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Franklin Delano Roosevelt: The Diagnosis of Poliomyelitis Revisited

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Abstract

Revisiting the ailments of famous historical persons in light of contemporary medical understanding has become a common academic hobby. Public discussion of Franklin Delano Roosevelt's (FDR) diagnosis of poliomyelitis after his sudden onset of paralysis in 1921 has received just such a revisitation. Recently, this 2003 historical analysis has been referenced widely on the Internet and in biographies, raising speculation that his actual diagnosis should have been Guillain-Barré Syndrome, a noncontagious disease of the peripheral nervous system rather than poliomyelitis. The authors of that 2003 analysis used a statistical analysis of his case by selectively choosing some of his reported symptoms. FDR's diagnosis of poliomyelitis, however, was fully supported by the findings of leading expert physicians of that time, who were very knowledgeable in the then-common disease and who periodically examined him during the period of 1921-1924. The most significant diagnostic features of polio are the absence of objective sensory findings in the presence of flaccid motor paralysis. These features are consistent with diagnostic criteria extant during the periods of major poliomyelitis epidemics as well as those of the Center for Disease Control 90 years later. Additional findings of fever, prodromal hyperesthesia, more severe residual proximal muscle weakness, and extensive lower extremity impairment requiring mobility with long leg braces or a wheelchair give further evidence for the diagnosis in FDR's case. Nonbulbar Guillain-Barré Syndrome, which shares the features of a flaccid paralysis and thus mimicking the initial presentation of poliomyelitis, has more than an 80% complete recovery with no reported cases of eventual wheelchair use. The most severe cases of Guillain-Barré Syndrome often have persistent objective sensory loss, associated with greater weakness in the feet and hands, which show no resemblance to FDR's impairment and disability. In light of the expert initial assessments by physicians completely familiar with the signs and symptoms of the then-common disease, review of his initial and subsequent disease course, and residual symptoms in comparison with those of Guillain-Barré syndrome, we find no reason to question the diagnostic accuracy of poliomyelitis and wish to put this debate to rest.

Introduction

In recent decades, the popularity of retrospective analysis of the medical history of historical figures has received significant public attention. Such efforts have been made by medical historians, general historians, and the media, and some of these efforts have become accepted widely [1]. One such example of this is the attribution of Marfan syndrome to Abraham Lincoln, which despite controversy, has received common acceptance [2-4]. Pertinent to this paper, it has been more than 90 years since Franklin Delano Roosevelt (FDR) experienced the onset of paralysis in the summer of 1921, but only in the past decade have the features of his illness, and the historical impact of his illness on disability and health care, been scrutinized systematically.

In the vein of retrospective diagnosis, a 2003 paper published in the *Journal of Medical Biography* analyzed some of FDR's clinical symptoms and course with the use of Bayesian statistical analysis of probability; the authors concluded that a more probable diagnosis than poliomyelitis was that of Guillain-Barré Syndrome (GBS) [5]. This paper has received considerable recent attention, even being referenced in the Wikipedia listing of FDR and his polio diagnosis [6], other Web site listings [7], a recent biography from James Tobin—a National Book Critics Circle Award historian [8], and referenced in the 2006 Pulitzer Prize—winning history, *Polio: An American Story* [9].

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Despite this current speculation, retrospective diagnosis has many limitations [1]. The authors of this paper have reviewed the missing critical pieces of information from that 2003 retrospective and will show how the inclusion of that data dramatically supports the conclusion that FDR contracted poliomyelitis and that his subsequent symptoms were classic for that disease.

FDR's Polio Diagnosis and Its Broad Repercussions

Papers by physicians regarding FDR's illness, restoration of function, and his founding of Georgia Warm Springs Foundation have written that his legacy has had a profound influence on the development of the medical specialties of orthopedic surgery [10] and physical medicine and rehabilitation [11,12]. The impact of his illness extended far beyond medicine, dramatically increasing public concern of poliomyelitis across the highly populated Northeastern and Midwestern cities of the nation, which had seen several epidemics during the preceding decades, including a major outbreak in New York City in 1916, the year in which the total number of national cases numbered 29,000 [9,13].

FDR's course of treatment was directed by his physician Robert Lovett, professor of surgery at Harvard and then the leading national expert on poliomyelitis. As his recovery progressed, FDR began to explore more effective treatments for the disease, in the process becoming an expert on the then-current state of the art of medical and rehabilitative care [14]. FDR, through his work with Lovett, became a believer in the value of warm water therapy. In 1924, FDR journeyed to Warm Springs, Georgia, at the invitation of his friend, the Wall Street banker George Foster Peabody, who was a part owner of a warm spring spa there [14]. Peabody had described to FDR the beneficial impact of those hot springs on a young man with polio.

While there, Roosevelt began a regimen of swimming 3 times a day, and by the end of that stay felt he had developed improved strength [11]. Newspaper reports of his improvements were published in the *Atlanta Journal*, producing a flood of national interest and visitors to the Warm Springs facility [11]. FDR became a tutor to the many polio survivors who came there, instructing them in exercises, and recorded the gains seen in these individuals for review by skeptical physicians [15].

Against the advice of his wife and financial advisors, FDR purchased the Warm Springs property in 1926, expanding its lodging capacity and facilities. In the process he created what was at that time the first comprehensive rehabilitation hospital, featuring physical, occupational, and recreation therapies, as well as bracing and orthotic care, and social services (Figure 1) [11]. By 1940, Warm Springs housed 400 residents in a truly architecturally accessible facility, the first in the nation [11]. FDR was a tremendous fundraiser for the facility, and his ascendency to the Presidency in 1932 only raised this visibility.

Figure 1. A day in the therapy pools in Warm Springs (1935). Photo courtesy of Warm Springs Vocational Rehabilitation Campus.

In 1938, he and his former law partner, Basil O'Connor, created a separate foundation to create a national program to combat polio, the National Foundation for Infantile Paralysis [11]. The Foundation and its very potent fund-raising arm, the March of Dimes, became "by a wide margin the single most popular medical cause in the post-war period" and was critical in funding the medical research that resulted in the creation of polio vaccines [16]. Roosevelt through his own experience and that of Warm Springs came to fully understand the role that comprehensive rehabilitation could play, not just in polio survivors but also in wounded veterans and civilians. In 1943, President FDR signed into law a bill creating the Office of Vocational Rehabilitation under the Federal Security Agency, creating comprehensive vocational rehabilitation programs for both veterans and civilians, each under different oversight structures [15]. The results of his illness were to have a profound impact not just on FDR's life but far beyond.

The Literature and the Controversy

Two papers authored by physicians in recent years have reported on FDR's immediate onset of paralysis, diagnostic considerations, and his progress through rehabilitation [5,17]. One of the papers questions the diagnosis of poliomyelitis and offers a rationale for the diagnosis of GBS based on a statistical interpretation of some of his symptoms and physical findings reported in letters and medical records [5]. That same paper states that "other etiologies of flaccid paralysis …were unknown," despite referencing Landry's ascending

paralysis as being mentioned in Lovett's 1916 textbook on poliomyelitis [5]. An extensive literature describing the signs and symptoms of acute ascending paralysis dates from at least 1859, the year Landry published his detailed report of an afflicted individual [18]. Westphal in 1876 described the differences between what he then termed "Landry's ascending paralysis" and poliomyelitis, and 4 years later, Leyden divided the t2 clinical entities as separate, both clinically and pathologically [19,20]. The existence of Landry's ascending paralysis (later to be labeled as GBS) certainly was known to expert physicians such as Lovett and Draper. The conclusions of that same paper questioning FDR's diagnosis of polio [5] have been reported in considerable detail in lay citations [6,8,9]. Although an effort to reexamine the evidence by calculation of probabilities based on interpretation of findings from letters and lay publications is interesting, it does not substitute for the accurate description and analysis by FDR's clinicians, who observed his illness firsthand and were preeminent experts in the disease. It fails the test of validity described by Karenberg in his paper on medical historiography. Karenberg states, "retrospective diagnosis…runs the risk of restricting the understanding of history to a biologic process. If done in this way it is abused" [21].

The findings and impression of those experts in poliomyelitis who examined and cared for FDR in 1921 felt the diagnosis of Roosevelt's paralysis was neither difficult nor seriously in question [22]. Dr Robert Lovett was the nation's foremost authority in the diagnosis and treatment of poliomyelitis and author of the definitive textbook on the disease [23]. In 1922 he published a definitive article in *JAMA* on the diagnosis and treatment of polio based on his personal study of 5100 patients for which he cared between 1916 and that date [24]. After his initial examination of FDR, Lovett wrote about FDR's diagnosis to another expert in both basic polio research and clinical care, Dr George Draper under whose care FDR would be entrusted in several weeks, "I thought it perfectly clear so far as the physical findings were concerned" [23]. Lovett wrote in 1922 that the diagnosis could usually be made solely from the physical findings [24].

In resolving this newly contrived controversy, we believe that there is value to revisiting the diagnostic and prognostic features of FDR's illness, based on a careful review of the objective physical findings recorded by his physicians and therapists during the initial years of his illness. The primary purpose of this paper, therefore, is to present objective evidence recorded by experts in the disease through numerous examinations of Mr. Roosevelt during at least a 3-year period. A secondary purpose is to confirm that the objective evidence of the diagnosis, prognosis and outcome of FDR's illness are far more characteristic of poliomyelitis than GBS.

Methods

A literature review used an electronic search of publications in journals and textbooks, supplemented by hand searches of the older literature in the early half of the 20th century before the discovery of polio vaccines. The search encompassed data on incidence of poliomyelitis (polio), the presentation and clinical course in children and adults, diagnosis, prognosis, outcomes, and rehabilitation. The same topics were searched in regard to GBS. Symptoms, physical findings, and other clinical features as listed in the results section were searched by hand and electronically. The research was further supplemented by extensive archival library research compiling actual correspondence between FDR's treating physicians and therapists, as well as some family letters.

Data are presented in a case report of the clinical features regarding the diagnosis and prognosis of FDR's illness from August 10, 1921, until February 1924. The results of this search are analyzed and tabulated in a table to illustrate the similarities and differences between the important clinical features of the FDR case report, poliomyelitis and GBS. The frequency of the clinical features in Table 1 reflects percentages from case series, although estimates were necessary in the context of bulbar paralysis. Bulbar polio and bulbar GBS are known to have more severe outcomes, which required extrapolation as patients with a history of ventilator use were excluded from the estimates of severity of disability and will be identified in the results/discussion sections.

FDR Case Report

The following case report will emphasize those findings reported by the clinicians (so noted by the authors of this paper in italics) who examined FDR. The italics will be further emboldened in the first paragraph, which represents Lovett's notes of the onset for the period of August 10 to 14, 1921, before his examination of FDR on August 25, 1921 [25].

FD Roosevelt at age ***39*** developed malaise on ***August 10th after bathing*** in Lake Glen Severn on Campobello Island in Canada. The following day, ***August 11*** the ***pain*** was so severe in "his back and legs" that Dr Bennett from Lubec, Maine was called by Eleanor Roosevelt [26]. On ***August 12*** both ***legs*** (were) ***weak*** accompanied with urinary ***retention***. On ***August 13 he had to be helped to walk*** and was ***completely paraplegic***. On ***August 14*** he was ***seen by Dr Keen***, who after a "most careful thorough examination" that morning and the following morning indicated that FDR's problem had resulted in "*removing the power to move* (his legs) *though not to feel*," as reported in a letter from Eleanor Roosevelt to James Roosevelt [26]. Keen sought the opinion of Dr Lovett, when the family indicated that they wished a

Table 1
Serial manual muscle tests performed on Franklin Delano Roosevelt by R. W. Lovett (Lovett Papers; Francis A. Countway Library, Boston, Massachusetts)

Left 1923		Left 1922		Muscles Tested Back and Legs	Right 1922		Right 1923	
Normal	5	Good	4	Back	Good	4	Normal	5
Poor	2	Poor	2	Abdominal lateral	Poor	2	Fair	3
		Poor	2	Quadratus lumborum	Fair	3		
Poor	2	Poor	2	Gluteus maximus	Poor	2	Poor	2
Trace	1	Trace	1	Iliopsoas	Poor	2	Poor	2
Trace	1	Zero	0	Tensor fasciae latae	Trace	1	Poor	2
Poor	2	Poor	2	Sartorius	Trace	1	Zero	0
Poor	2	Poor	2	Hip abductors	Trace	1	Trace	1
Poor	2	Poor	2	Hip adductors	Trace	1	Trace	1
Poor	2	Poor	2	Quadriceps	Poor	2	Trace	1
Poor	2	Poor	2	Inner hamstrings	Zero	0	Zero	0
Zero	0	Zero	0	Outer hamstrings	Poor	2	Poor	2
Poor	2	Trace	1	Gastrocnemius	Poor	2	Poor	2
Zero	0	Zero	0	Anterior tibialis	Zero	0	Zero	0
Zero	0	Trace	1	Posterior tibialis	Trace	1	Trace	1
Poor	2	Trace	1	Peroneals	Fair	3	Fair	3
Poor	2	Poor	2	Extensor digitorum longus	Fair	3	Poor	2
Fair	3	Poor	2	Extensor digitorum brevis	Fair	3	Trace	1
Poor	2	Poor	2	Extensor proprius hallucis	Fair	3	Fair	3
Fair	3	Poor	2	Flexor longus	Poor	2	Poor	2
Fair	3	Poor	2	Flexor brevis	Poor	2	Poor	2
		Poor	2	Flexor lumbricale	Poor	2		
Fair	3			Flexor halluces			Poor	2

The examinations in 1922 and 1923 used the designation of normal, good, fair, poor, and trace. These have been converted to the nearest number of 0-5 (0 = zero; 1 = trace; 2 = poor; 3 = fair; 4 = good; 5 = normal), which is the current convention for manual muscle testing and permits ease of comparison. In addition, some muscles have been deleted or substituted in the hands or feet to allow comparison.
Reprinted from Ditunno JF Jr, Herbison GJ, Franklin D. Roosevelt: Diagnosis, clinical course, and rehabilitation from poliomyelitis, American Journal of Physical Medicine & Rehabilitation 2002;81(8):557-566 [17], with permission from Wolters Kluwer Health, Inc.

second opinion. Lovett arrived at Campobello 15 days after the onset, August 25th, recorded the above historical features and examined the patient.

Lovett documented the findings that support his diagnosis of polio in 2 letters from his examination on August 25, 1921 [22,27]. On September 12 he reported his history and physical findings gained on August 25th:

> "he went down there *very tired*, took a bath, went swimming and stayed there a good while. He ran home in his wet bathing suit and subsequently had *chills, high temperature and pain*. Questioning however showed that there had been *hyperesthesia of the legs preceding the bath (swim) for a day or two.*" "*He was tender*, when I examined him …so my examination had to be superficial. He had…*facial* involvement, apparently *no respiratory*, but *weakness in the arms … not grouped* at all. There was some *atrophy of the left thenar eminence*… His *bladder* was *paralyzed*…*scattered weakness in the legs*, most *marked* in the *hips*…."[22]

Dr Bennett became concerned and sent a telegram on August 31, 3 weeks after the initial attack to Lovett followed by a letter the following day indicating that "the *atrophy* has *increased* and power lessened. *Bladder and bowel function* remains *impaired*, the *muscles are flabby* and there is evidence of *hyperesthesia* over the *thighs*. There has been *improvement of muscle power above the waist but not below*," (again, italics ours) [28]. On September 8th, Bennett updated Lovett of mild temperature elevations (99.5-100.5°F) from September 4th through September 8th (4 weeks after onset) associated with increased leukocytes in the urine several days before FDR's pending transfer to NYC [29]. FDR was transferred to NYC under the care of Dr George Draper at Presbyterian Hospital on September 13, 1921, when he entered the admitting diagnosis of "anterior poliomyelitis" into FDR's medical chart [30]. Draper noted that FDR had pain and severe paralysis particularly in the lower extremities. He documented asymmetrical weakness in the upper extremities with involuntary twitching in the forearm muscles (fasciculations), but refrained from a complete examination of the arms to spare the patient further anxiety. Draper reported his findings to Lovett:

> "marked *falling away* of the *muscle masses* on either side of the spine in the *lower lumbar region*…(and) *buttocks*. …marked *weakness* of the posterior part of the *left deltoid*; very marked *weakness* of the *right triceps*; and an unusual amount of *gross muscular twitching* of both *forearms*. …coordination of *fine muscles of the hands* very well… the *biceps*… *good*

so…he can pull himself up by a strap. "little motion…*long extensors of the toes* of each foot; a little in the *perinea* of the *right side*; little ability to twitch the bellies of the *gastrocnemii*, but not really extend the feet. There is little *slight power* in the *left vastus*…*voluntary twitching* of the *hamstring* masses [31].

Draper apprised Lovett of the resolving muscle tenderness and extent of back, pelvic, and leg muscle paralysis on October 11, close to 9 weeks after the onset:

"he still has a little tenderness in his ham strings …much more power in the back muscles than I thought…but…pelvic girdle…thighs…most of the leg muscles are in poor shape" [32].

Lovett visited FDR at "Roosevelt Hospital" and wrote to Dr Bennett on October 17, stating that FDR was sitting up but was still "*tender in spots*," remarking that he had power in all hip muscles. Lovett approved his discharge home whenever the patient wished to go [33].

In December 1921, Lovett approved of progressive exercises after his receipt of a letter from the physical therapist, Kathleen Lake, apprising Lovett of her findings [34]. In her letter she stated that there were knee flexion contractures and there was still some "*sensitiveness of the gastrocnemii*…but all the *soreness has gone from his back*" [34]. Dr Lovett ordered serial casting to correct the knee flexion contractures and was informed the program had begun [35]. Apparently the progression of the serial casting was rather aggressive (4 wedges in 22 hours) according to the physical therapist and "*sensitiveness*" returned to the calf muscles accompanied by "*weakness*" [36].

In May 1922 Draper and Lovett agreed that FDR needed to be admitted to the Phillips House in Boston for a complete reassessment including accurate manual muscle testing (MMT), prescriptions for new braces, and ambulation training. Roosevelt was subsequently admitted to the Phillips House on May 31, and Dr Lovett and his staff performed a complete MMT on June 1, 1922, approximately 10 months after the onset of FDR's paralysis.

The MMT on June 1, 1922, was repeated by Lovett and his staff in 1923 [37] and was published in modified format in 2002 in the *American Journal of Physical Medicine and Rehabilitation* (Table 1) [17]. Draper's last letter to Lovett was written on February 1, 1924, stating that in his opinion FDR had "reached the limit of his possibilities" [38]. Dr Lovett died in July of that year at the age of 64.

Results

Table 2 reflects the results of the case study and literature search [24,39-62].

Table 2
Symptoms/signs of FDR case report, poliomyelitis, and GBS

Symptoms and Signs	FDR Case Report	Poliomyelitis	GBS
Fever	Present [22,28]	Typical [42]	Absent[42]
Hyperesthesia	Thigh and calves onset–5 months [22,25,28]	Typical Up to 5-6 mo [24,44,45,51]	Dysesthesia fingers and toes for years [40,41,52]
Menigeal irritation	Severe back and leg pain [22,26]	Meningeal symptoms = severe head, back and thigh pain [50]	Uncommon
Muscle tenderness	Present [22,30] duration 8 weeks [53]	Very common [24,51,54] duration 4 weeks to 6 months	Less common (11%) [55]
Muscle weakness			
Distribution	Scattered in UE roughly sym. LE [22,30]	Typically scattered roughly symmetrical [24,54] Adults 50% both LE	Symmetrical [48]
Recovery	Minimal LE [36]	Moderate	Maximal [55]
Residual proximal vs distal weakness	Proximal > distal [36]	Proximal > distal [54,56]	Distal; rare proximal [55]
Severity and disability use of braces and wheelchair	Severe; long leg braces/wheelchair [14]	5%-20% long leg braces/wheelchair [57,58]	Not reported in nonbulbar [59]
Objective sensory findings	Absent [26]	Absent [24,43]	Present 75%[48]
Facial paralysis	Present unilateral [22]	"Not uncommon" [60]	Common [48]
Bladder paralysis	Present 3-4 wk duration [66]	40% in adults several wk duration [61]	Bladder problems 30% [62]

FDR = Franklin D. Roosevelt; GBS = Guillain-Barré syndrome; LE = lower extremity.

Discussion

The diagnosis and prognosis of polio based on the records of physicians and therapists who examined FDR during his illness requires an understanding of the criteria used at that time. In 1922, the year after his initial examination of FDR, Lovett published his diagnostic criteria based on his observation of more than 5000 cases. Lovett summarized his diagnostic criteria as follows:

- a scattered, irregular, widely spread loss of motor power on one or both sides;
- no diminution of sensation in affected parts; and
- diminution or loss of reflexes in the parts affected [24].

The recent Center for Disease Control case definition for paralytic poliomyelitis identifies the same features; "Acute onset of a flaccid paralysis of one or more limbs with decreased or absent tendon reflexes in the affected limbs, without other apparent cause, and without sensory or cognitive loss" [43].

The symptoms and signs described in the case report of FDR's onset in August of 1921 and subsequent course will be assessed in the context of Lovett's criteria and other experts in poliomyelitis [45,46,63]. The diagnosis/prognosis features of polio in general, and in FDR's case report in particular, will be contrasted with the features of GBS [41,48,52,55,62].

Adult Features

Adults have a greater incidence of severe pain on day 1, usually in the lumbar region with a greater incidence of prodromal hyperesthesia [47]. These 3 features clearly were present in FDR's case. Children have a much greater frequency of monoplegia, with a recorded incidence of 85%-91% in more than 500 cases of spinal paralytic polio [64]. This pattern in children is likely the basis for the criterion of asymmetry cited in the literature [56,61,65]. Adults older than 30 years of, however, have 4-extremity paralysis in more than 50% (74/141) cases, which was the pattern in FDR's case. Bladder paralysis "a common feature in adults (> 40%)... is most infrequent in children (2%-4%)" [51].

Fever

Lovett recorded the history of "chills, high temperature and pain" the evening before the onset of muscle weakness. The presence of fever is unusual in GBS and is listed as one of the features important in the differential diagnosis between polio and GBS [42].

Hyperesthesia and Other Sensations

Authorities on the diagnosis and treatment of polio such as Lovett, Draper, and Horstman recognized cutaneous hyperesthesia as a prominent symptom of polio. They indicated, however, that the characteristic feature of the diagnosis was the absence of sensory loss. Draper regarded hyperesthesia as "the most characteristic symptom" of polio if it occurred during an epidemic [54]. He described the findings as increased sensitivity of the skin (hyperesthesia) that may be elicited by rubbing the skin and distinguished it from muscle tenderness, which was elicited by squeezing the muscle [45].

Lovett referred to the term "hyperesthesia" several times in his correspondence with Draper and Bennett regarding FDR's clinical course. When Bennett reported FDR's continued hyperesthesia over the thighs at 3 weeks after onset, Lovett advises Bennett that "massage will prolong hyperesthesia...and the thigh sensitiveness should be watched from this point of view." As illustrated in this comment to Bennett, Lovett used sensitiveness as synonymous with hyperesthesia. In his 1922 paper on diagnosis he lists "no diminution of sensation" as one of the 3 diagnostic features of polio, but refers to the following signs and symptoms: "in practically all cases [18] is accompanied by marked tenderness, sensitiveness and pain in the affected parts."

Kathleen Lake, who was trained by Lovett, used sensitiveness in describing the presence at 4 months and after aggressive stretching of FDR's knee contractures [34,66]. FDR used this term sensitiveness in describing his discomfort in 1924 [53]. A specific reference to "cutaneous hyperesthesia" is listed in Brain's Diseases of the Nervous System 2009 description of polio [44].

FDR is reported to have complained of his legs feeling numb during the initial onset, but there were never findings of sensory loss by any of the physicians who examined him, and Keen was quoted as saying that he lacked power but not feeling. Lovett again in his paper on diagnosis states, "The attack may be preceded by queer sensations in the parts to be affected, such as prickling or numbness" [24]. This early symptom of numbness was not evidence of sensory loss by physical examination. It is inconceivable that Lovett and Draper found sensory loss on numerous examinations of FDR, as both were aware that absence of sensory findings was diagnostic of polio and was referenced in their publications [24,67].

Pain

Intense pain in the back and legs was an important feature of polio at the onset, particularly in adults [47,63]. FDR's complaint of intense pain in the back and legs was the reason Eleanor Roosevelt called for

Dr Bennett on August 11th before the onset of leg weakness [26] and was recorded by Lovett in his notes on FDR [22] Russell used the severe onset of pain in the back and legs as equivalent to meningeal irritation during onset in a polio epidemic [63].

Tenderness

Lovett emphasized the importance of muscle tenderness as a diagnostic and prognostic feature and that "tenderness of the parts to be affected occurs early and may be excessive" [24]. Tenderness is such a prominent feature of the affected muscles in the acute phase that Lovett refrained from precise muscle testing because in his opinion it risked further muscle damage. Draper indicated his concern over the persistence of tenderness at 6 weeks and continued tenderness of the muscles at 2 months, which was confirmed by Lovett the following week [60]. The average duration of tenderness according to Lovett's experience was 6 weeks and this deadline was already past [24]. Because Lovett did not commence exercises during the acute phase (duration of muscle tenderness), he must have been satisfied that the tenderness was gone in mid-December (16 weeks) when he initiated exercises and physical therapy.

Muscle Weakness

The pattern of muscle weakness from the time of onset to maximum paralysis was a period that typically ranged from 1 to 6 days [67]. This progression to maximum paralysis in FDR's case, however, is not documented by expert clinical examination between Keen's findings on the third day and Lovett's examination at 2 weeks [22].

In his 1922 paper on poliomyelitis, Lovett reported that the typical pattern of the extremities involved and their symmetry was "roughly symmetrical" with the lower extremities more often involved that the uppers [24] Although 70% involved 1 or more extremities unilaterally, there was a 25%-30% involvement of both legs and was slightly greater bilaterally (10%) in New York State [57]. FDR's involvement was roughly symmetrical. He had asymmetry of the deltoid, triceps, and vastus lateralis [31]. His lower extremity involvement (Table 1) shows involvement of both legs, more severe in the proximal muscles and less severe in the feet. These finding of "roughly symmetrical" are consistent with Lovett's experience. In adults, the involvement of both legs and arms has been reported to be as high as 50% in epidemics in Massachusetts in the 1950s, in contrast to children in which monoplegia (asymmetry) is the typical pattern [51,64].

The severity of the paralysis similar to FDR's case, which would require ambulation with long leg braces and/or a wheelchair is from 6% to 20% in acute cases, but these findings reflect reports on postpolio studies, which are not population based [68]. An epidemic in 1941 reported asymmetry in those with residual moderate paralysis 27/32, but symmetry in severe paralysis 20/20 [58]. In more than 64,000 cases of paralytic polio reported to the National Foundation from the years 1952-1956, the percentage of persons with some residual paralysis of both legs was 45% and severe paralysis of both legs of 15% [69].

The "weakness in the arms…not grouped" and the "scattered weakness" in the arms and legs had great significance to Lovett, because he regarded this pattern of muscle weakness as he described in FDR's case to represent poliomyelitis as the only diagnostic possibility in an acute onset of motor flaccid paralysis [22,24]. "There is no other widely distributed lesion which picks out motion alone and leaves sensation untouched" [24]. "Only a lesion of the anterior horn cell" will produce the clinical picture described in Lovett's examination [24]. The involuntary "twitches of forearm muscle" observed by Draper is also consistent with the fasciculations seen in other anterior horn cell diseases such as postpolio syndrome, amyotrophic lateral sclerosis and primary muscular atrophy [56].

The prognostic significance of the pattern of weakness and final recovery in FDR's case is completely consistent with the diagnosis of polio. FDR had profound weakness of the proximal muscles of the hips and thighs, which failed to improve more than 1 muscle grade from a trace (1/5) to poor (2/5) muscle grade over 11 years. Sharrard [50] offers the pathophysiologic explanation as to why proximal muscles are more involved. Sharrard's concept of motor cell column damage in the spinal cord fits with the "scattered" muscle weakness found by Lovett as manifestations of anterior horn cell origin rather than peripheral neuropathy [70].

Muscle Atrophy

Atrophy of specific muscles when it had relevance to the diagnosis of polio is listed in Lovett and Draper's letters. In particular "atrophy of the left thenar eminence" was a frequent occurrence in polio and "throws light on diagnosis of doubtful cases" [22]. Lovett documents "some atrophy of the left thenar eminence" in his initial examination of FDR. Draper expresses concern to Lovett regarding the "marked falling away of muscles masses …[of the] buttocks" and other proximal muscles on September 24, 1921. The profound atrophy of the buttocks and thighs are illustrated in Figure 2 (FDR in bathing suit lateral view) in 1924, 3 years after the onset of FDR's paralysis. This marked degree of atrophy correlates with the profound proximal muscle weakness recorded in the MMT by Lovett in 1922 and is unchanged in 1923 (Table 1). The marked wasting of the thighs, in Figures 3 and 4, in 1932 illustrates the permanent features of FDR's proximal

Figure 2. Franklin Delano Roosevelt at poolside showing severe lower extremity muscle atrophy (1924). Photo courtesy of Franklin Delano Roosevelt Library.

muscle disease, typical of polio and rarely seen in polyneuropathies such as GBS.

Facial and Bladder Paralysis

Lovett indicates that facial paralysis was "not uncommon." In the spinal form of polio in one series

Figure 3. Franklin Delano Roosevelt again showing proximal and distal lower extremity atrophy (c1932). Photo courtesy of Warm Springs Vocational Rehabilitation Campus.

Figure 4. Franklin Delano Roosevelt eating poolside lunch showing lower extremity atrophy (1932). Photo courtesy of Warm Springs Vocational Rehabilitation Campus.

unilateral transient facial paralysis occurred in 5 of 66 cases [71], nor does the duration of the bladder paralysis for a period of 2-3 weeks seem an issue of concern for Lovett as he assures Bennett 20 days after onset that "urinary retention is typical in this type of case," particularly in patients with abdominal and/or pelvic girdle weakness, which Lovett document's in FDR's case [72,73]. With paralysis of abdominal and pelvic muscles, it would be more difficult to compress bladder contents resulting in prolonged urinary retention. In adults, bladder paralysis is much more frequent and was present in 44.4% of individuals age 40-60, which often required catheterization [64].

GBS versus Polio

The authors of the 2003 paper [5] used Bayesian probability analysis, which has been proffered by them as an analytical approach to achieve more accuracy in clinical judgment of differential diagnosis than methodical diagnosis by experienced clinicians. The authors make a serious attempt to us this approach by calculating the anterior and posterior probabilities based on a retrospective analysis of clinical features as stated previously. Their analysis, however, contains serious flaws in symptom omission, inclusion and interpretation. Those errors may be due to the authors' lack of awareness of the differences between the infantile and adult forms of polio, the characterization of symptoms/signs, simple oversight, or other unknown reasons.

Important symptoms and signs such as muscle soreness and sensory loss on physical examination are missing from their list in Table 3 [5]. Muscle soreness is a major factor in acute polio but typically abates by 2 months. Muscle soreness is far less common in GBS (10%) but when present tends to persist [18,55]. Physical

Table 3
Clinical features of Franklin D. Roosevelt's case compared with those of GBS and poliomyelitis*

Clinical Features	Roosevelt's Case	GBS	Poliomyelitis
Age of onset	39 years	Mainly adults	Mainly young children
Flaccid paralysis	Symmetric, ascending	Symmetric ascending	Asymmetric
Progress of paralysis	10-13 days	10-14 days	3-5 days
Facial paralysis	Present	Common, bilateral	Rare, save in bulbar type
Bowel/bladder dysfunction	14 days	7-14 days	1-3 days
Numbness	Present	Common	Absent
Dysesthesia	Protracted	Protracted	Absent
Meningismus	Absent	Absent	Common
Fever	Present	Rare	Common
Recovery from paralysis	Symmetric, descending	Symmetric, descending	Asymmetric
Permanent paralysis	Symmetric	In about 15% of cases	In about 50% of cases

GBS = Guillain-Barré syndrome.
* The clinical features of poliomyelitis and GBS have been drawn from many past publications.
Reprinted from Goldman AS, Schmalstieg EJ, Freeman DH Jr, Goldman DA, Schmalstieg FC Jr, Journal of Medical Biography (114/4), pp. 232-240 [5], copyright © 2003, with permission from SAGE Publications, Ltd.

findings of sensory loss, which are absent in polio, are typical in GBS and may also persist for years [48,59]. None of FDR's physicians reported sensory loss and on physical examination and his symptoms of hyperesthesia had cleared at 6 months.

Of 11 clinical features listed in Table 3 [5], only 2 (fever and permanent paralysis) are listed as favoring polio. Many of the remaining 9 features are flawed, such as listing FDR's progression of paralysis at 10-13 days. Lovett's notes indicate that by August 13th, 3 days after symptom onset he had become paraplegic, and Keen reported on August 14th that he "had lost the ability to move his legs though not to feel" [26]. Another feature, dysesthesia, is listed as absent in polio, illustrating a lack of awareness of the literature (Lovett; Draper; Horstman) regarding the typical presence of hyperesthesia/sensitiveness in polio as well as the clinical observations by the clinicians who examined FDR and reported on his hyperesthesia/sensitiveness [24,45,46]. It appears that the authors of the 2003 paper may have interpreted symptoms of cutaneous hyperesthesia, common in polio, with the dysesthesias associated with GBS.

Another error within their 9 listed factors is bladder paralysis, which is described as lasting 1-3 days in polio. Lovett offers the association of abdominal, pelvic floor, and girdle paralysis as features associated with prolonged urinary retention in polio [24]. The patterns of recovery that clearly distinguish polio from GBS in general, and especially in FDR's case, are the major differences in residual proximal muscle weakness in polio contrasted with distal weakness in GBS [47,48,50,69,70]. Finally, the severity of the FDR's impairment and wheelchair mobility, which may occur in up to 20% of the polio population, is not reported in non-bulbar GBS [55,59]. In our opinion, the sum of these errors dramatically alters the statistical analysis as held true by Goldman et al.

Conclusions

It is apparent in reviewing FDR's initial clinical presentation, subsequent medical management, and his partial recovery that the diagnosis of poliomyelitis was neither made casually nor by physicians and therapists unfamiliar with this then-common disease. He was evaluated and subsequently cared for by the nation's leading experts in the disease. Virtually every one of his initial symptoms were examples of common findings and complaints seen in the adult-onset form of the disease, which although less common than the infantile form, in 1921 was still very much a disease to be feared.

Although GBS is a diagnosis with some commonalities with poliomyelitis, there are critical distinguishing factors that made the differentiation possible, even at a time when laboratory testing of cerebrospinal fluid was uncommon. A statistical analysis of diagnostic probabilities is not valid when several of these significant distinguishing factors are omitted from such an analysis. A careful inclusion of all symptoms, the differentiating significance, and their presence or absence, is critical in drawing conclusions. There seems little reason to conclude anything other than the fact that FDR contracted poliomyelitis after exposure in the late summer of 1921, had profound and permanent muscle function loss as the result of that disease, and despite that disability, became one of the most influential public figures of the 20th century, both within our nation as well as across the globe during World War II.

The question of FDR's diagnosis may seem esoteric as a present-day issue but is not simply an epistemologic exercise. The management of acute and chronic polio was significantly enhanced by FDR's work at Warm Springs, his close relationship with medical leaders, and his close associations with major philanthropists, federal power-brokers, and his family connections. FDR's close relationship with Bernard Baruch, a major

philanthropist of the time, aided the development of a major field of contemporary medicine, the specialty of physical medicine and rehabilitation. As a consequence of his illness and lifelong disability, the very nature of how Americans viewed disability was changed, and the cure for polio was expedited dramatically, improving the lives of millions the world over. The world is now close to the eradication of this disease, in large part because of the vaccines developed through research initially funded by the March of Dimes and Roosevelt's subsequent efforts as President of the United States. It is time to put this controversy to rest.

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