PARALYSIS IN FLEXION AND TREMOR IN THE MONKEY FOLLOWING CORTICAL ABLATIONS*

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INTRODUCTION

Paralysis with flexion attitude, spasm and contracture in the lower extremities, is well known in injury or disease of the spinal cord. Clinically cerebral lesions inducing flexion paraplegia have been described by Demange,4 and others 1,6,10,11,12,13,14. The syndrome occurs with extensive degenerative cerebral disease, most frequently of arteriosclerotic origin. Marie and Foix11 and Alajouanine1 have emphasized lesions in the paracentral lobules and subjacent white matter. Verhaart13 has stressed lesions of the central gyri and frontal lobe, and, in one patient, attributed the flexion pattern to decerebration above the red nucleus.14 The lesions are often diffuse and Herman’s attempt to localize the significant one in his case was impeded by too numerous and extensive arteriosclerotic changes.6 This subject has been recently reviewed by Daniels.2 Unilateral flexion paralysis sometimes results from capsular hemorrhage15 and Holmes and Sargent8 described flexion spasms of the legs in a number of patients with the sagittal sinus syndrome.

Few experimental observations have been recorded. Alajouanine1 produced paraplegia in flexion in the dog by bilateral, midline cortical ablations. Hines7 noted permanent shortening of the hamstring muscles following unilateral ablation of areas 4 and 4s in monkeys. Walshe16 correlated extensor tonus following cord injury with damage to the pyramidal tract, and flexor reflex exaggeration with more extensive lesions involving extrapyramidal tracts as well. Flexion of the extremities, however, is not remarkable following unilateral or bilateral seriatiim ablations from area 6, the principal extrapyramidal region of the cortex. This paper describes the experimental production of flexion paralysis in monkeys by simultaneous extirpation of area 6 (including its mesial surface) bilaterally.

Tremor, which appeared also in these animals, has been previously noted as occurring in monkeys with bilateral lesions of area 69. The augmentation of the involuntary movements associated with cerebellar destruction5 and with basal ganglia lesions9 by additional removal of area 6 has been discussed.

MATERIALS AND METHODS

Four adult sooty mangabey monkeys (Cercocebus torquatus atys) were used in these experiments. Operations were performed by accepted neurosurgical techniques and postoperative

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Observations were made daily at first and at intervals of two or more days as the animals' neurological status became more nearly static. Gross and microscopic examination of the nervous system was carried out post mortem.

This phenomenon of paralysis in flexion was observed, by chance, in an experimental study of spasticity. These four animals which developed flexion paralysis were compared with a group of other monkeys with cortical lesions elsewhere, which showed paresis, either spastic or flaccid, without the flexor attitude in the lower extremities.

**EXPERIMENTAL DATA**

Abstracts of the protocols of the experimental animals follow.

**Experiment 1. (R.S. 28)** Male sooty mangabey age ca. 4 yrs. (wt. 6.8 kg.). Bilateral ablation of areas 6 and 4s. Immediate flexion paralysis. Death on 2nd postoperative day from trauma.

*Operation May 14, 1943.* Under sodium amytal anesthesia a large bone flap was reflected and a bilateral ablation of area 6 and the greater part of area 4s was performed.

*Postoperative Notes. 1st day.* During the night the animal had opened the operative incision by pulling its head against the cage side and the bone flap had been displaced. It was quite drowsy and lay in its cage with legs and arms tightly flexed, grasping the cage side with both hands. The opening was repaired and sulfathiazole was dusted into the wound.

*2nd day.* The animal went rapidly downhill and died.

*Autopsy.* Lacerations of the pole of the right temporal lobe and of the left parietal cortex were found. There was no gross evidence of meningitis. The convolutions were somewhat flattened. Other organs were grossly normal.

**Summary.** Reflex grasp, paresis and flexion pattern appeared bilaterally immediately after operation. No other observations were possible because of postoperative cortical trauma.

**Experiment 2. (R.S. 29)** Male sooty mangabey (wt. 6.8 kg.). First operation: Bilateral ablation of areas 6 and 4s. Paresis in flexion and tremor of all four extremities. Second operation: Ablation of left areas 2, 5 and 7. Contralateral temporary diminution in spasticity.

*First Operation May 20, 1943.* A large bone flap was reflected and a bilateral ablation of area 6 and the anterior part of area 4s was performed.

*Postoperative Notes. 2nd day.* The animal lay on its belly with both thighs flexed, adducted and internally rotated. The knees were partially flexed. There was piloerection, immobility of the face, slowness of movement and reflex grasp in all extremities. A fine tremor accompanied movement.

*4th day.* There was little change. Voluntary movement was performed only grossly in the arms and was greatly impeded by reflex grasping. Posture was unchanged except that the animal was lying on its side. Resistance to passive extension was increased slightly in both legs; tremor continued.

*Interval Note.* On the 5th day alternating movements of the legs were performed when the animal was supported and dragged along the floor but these soon disappeared. It could neither stand nor walk and the flexed posture of the legs was maintained. Atrophy rapidly appeared in the legs. Knee jerks were equal and active and forced grasp and Rossolimo were present bilaterally. Resistance to passive movement was increased in all extremities but this was slight in the legs and on extension only. Tremor continued.

*Second Operation June 2, 1943.* The bone flap was reopened and areas 2, 5 and 7 were removed from the left side.

*Postoperative Notes. 2nd day.* Posture and movement were essentially unchanged. Resistance was met in trying to extend the legs and to flex and extend the arms. The resistance was more marked on the left side.

*5th day.* The animal lay on the floor of the cage and could neither stand nor sit up. Posture was unchanged. Resistance to passive manipulation was marked in all extremities and was most marked on the left side. Only grasping movements were performed by the hands.

*8th day.* There had been no change.
10th day. The difference between the two sides was still definite but much less marked. There was extreme resistance to extension of the legs. Atrophy was severe.

14th day. Resistance had equalized again and was extreme against extension in the legs. There was tremor accompanying movements of the arms and moderate resistance in the arms. Placing responses had returned and the animal could grasp quite well with the toes but movements of the leg and thigh were not observed. Flexion in the lower extremities remained. On this day it was killed because of diarrhea and because it had developed pressure sores on its legs.

Autopsy. Nothing unusual was found in any of the viscera. There were numerous decubitus ulcers on the legs. The brain weighed 114.5 gm.

Anatomical Notes. The frontal lesions bilaterally were confined to the gray matter of areas 6 and 4s and extended to the cingulate gyrus in the midline. Adjacent cortex was not involved in the ablation or by secondary changes. The corpus callosum had been injured by the right ablation. The basal ganglia were grossly intact. The parietal lesion on the left did not involve area 4 or subcortical structures. Subsequent histological examination confirmed these findings. It further revealed scattered and sparse, but definite degeneration in the sciatic nerves.

Summary. A large male mangabey, following bilateral removal of areas 6 and 4s, showed reflex grasp, increased resistance to extension of all extremities and a posture of flexion, adduction and internal rotation of the lower extremities and flexion of the upper extremities. Posture was not altered by the removal of left parietal areas two weeks later but extension resistance on the right seemed slightly diminished temporarily. Tremor occurred in all four extremities on movement or on static maintenance of posture.


Operation April 26, 1943. A large bone flap was reflected under amytal anesthesia and a bilateral excision of area 6 and the anterior part of area 4s was performed.

Postoperative Notes. 1st day. The anterior portion of the operative incision had been broken while the strong reflex grasp pulled the animal against the cage; this was repaired. Later in the day it was observed that although alert, he could not right himself or stand.

2nd day. The animal lay on its left side with both legs flexed at the knee and thighs flexed upon the abdomen. The arms were partially flexed and the fists clenched. No voluntary movements of arms or legs occurred. Resistance to extension was present in the arms but the legs could be moved freely.

6th day. The picture was unchanged except that resistance to passive extension of the lower extremities was now increased. The knee jerks were 2+.

7th day. Gross voluntary movement of the arms was manifest and resistance to passive extension of the legs seemed most marked on the left. The flexion, adduction and internal rotation in the lower extremities were maintained. Fine tremor was present with movement.

Subsequent Course. Great atrophy occurred in the legs and hyperflexion continued. Knee jerks were 4+ bilaterally. Resistance to passive extension became extreme as did atrophy. Tremor on movement continued.

24th day. The animal was sacrificed and autopsy was performed. Decubitus ulcers were present on both buttocks and the extensor surface of the legs.

Anatomical Note. On the surface and on section of the brain nothing except the operative lesions were seen. These were confined to areas 6 and 4s. There was no involvement of subcortical structures. Histological examination confirmed these findings. In the cord, slight degeneration was found in the pyramidal tracts.

Summary. Following bilateral ablation of areas 6 and 4s this adult mangabey showed limited patterns of movement. There was reflex grasp and tremor; flexor posture of the arms; flexion, adduction and internal rotation of the legs, increased resistance to extension of both arms and legs and extreme atrophy of the legs.

Experiment 4. (R.S. 35) Maturing female sooty mangabey (wt. 4.15 kg.). First operation: Bilat-
eral ablation of areas 6 (mesial part). Flexion paresis with partial recovery. Second operation: Ablation of left areas 3, 1, 2 and 5. Little change.

First Operation July 21, 1943. Under amytal anesthesia a large bone flap was reflected and midline ablations of the mesial part of area 6 were made bilaterally.

Postoperative Notes. 1st day. The animal lay, ventral side down with all extremities flexed, the thighs adducted and internally rotated. Food could not be carried to the mouth; standing and walking could not be performed. Forced grasp was present in all extremities; knee jerks were active. All extremities showed increased resistance to passive extension.

2nd day. There was no change except that resistance to passive flexion as well as extension was now present in the legs.

4th day. A pressure sore had appeared on the left knee and resistance to passive movement of that leg was greater than on the right.

6th day. The animal was now able to move its toes when the dorsum of the foot was brought in contact with the under surface of the table-top (placing response)^2.

13th day. Movements in the upper extremities had improved. Resistance to extension of the legs was extreme.

Interval Note. During the next two weeks movement in the upper extremities showed further improvement; movement was observed in the toes more frequently; the animal sat up, walked clumsily with a scissors gait and finally began to climb.

Second Operation August 18, 1943. The left postcentral gyrus was excised under amytal anesthesia through the old bone flap.

Postoperative Note. 1st day. Posture and movement were but slightly changed by operation. No change occurred until time of death.

September 28, 1943. The animal was sacrificed and autopsy was performed.

Anatomical Note. Brain weight: 93.1 gm. There were bilateral midline lesions of area 6 extending neither into area 4s nor the lateral part of 6a. The corpus callosum was injured in the depths of the excavations. On the left there was ablation of the postcentral gyrus. Marchi sections showed moderate degeneration in pyramidal tracts of the cord.

Summary. Following simultaneous bilateral ablation of the medial part of area 6 this animal showed extreme paresis in all extremities, inability to stand or walk, flexion of all members and adduction and internal rotation of the thighs. Forced grasp was present, knee jerks were active. After the left postcentral gyrus was removed there was but slight change.

DISCUSSION

A brief examination of some features of this syndrome reveals several significant points.

1. Onset. The attitude of flexion, adduction and internal rotation in the lower extremities became manifest as soon as the animal recovered from anesthesia and thus may be considered immediate in onset. This observation is important in considering the genesis of the flexion reflex pattern because it is not in harmony with the view that the posture represents a bilateral flexion reflex caused by painful pressure sores. The latter may, however, be operative in maintaining or accentuating the flexion after it has been established. Contractures, also, can have no part in development of this posture.

2. Involved Muscles. The adductors and flexors of the arm, the flexors, adductors and internal rotators of the thighs and the flexors of the legs were the muscles that showed contraction. Attempts passively to extend arms and legs were met with increased resistance. All extremities were paretic but the legs were more severely involved than the arms. The pattern was not modified by the position of the animal since it was present when the animal lay
on its belly or on either side, when held in the sitting posture, or when sus-
pended. It was not, therefore, the mechanical result of position in space.

3. Tremor. Voluntary movement of the extremities was accompanied by
coarse tremor, accentuated by excitement. This occurred without damage to
subcortical gray matter and must therefore be attributed to cortical injury.
It was as marked in No. 4, in which only the mesial part of area 6 was re-
moved, as in the other three animals. Tremor is mentioned here as another
instance of its appearance after a purely cortical lesion and it in no way dif-
fered from the tremor described elsewhere following *seriatim* removal of these
same areas in monkeys and chimpanzees.9

4. Atrophy. Muscular atrophy in the lower extremities was early in onset
and extreme in degree. It was more severe than that seen in spastic paralysis,
following unilateral removal of area 6, but can be accounted for by the al-
most complete immobility of the legs in the present instance. The early de-
generation found in one sciatic nerve examined might also be a contributing
factor in the atrophy. Its cause is unknown, but it could be due either to
nutritional defect or to pressure.

5. Recovery and Residue. A notable feature of the flexion paralysis syn-
drome as produced in these experiments is that movements of the toes and
feet reappeared while legs and thighs still remained flexed and immobile.
The one animal that regained the use of its legs was left with residual flexion,
adduction and internal rotation and walked, as a result, with a peculiar gait,
knees together and feet apart.

6. Reflexes. As would be expected, forced grasp occurred in all extremities
and Hoffmann’s and Rossolimo’s signs could be elicited. Knee jerks were
normal or, more frequently, hyperactive. The latter suggests that increased
extensor activity, was present but masked or overpowered by great flexor
overaction.

The reflex grasp, present in all four extremities, was in most respects
similar to that described by many previous authors as the result of damage
to area 6.5 There are, however, several characteristics usually associated with
reflex grasping which did not appear here. When reflex grasping occurs as the
result of bilateral removal of *areas 4 and 6* it appears as a reflex flexion of the
fingers and toes which is clearly affected by change in the position of the
animal with respect to gravity. There is always then a relative increase in
the reflex grasp in uppermost hand and foot and a decrease in undermost.
This is accompanied by a relative extension of the undermost and flexion of
the uppermost extremities. Although the grasp itself was thus modified in
the present animals, there was little or no change in the flexion posture or in
resistance to passive manipulation as a result of change in space. Also, al-
though the reflex grasp was transitory, as it always is from lesions of area 6,
the flexor posture was maintained in the two animals which lived long enough
beyond the time when reflex grasping had disappeared.

It is to be expected, from existing knowledge of the specific functions of
area 6, that postural changes and reflex grasp should be greatest when there
is a *simultaneous bilateral* extirpation because of the known bilaterality of function of this region. That the marked flexor posture had not been observed following *seriatim* ablation of area 6 may be due to the recovery of function that takes place between two such operations.

In this connection the relation of the midline tissue of area 6 should be stressed and *Experiment 4* cited. In the first three experiments an effort was made to remove all of area 6 including the tissue from the midline surface to the cingulate sulcus. When the striking picture of flexion and tremor appeared in three successive animals with this lesion it was felt that a smaller lesion might have the same effect. Therefore, in Experiment 4, only the

![Brains of two monkeys. Left shows ablation of mesial part of area 6 and left postcentral lesion (Expt. 4). Right shows bilateral removal of area 6 (Expt. 3).](image)

mesial portions of the lateral surface of area 6 were removed together with all tissue to the cingulate sulcus (Fig. 1). In this animal the tremor and flexor postures were as marked as in the other three, except that the paresis was less extreme, thus enabling the animal in the space of a few days to walk about.

Indications are then, from these experiments, that the strong flexor posture accompanied by forced grasping is produced by lesions of the mesial surface, and that ablations here more greatly influence flexor posture than paresis. The posture may in this connection be thought of as a part of the complex reflex pattern of involuntary grasping.

The tendency to maintain a flexed posture may be compared with the extensor tendency seen in decerebrate rigidity. Both are so strong that they overcome, in part at least, all stimuli which would otherwise produce
changes in postural pattern such as righting. By the addition of area 4 to ablation of area 6 an equalization of extensor and flexor mechanisms is produced, because the monkey following bilateral removal of areas 4 and 6 not only develops changes in resistance to passive flexion and extension with change in position in space, but also has a spasticity in which resistance is more nearly equivalent in the flexors and extensors.

SUMMARY

1. Simultaneous bilateral removal of areas 4 and 6 produced paresis in flexion in four mangabey monkeys.
2. This was associated with reflex grasping and with increased resistance to passive manipulation in all extremities, greater on extension than on flexion.
3. Tremor, coarse and present on movement, occurred as the result of this purely cortical lesion.
4. It is suggested that the reflex flexion pattern is an extrapyramidal release phenomenon and that it is functionally related to the pattern of reflex grasping.

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