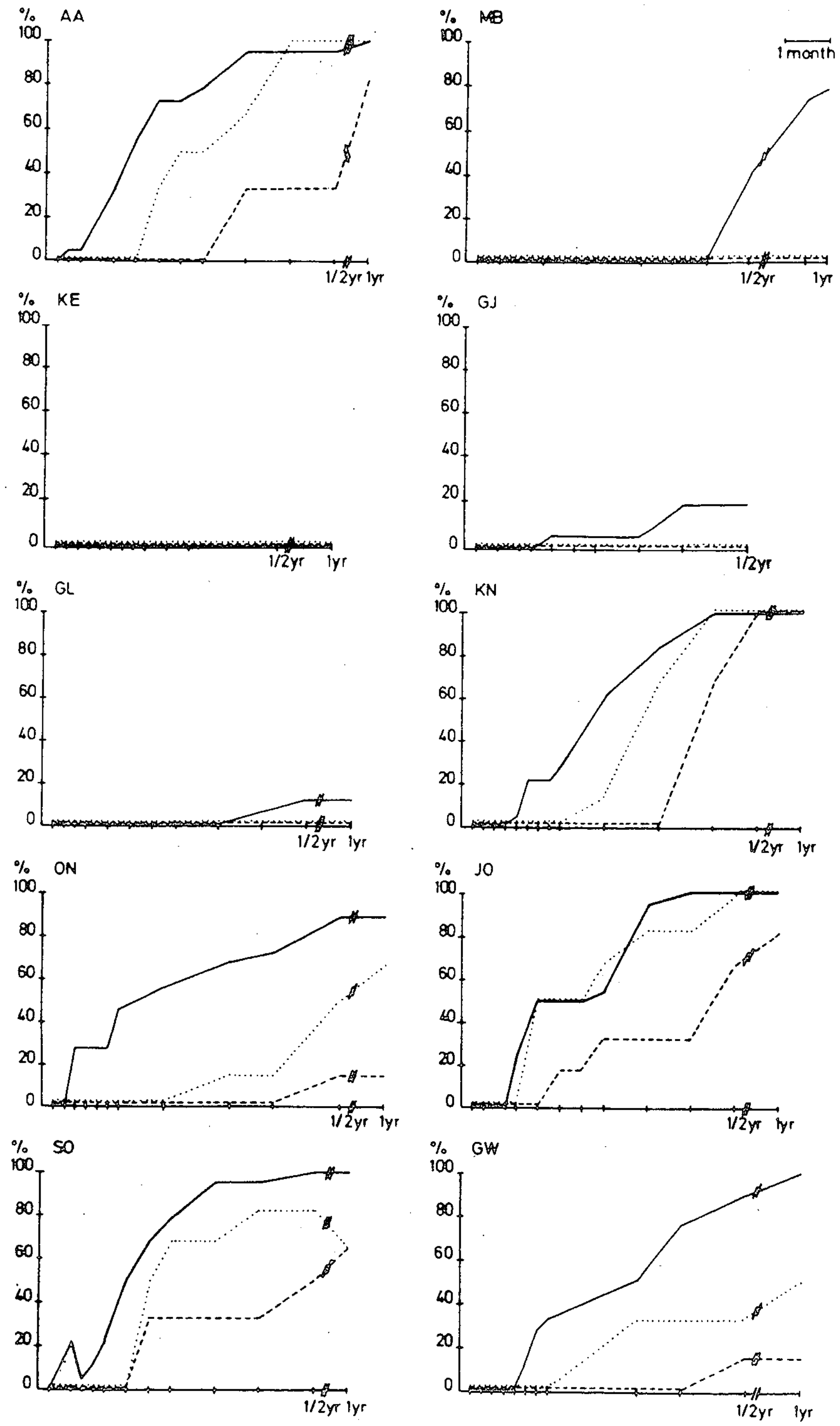

Fig. 7. Development of stages II, III, and IV in the shoulder–arm in 10 hemiplegic patients. —: stage II; ···: stage III; – – –: stage IV. The measured qualities are given in percent of the maximum obtainable score.

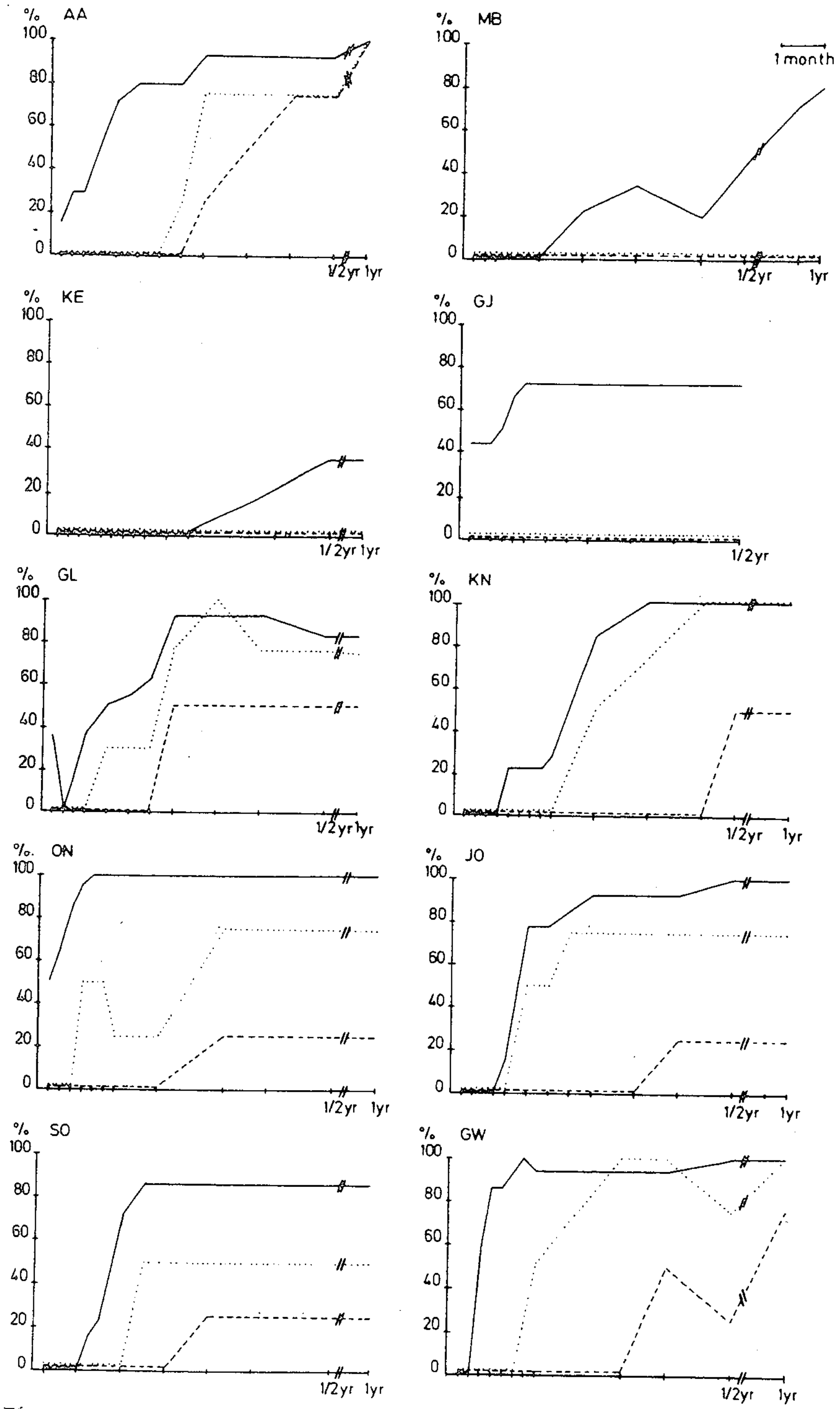

Fig. 8. Development of stages II, III, and IV in the lower extremity in 10 hemiplegic patients. —: stage II;, ···: stage III; - - -: stage IV. The measured qualities are given in percent of the maximum obtainable score.

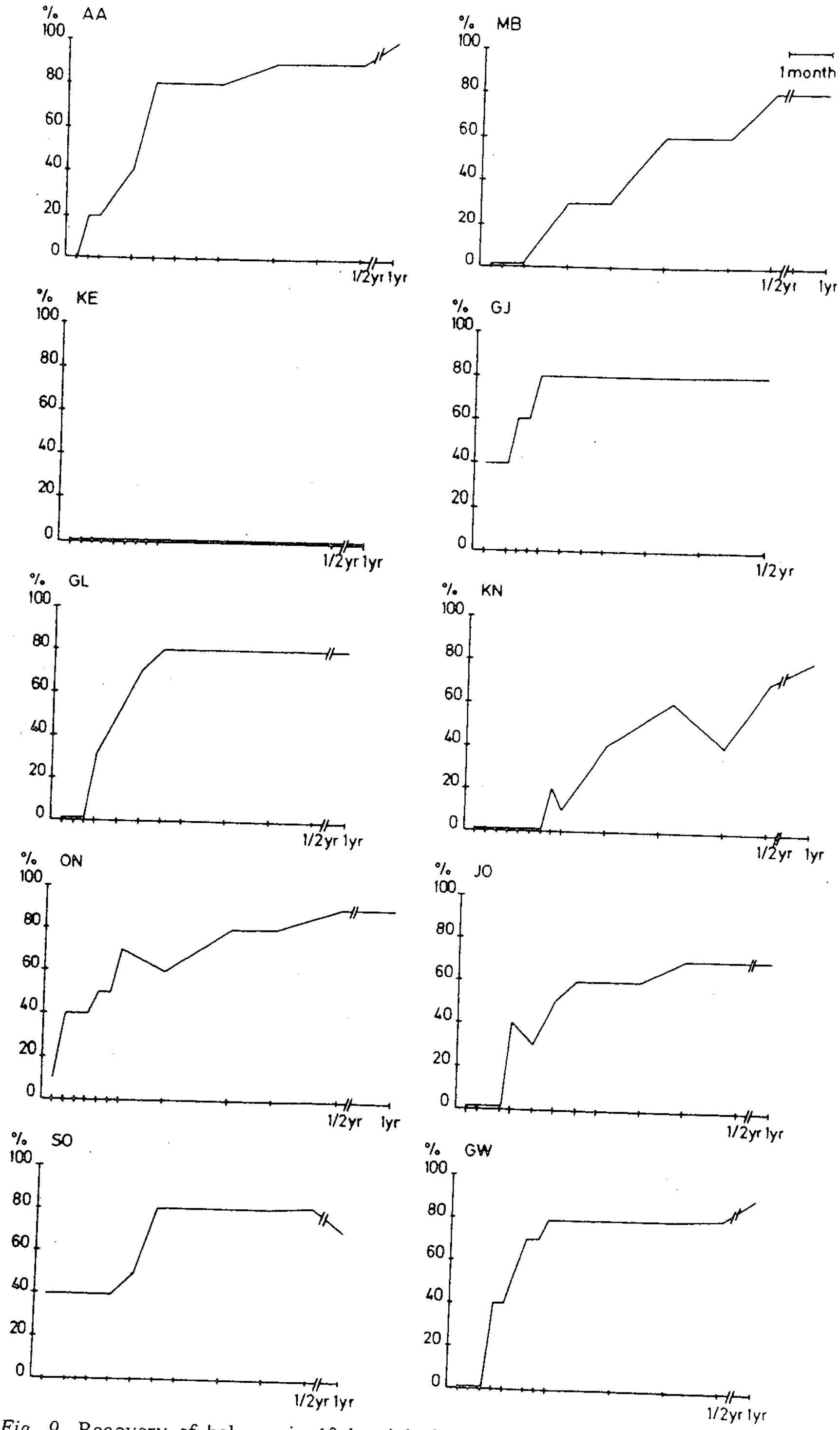

Fig. 9. Recovery of balance in 10 hemiplegic patients. Along the Y-axis, the measured quality is given as percent of maximum obtainable score.

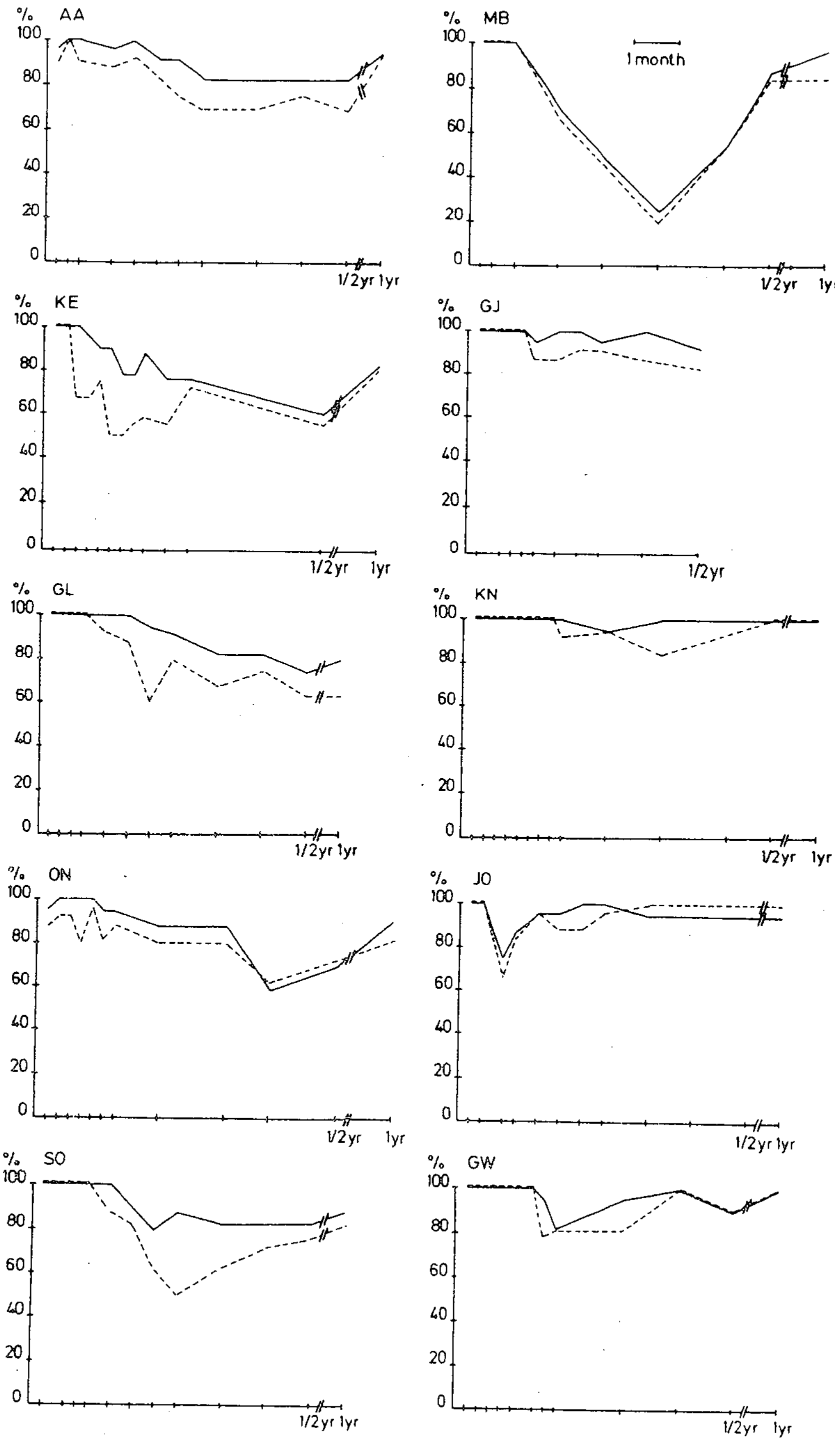

Fig. 10. Occurrence of joint pain and decreased passive range of joint motion in 10 hemiplegic patients. Values are expressed as percent of normal: (Full range of motion and absence of joint pain (Y-axis)). Along the X-axis the follow-up investigations are indicated. —: passive range of motion; - - -: occurrence of joint pain at passive range of motion manoeuvres.

detailed study on the order of development of stages II, III, and IV of the motor behaviour.

Although in a further study (37) we have found that a significantly high degree of correlation exists between the ADL-capacity and the motor function evaluated according to the principles here described, the ADL-testing does not, as such, given an adequate, reproducible picture of the neuromotor and articular properties of the patient, as the ADL may also reflect the patient's psychological and social adjustment and, furthermore, the adequacy of rehabilitation. On the other hand, the described system for reproducible and standardized evaluation of the motor function, balance, qualities of sensation, and joint function only gives a survey of the patient but does not give complete information for physiotherapists and occupational therapists for a detailed treatment plan. In this context it is interesting to note that Hughes (34) recently pointed out the need for a reproducible system of evaluation and specifically thought that the Brunnström method of evaluation, whichever type of treatment the patient was given, seemed to be the most adequate.

Physical treatment aiming to improve the hemiplegic patient's motor behaviour must, in our opinion, be based on aspects of motor development; but in the actual treatment situation the physiotherapist and the occupational therapist must keep in mind the influence on muscle tone exerted by changes in postural and psychological (6) stimuli. This standardized assessment of motor function is confined to stereotyped positions and should not result in a stereotyped treatment.

We have found that the motor behaviour can improve even when more than half a year has elapsed post-stroke. Thus, although for most hemiplegic patients the major part of motor recovery takes place within the first months post-stroke, further improvement may still be expected. This indicates that, in order to obtain optimum functional independence for the patients who have not yet fully recovered motor and joint function, they should be followed for an appreciable length of time post-stroke so that relevant measures of rehabilitation can be taken.

If more than about one week post-stroke the motor behaviour is at a low developmental stage in both extremities, there is a high correlation between the development of motor behaviour in the shoulder-arm and in the leg. In most cases, also, the recovery of function in the wrist rather closely follows the general pattern of improvement. Even if the recovery of motor function in the upper extremity often lags somewhat behind that of the lower extremity, the former will usually eventually recover to nearly the same stage as that of the leg.

Although the spontaneous recovery of motor function in hemiplegic and/or hemiparetic patients may make it difficult to interpret the effect of different physical re-education methods, it seems clear that the occurrence of joint pain and contracture is related not only to deficiency in motor behaviour, but also to the intensity of medical care. As both pain and contracture may influence the motor recovery, it should be underscored that joint pain usually is the precursor of decreased joint motion.

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Key words: Stroke, hemiplegia, reflexes, spasticity, motor behaviour, joint function

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