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Original Article

Brain Death-Associated Reflexes and Automatisms

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Abstract

Background: In several instances, the diagnosis of brain death has been questioned due to the presence of movements. This case report and review of the literature illustrates the spectrum of movements that have been encountered in brain death.

Methods: A case report and review of the literature on movements seen in brain death was conducted.

Results: Movements in brain death are common and have a wide range of phenomenology. Several movements wax and wane over time, making movements in brain death difficult to classify. In addition, varying terminology has been used (e.g., Lazarus sign, spinal man, spinal reflexes, spinal automatisms). Although evidence points to a spinal origin for such movements, the pathophysiology in many cases remains speculative. Characteristics of movements in brain death have been identified that can help differentiate them from brainstem or voluntary origin.

Conclusions: Based on our review, we suggest referring to stimulus-provoked movements as reflexes and spontaneous movements as automatisms. We propose using the terms *brain death-associated reflexes* and *brain death-associated automatisms* as two main categories for movements that occur in brain death. These terms do not imply a specific pathophysiology, but consistent clinically oriented nomenclature may be useful when reporting such phenomena.

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Background

Brain death is defined as the permanent absence of cortical and brainstem function. The growth of critical care has contributed to the need for accurate and timely diagnosis of brain death. Occasionally, certain movements may raise the possibility of persistent brainstem function, such as the spinal cord-generated endotracheal suction-thoracic contraction reflex that can mimic a cough reflex. We present an illustrative case report and review the literature on the spectrum of movements observed in the setting of brain death. To improve clarity in reporting, we also suggest a consistent nomenclature for these movements.

Methods

A retrospective review of handwritten and electronic records of a patient with motor activity in the presence of brain death was conducted, followed by a review of the literature. The Institutional Review Board of The Cleveland Clinic Foundation approved this study.

Case Report

A 41-year-old man presented with dyspnea and hypoxia after 1 week of cough, pleuritic chest pain, nausea, and vomiting. Pulmonary embolism was suspected, and he was anticoagulated with intravenous heparin. Shortly thereafter, he developed asystole and ventricular fibrillation. He was resuscitated after 15 minutes but again developed asystole. Echocardiography demonstrated a large pericardial effusion, and a pericardiocentesis was immediately performed. Return of spontaneous circulation occurred after 23 minutes.

Neurological examination found him to be intubated and comatose. He had spontaneous and frequent eye opening that was not stimulus sensitive. Pupils were minimally reactive bilaterally. Eyes were straight ahead with no movement with oculo-cephalic maneuvers. Corneal and gag reflexes were absent, although he was breathing spontaneously above the set ventilator rate. There were no limb movements to painful stimulation. He had myoclonic jerks of the face and body, with bilateral lower extremity adductor myoclonic movements. Muscle stretch reflexes were present in the upper extremities and absent in the lower extremities. Babinski sign was absent. A brain computed tomography scan showed effacement of the basal cisterns consistent with early brain edema.

Later that day, the patient again developed ventricular fibrillation terminated by countershock. Echocardiography showed a small residual pericardial hematoma. The next day, the patient had fixed and dilated pupils and bilateral papilledema. He had no spontaneous respirations and no brainstem reflexes, fulfilling brain death criteria. Motor examination demonstrated triple flexion of the lower extremities. In the upper extremities, noxious stimulation of the right arm resulted in ipsilateral flexion at the elbow and supination of the arm, bringing the forearm to rest on the patient's abdomen. Minute flexion and extension movements occurred spontaneously in the toes. These movements persisted for 5 days after the anoxic event. Electroencephalography revealed electrocerebral silence.

Review of the Literature

History

Movements occurring in the setting of death have been noted for centuries. During the French Revolution, body movements among the beheaded, such as eyelid and jaw contraction, were frequently observed. The guillotine usually cut through the lower part of the fourth cervical vertebra *(1)*. Brain death was formally defined in 1968 as the irreversible loss of cerebral and brainstem function *(2)*. At that time, the presence of any spontaneous or reflex movements invalidated the diagnosis. Since then, several other criteria have been published that account for brain death-associated motor activity *(3)*.

Most of the literature on this subject includes case reports or small series. A summary of the literature is provided in Table 1. Major difficulty in discussing such movements is the lack of consistent terminology or categorization. Discussion could be organized in terms of phenomenology, time of appearance after brain death, pathophysiology, or phylogentically. We chose to organize our review by phenomenology, because this category is the least speculative and would likely be of most clinical use. We then briefly discuss time of onset and pathophysiology.

When describing movements in the presence of breath death, there can be linguistic challenges *(1)*. Once a patient is declared brain dead, some have argued it is inappropriate to continue to use the term "patient." In the literature, terms include "heart-beating cadavers" *(1)*, "spinal man" *(4)*, and "brain dead body" *(5)*. In this review, we prefer the simple term of brain dead body.

Epidemiology

Ivan retrospectively reviewed 52 brain dead bodies and found muscle stretch reflexes in 35%, plantar flexor responses in 60%, plantar withdrawal in 35%, and abdominal reflexes in 75% *(6)*. In the same year, Jorgensen introduced the term "spinal man" in reference to such phenomena *(4)*. In his series of 63 brain dead bodies, he found a withdrawal response in the lower limbs in 79%, and muscle stretch reflexes in 49% of upper extremities and 33% of lower extremities. Jorgensen first described extension and pronation of the arm in response to cutaneous stimulation, seen in one-third of brain dead bodies.

Saposnik and coworkers prospectively evaluated spontaneous and reflex movements in 38 brain dead bodies *(1)* through noxious stimuli to the sternum, four limbs, and supraorbital area; neck flexion; tactile simulation to the palms of hands and soles of feet; and elevation of four limbs. Thirty-nine percent of brain dead bodies had either spontaneous or reflex movements. These movements were observed mainly within the first 24 hours after declaration of brain death and consisted of spontaneous jerks of the fingers, undulating toe flexion, triple flexion, unilateral facial myokymia, "Lazarus sign," upper limb pronation/extension reflex, and flexor plantar response. In another study, Dösemeci and coworkers found similar spinal reflexes in 18 of 134 brain dead bodies (13.4%) *(7)*. Saposnik and coworkers reported movements in 47 out of 107 brain dead bodies (44%) *(8)*.

Conci and coworkers looked at 25 brain dead bodies during kidney removal with a mean time on the ventilator before nephrectomy of 31 ± 6 hours *(9)*. Abdominal muscle contraction was noted in 60% of brain dead bodies when the parietal peritoneum was cut. Twenty-four percent had sudden changes in blood pressure and heart rate during the incision. No response was seen to bowel manipulation.

Patterns of Motor Activity

Movements that have been studied in brain dead bodies are numerous. What follows is not intended to be a comprehensive listing of all movements documented in brain death. Rather, patterns of well-documented motor activity in the presence of brain death are summarized. This summary includes polysegmental spinal reflexes and automatisms, "Lazarus sign," undulating toe sign (undulating toe flexion movements), eyelid opening, respiratory-like movements, head turning, pseudodecerebrate posturing, facial myokymia, eyelid opening, abdominal movements, upper and lower facial movements, eyelid and tongue myoclonus, and spinal myoclonus.

Spittler and coworkers focused on systematically describing polysegmental spinal reflex patterns and polysegmental spinal automatism patterns in brain death *(5)*. They categorized spinal movements as monosegmental muscle stretch reflexes, oligosemental cutaneo-muscular reflexes, polysegmental spinal reflex patterns (PSRPs), polysegmental spinal automatism patterns (PSAPs), and "Lazarus sign."

Spittler et al. examined 235 patients on 278 examinations for brain death. Interindividual and intraindividual phenomenological variability was noted. Thus, the authors set out to distinguish characteristics by which PSRPs and PSAPs can be differentiated from voluntary or brainstem-generated involuntary movements. They assigned the loss of pupillary light reflex as the start of the brain death process and loss of the cough reflex the completion of the brain death process.

Spinal movements were observed on 42 occasions in 27 of the brain dead bodies. Up to five distinct spinal reflexes were observed in a single body. Thirty-one different spinal reflexes

Table 1
Brain Death-Associated Movements

Movement	*Description*	*Onset after BD dx*	*Age, sex (M/F)*	*Source (no. of subjects)*	*Automatism or reflex*[a]
Lazarus sign[b]	Seems to be grasping for endotracheal tube: one or both arms flexed at elbows with hands brought to chin or face and then returned to the bed beside the body; reported spontaneously, during apnea testing, and with neck flexion during transcranial doppler examination	0–2 days	26/67 M/F	Heytens et al. (1)[14] Ropper (5)[15] de Fretas et al. (4)[10] Urasaki et al. (1)[11] Turmel et al. (2)[12] Jastremski et al. (1)[13]	Automatism and reflex
Undulating toe	Slow flexion/extension movements of toes, spontaneous or elicited by tactile/noxious plantar stimulation	NA	NA	McNair et al. (3)[24] Saposnik et al. (25)[8]	Automatism and reflex
Unusual facial movements	Flaring of alae nasi	NA	14 M	Rodrigues et al. (1)[18]	Automatism
Extensor posturing	Asymmetrical opisthotonus (back arching to left or right spontaneously)	2 days	51 M	Heytens et al. (1)[14]	Automatism
Facial myokymia	Intermittent repetitive undulating muscle contractions of left cheek	NA	54M	Saposnik et al. (1)[1]	Automatism
Spinal myoclonus	Multifocal myoclonus involving lower limbs and abdominal muscles lasting 15 hours, bilateral and asymmetric, causing the body to jump over the bed	6 days	56 M	Fujimoto et al. (1)[19]	Automatism
Respiratory-like movements	Both shoulders adduct and slow cough-like movements minutes after respirator removal	35 minutes	67 F	Urasaki et al. (1)[11] Ropper (5)[15]	Automatism
Hugging-like motion	Sudden hugging-like motion with both arms and flexion of the trunk to 30° for a few seconds	NA	NA	Aranibar (1)[20]	Automatism
Decerebrate-type movements	Spontaneous decerebrate type movements in all four extremities	24 hours	35 M	Jastremski et al. (1)[13]	Automatism
Eyelid opening	Left or bilateral eyelid opening with noxious stim to ipsilateral nipple	24 hours	57 M	Friedman (1)[21]	Reflex
Head turning	Inconsistent extension of both upper extremities at the elbow and wrist after noxious stimulation; head intermittently turns from side to side for 10–30 seconds with passive neck flexion, extension, or sternal rub	4 days	42 M	Christie et al. (1)[22]	Reflex
Decerebrate-like posturing with mechanical ventilation	Symmetric movements lasting 5 seconds in both arms with hyperpronation and forearm extension, wrist flexion, metacarpophalangeal joint extension, and interphalangeal joint flexion synchronously triggered by insufflation of mechanical ventilation and by superficial pressure or noxious stimulation to the arms, thorax, or abdomen	Immediate	30 F, 11-month-old boy	Marti-Fabregas et al. (2)[23]	Reflex
Limb elevation with neck flexion	A rapid jerk raising all four limbs off the bed 0.5–8 inches with passive neck flexion	NA	NA	Ropper (5)[15]	Reflex
Viscero-somatic reflex	Contraction of the abdominal musculature after parietal peritoneum was cut during organ harvest	Immediate	15–61, M and F	Conci et al. (15)[9]	Reflex
Other studies					
Spinal reflexes and automatisms	31 different reflexes and 4 automatisms in 11% of 235 BD bodies	NA	NA	Spittler et al. (27)[5]	4 automatisms and 31 reflexes
Spinal reflexes	7 different reflexes in 79% of 63 BD bodies	0–72 hours	NA	Jorgensen (50)[4]	Reflex
Spinal reflexes	7 different reflexes in almost 75% of 52 bodies	0 hours	NA	Ivan (~39)[6]	Reflex
Spinal reflexes	6 different reflexes in 13% of 134 bodies	0–72 hours	NA	Dösemeci (18)[7]	Reflex

NA, not available.

[a]Reflexes are defined as movements elicited by a defined stimulus, and automatisms are spontaneous movements.

[b]The term Lazarus sign was not used in all published material. We listed studies in this category if the cases matched the phenomenology described. Features associated with the Lazarus sign include occuring with apnea test (2–8 minutes after vent disconnected), hypertension, hypotension, tachycardia, facial flushing, gooseflesh on arms and trunk, and shivering extensor movements.

Source reference numbers indicated in superscript.

and four different spinal automatisms were documented. When discussing their findings, Spittler et al. stated, "The variable elicitation mechanisms and the different patterns of reflexes and automatisms make a systematical classification difficult: A uniform registration even of latency and duration for all forms of reflexes is not feasible and in cases of automatisms is impossible" *(5)*. Dösemeci and coworkers described spinal reflexes which included the Lazarus sign, flexion of the arms with abduction of the shoulders, extension at the arms and shoulders, and flexion of the arms and feet. The most common movement they reported was finger and toe jerk *(7)*. Saposnik and coworkers found undulating toe flexion movements to be the most common, seen in 23% of brain dead bodies *(8)*.

Spittler et al. noted wide interindividual variation, and most patterns were observed in only one body. However, salient characteristics of polysynaptic spinal reflexes and automatisms were found, which can be useful when attempting to rule out brainstem activity. Spinal movements were found to have stereotypical elicitation upon a trigger of limited variation, constant pattern of latency and duration, habituation with frequent triggers (refractory period), no habituation with slow sequence of triggers, similarity of reflexes and automatisms, and a monotone stereotyped course of the motor pattern. Well- documented brain death movement patterns are summarized in Table 1.

Timing of Movements in the Course of Brain Death

Although most movements are observed within the first 24 hours after the declaration of brain death, the timing can be highly variable (hours to days). The timing of brain death is defined by the time a clinical brain death exam fits accepted criteria, which may be seconds, minutes, hours, or days after physiological brain function has ceased. Jorgensen made the observation that those who lost spinal reflexes and regained them did so within 6 hours *(4)*. This timing occurred with the flexion-withdrawal response first, followed by the cremasteric and abdominal reflexes, and then muscle stretch reflexes. The delayed appearance of spinal reflexes was invariably associated with severe arterial hypotension. Dösemeci noted that all spinal reflexes were seen during the first 24 hours after brain death was confirmed and remitted by 72 hours *(7)*. Undulating toe flexion movements are more likely to be seen in the first 12 hours after the diagnosis of brain death *(8)*.

Pathophysiology

The spinal cord is the putative source for movement of the brain dead body. Various mechanisms have been proposed for these movements. Conci and coworkers proposed that spinal reflexes are present in brain death if the ischemic lesion is above C1–C4 *(9)*. Within the spinal cord, neuronal networks exist that serve as central generators for specific motor patterns *(1)*. Corticospinal and rubrospinal tracts located in the lateral funiculus control distal portions of the limbs. Vestibulospinal and reticulospinal tracts modulate tone and posture, contributing to synergistic movement of an entire limb. Supraspinal disconnection of these tracts may increase their excitability at the spinal level, resulting in spinal movements emerging during brain death. However, this possibility has not been thoroughly studied, and the precise physiology is unknown.

Spittler and coworkers proposed that some spinal reflexes can be considered phylogenetically "old motor patterns," which may be set free when the cord is uncoupled from the "younger" input of the brainstem and neocortex. This perspective allows an orderly categorization of some observed phenomena. In this schema, spinal reflexes or automatisms that do not have an apparent evolutionary purpose can be understood as disintegration or irradiation of spinal circuitry. The temporal variability of the emergence of spinal reflexes has been explained by spinal shock that can be observed after brain death *(6)*.

Lazarus sign has been reported to occur spontaneously, after respirator removal, during apnea testing, in the setting of arterial hypotension, noxious stimuli, or passive neck flexion *(7,9–14)*. It has been thought to result from hypoxic stimulation of cervical spinal cord neurons functionally isolated from rostral brain areas. Supportive of this concept was the finding by de Freitas and coworkers of complex spinal reflexes in a subset of brain dead bodies with lower systolic blood pressures *(10)*. Mechanical stimulation of spinal roots, cord, or sensory neurons also may contribute to this complex movement *(15)*.

Hanna and Frank comment that automatic stepping is a spinal automatism that occurs in animals after transaction at the superior colliculus level and cite evidence that supports a spinal pattern generator for locomotion *(16)*. Stepping motions occur in patients before brain death when brain inhibition is released and transmission is continued in the ventral spinal cord and brainstem motor tracts.

Short-latency somatosensory evoked potentials have been recorded in the presence of upper and lower extremity movements during brain death *(8,11)*. During arm movements no responses were recorded on scalp electrodes except far-field components. The spinal N13 component was preserved. Auditory brainstem-evoked potentials were absent for both ears, demonstrating preserved spinal dorsal horn potentials in the presence of movements. Further evidence for such movements being spinal in origin comes from Saposnik and coworkers. In five brain dead bodies that had undulating toe flexion movements, SSEPs did not elicit cortical responses *(8)*. Urasaki and coworkers postulated that respiratory-like movements can be spinal in origin *(11)*.

Facial myokymia is a movement that has been studied by the orbicularis oculi reflex and facial nerve stimulation. When tested, the early and late components of the orbicularis oculi reflex were found to absent bilaterally, whereas peripheral nerve conduction was preserved. This finding suggests facial myokymia in brain death is due to muscle denervation *(2)*.

Discussion

Our review shows that movements in brain dead bodies are common and display a wide spectrum of phenomenology. The terms "automatism" and "reflex" have been used inconsistently, at times referring to the same movement. We suggest referring to stimulus-provoked movements as reflexes and spontaneous movements as automatisms. In the setting of brain death, we propose using the terms *brain death-associated reflexes* and *brain death-associated automatisms*. This terminology is clinically useful because all movements reported in brain dead bodies can be placed in one of these two categories.

Furthermore, it does not imply a particular mechanism, which remains speculative in some cases. Although primarily descriptive, these terms have important implications. Brain death-associated reflexes are stimulus provoked movements that do not contradict the diagnosis of death. Such movements may or may not be present during life. Thus, subsets of these reflexes include muscle stretch reflexes, abdominal reflexes, and plantar flexion. Likewise, brain death-associated automatisms are spontaneous movements that do not contradict the diagnosis of death.

Brain death-associated reflexes and automatisms can be time dependent, emerging or resolving depending on the time elapsed from the onset of brain death. If possible, it is important to determine the time elapsed from declaration of brain death to the onset of movements. Most reported brain stem-associated reflexes are no longer present 72 hours after brain death declaration. Certain characteristics are typical of movements in brain death that can help differentiate them from voluntary or brainstem-derived motor activity *(5)*. Evoked potentials may be helpful when the spinal origin of a particular movement is questioned *(11)*.

The diagnosis of breath death has evolved to incorporate the observations of brain death associated reflexes and automatisms. In 1995, the American Academy of Neurology established criteria for the diagnosis of brain death which included certain movements as acceptable findings *(16)*. These manifestations are occasionally seen and should not be misinterpreted as evidence for brainstem function:

1. Spontaneous movements of limbs other than pathological flexion or extension response.
2. Respiratory-like movements (shoulder elevation and adduction, back arching, intercostal expansion without significant tidal volumes).
3. Sweating, blushing, tachycardia.
4. Normal blood pressure without pharmacological support or sudden increases in blood pressure.
5. Absence of diabetes insipidus.
6. Deep tendon reflexes, superficial abdominal reflexes, triple flexion response.
7. Babinski reflex.

However, movements in the setting of brain death still cast doubt on the diagnosis *(7)*, resulting in consideration of confirmatory testing and prolonged treatment. When clinical criteria for brain death are met, the recognition of brain death-associated movements can reduce uncertainty of death and reliance on confirmatory testing. Greater awareness of such motor activity can reduce doubt for clinicians and provide an explanation for families in the difficult situation of witnessing brain death-associated movements.

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