

# Serum L-Carnitine Level and Its Correlation With The Degree Of Motor Function Impairment in Children With Spastic Cerebral Palsy

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## Abstract

**Background:** Cerebral palsy (CP) encompasses permanent movement and posture disorders. L-carnitine (LC) is essential cofactor for energy metabolism in mitochondria. Disturbances in this pathway may contribute to impaired muscle function and disease severity in neurodevelopmental disorders, yet its specific role in spastic CP requires further investigation.

**Objective:** to assess serum L-carnitine level in children having spastic CP and to assess the relation between serum L-carnitine concentration and the degree of motor function impairment.

**Patients and methods:** This cross-sectional analytical research has been done at the Pediatric and Physical Therapy Outpatient Clinics of October 6 University Hospital. The study included 90 participants, comprising 45 children with spastic CP and 45 healthy controls. The extent of motor function disability has been evaluated utilizing the Gross Motor Function Classification System (GMFCS), classifying the cases into five levels. Serum L-carnitine levels have been measured by ELISA in both cases & controls.

**Results:** Compared to controls, the CP group's serum LC concentrations were substantially reduced. (median: 790.0 vs. 5270.0 ng/mL,  $p < 0.001$ ). L-carnitine demonstrated good diagnostic accuracy for discriminating CP cases from controls (AUC=0.893, sensitivity: 82.22%, specificity: 77.78%). L-carnitine levels exhibited a highly significant negative association with GMFCS classification ( $r = -0.865$ ,  $p$  below 0.001) and delayed developmental milestones, while positively correlated with independent walking ability.

**Conclusion:** Serum L-carnitine levels are significantly reduced in children with spastic CP and are significantly inversely correlated to the severity of motor impairment.

**Keywords:** Cerebral palsy; L-carnitine; GMFCS; Motor impairment.

## Introduction

Cerebral palsy (CP) is a set of enduring conditions influencing mobility and postural development, resulting in activity restrictions due to non-progressive cerebral disruptions that transpired in the fetal or infantile period (1). It is the predominant cause of motor impairment in adolescents and children (2). CP manifests in approximately 3 to 4 cases per 1,000 live births globally (3). In Egypt, the prevalence varies between 2.9 and 3.6 per 1000 live births (4).

The lag in the acquisition of gross motor skills and stability in children with CP impacts their daily activities. (5). The Gross Motor Function Classification System (GMFCS) is regarded as a pivotal score assessing functionality in CP. This categorization is extensively employed to estimate the gross motor abilities in those children (6). It has been employed to categorize children with CP according to the intensity of their motor impairment (7-8). The GMFCS score emphasizes functional constraints and necessity for mobility aids and assistive technology for ambulation, like wheeled mobility, than it focuses on movement quality (9).

As a conditionally vital nutrient, L-carnitine (LC) has a significant role in human lipid metabolism. Additionally, LC is capable of producing acetyl-L-carnitine within the organism, which exhibits neurotrophic and neuroprotective properties (10). LC fulfils numerous critical activities inside intracellular processes, with its primary role being a promoter to energy metabolism of cell (11).

LC participates in the breakdown of internal organic acids, encompassing ketoacids originating from branched-chain amino acids (leucine, valine, & isoleucine), as well as the renal elimination of both internal and external acids resulting from xenobiotics, including certain antibiotics & valproic and salicylic acids (12).

Moreover, LC exhibits neuroprotective effects by enhancing mitochondrial energy and functionality, regulating gene expression, providing antioxidative benefits, and stabilizing cellular membranes. It additionally inhibits cellular demise and neurological injury. It promotes the development of nerve growth factors within the hippocampus (13).

This research sought to evaluate serum LC concentrations in children having spastic CP and its efficacy in differentiating them from healthy controls. It examines the correlation between blood LC levels and the extent

of motor function impairment measured by GMFCS, hence investigating the possible use of LC as a biomarker for motor dysfunction in this demographic.

## Methodology

This cross-sectional analytical research was done at the Pediatric Outpatient Clinics and Physical Therapy Outpatient Clinics of October 6 University Hospital over an interval of six months, from August 2025 to January 2026. The study included 90 participants, comprising 45 children with spastic CP and 45 healthy controls who were matched for age and sex.

## Inclusion and exclusion criteria

Patients were eligible for inclusion in this research if they were between the ages of 2-12 years and had a validated identification of spastic CP. Children were excluded if they were diagnosed with neurodegenerative disorders, congenital brain anomalies, renal or hepatic disease, metabolic disorders affecting carnitine metabolism such as fatty acid oxidation defects. Additionally, patients receiving immunosuppressive drugs, chronic corticosteroid therapy, antiepileptic medications, or LC supplementation within the preceding 3 months were excluded.

## Methods

All participants underwent detailed medical history taking, and clinical examination. The diagnosis of CP was established by professional neuro-pediatricians based on a thorough neurological examination. A specialized physiotherapist assessed the degree of motor function impairment using the GMFCS. Participants were classified into five levels accordingly.

## Biochemical Assay of serum L- Carnitine:

Three milliliters of venous blood have been drawn from each participant under complete aseptic conditions using a sterile needle and collected into plain tubes. After 30 minutes of samples' collection, the samples have been processed using centrifugation for 15 minutes at 3000 rpm for serum separation. Serum samples have been stored appropriately at -20°C until examination. Serum LC levels have been measured utilizing the Enzyme-Linked Immunosorbent Assay (ELISA) method, using commercial kit, according to the manufacturer's instructions (Cat. No.: In-Hu3999, NOVA, China).

## Ethical considerations

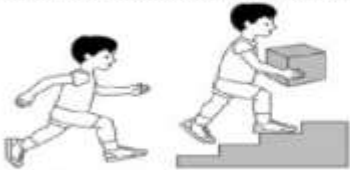
Approval from the Research Ethical Committee of October 6 University, Egypt, has been attained. Before initiating the research, informed consent has been secured after a comprehensive elucidation of the research aims, methodologies, potential advantages, and associated risks. The privacy and confidentiality of all participants' data were rigorously upheld during the research. Participation was optional, and caregivers have been made aware of their entitlement to exit the study at any moment without changing the medical treatment they received.

## Statistical analysis of the data

IBM SPSS software version 27.0 was used for analysis after the data was entered into Excel spreadsheets (Armonk, NY: IBM Corporation, published 2020). Categorical information has been depicted utilizing percentages and numerical values. The Shapiro-Wilk test has been utilized to estimate the normality of continuous data. Quantitative information has been defined by its range (maximum and minimum), mean  $\pm$  SD, and median accompanied by interquartile range (IQR). Significance was deemed when p-value was below 0.05.

To compare different groups, the chi-square test was employed. Mann - Whitney test was applied to compare both examined sets. One-way ANOVA used to assess variations across multiple groups using quantitative factors that are normally distributed. Kruskal-Wallis test used to assess several groups using quantitative factors that are not normally distributed. The receiver operating characteristic curve (ROC) is applied to identify the cutoff value. The Spearman coefficient has been applied to evaluate the correlation between two quantitatively measured variables that do not follow a normal distribution.

## GMFCS E & R between 6<sup>th</sup> and 12<sup>th</sup> birthday: Descriptors and illustrations

|                                                                                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
|-------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|    | <b>GMFCS Level I</b><br>Children walk at home, school, outdoors and in the community. They can climb stairs without the use of a railing. Children perform gross motor skills such as running and jumping, but speed, balance and coordination are limited.                                                                                                                                                                                                |
|    | <b>GMFCS Level II</b><br>Children walk in most settings and climb stairs holding onto a railing. They may experience difficulty walking long distances and balancing on uneven terrain, inclines, in crowded areas or confined spaces. Children may walk with physical assistance, a hand-held mobility device or used wheeled mobility over long distances. Children have only minimal ability to perform gross motor skills such as running and jumping. |
|    | <b>GMFCS Level III</b><br>Children walk using a hand-held mobility device in most indoor settings. They may climb stairs holding onto a railing with supervision or assistance. Children use wheeled mobility when traveling long distances and may self-propel for shorter distances.                                                                                                                                                                     |
|   | <b>GMFCS Level IV</b><br>Children use methods of mobility that require physical assistance or powered mobility in most settings. They may walk for short distances at home with physical assistance or use powered mobility or a body support walker when positioned. At school, outdoors and in the community children are transported in a manual wheelchair or use powered mobility.                                                                    |
|  | <b>GMFCS Level V</b><br>Children are transported in a manual wheelchair in all settings. Children are limited in their ability to maintain antigravity head and trunk postures and control leg and arm movements.                                                                                                                                                                                                                                          |

GMFCS descriptors: Palisano et al., (1997) Dev Med Child Neurol 39:214-23

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Figure 1: gross motor functional classification scale (Palisano et al., 1997)

## Results

This study included 45 children with CP aged from 2-12 years, with a mean age of  $7.20 \pm 3.35$  years with 55.6% females and 44.4% males. A positive family history has been described in 60% of the cases (Table 1).

Table 1:-Demographic data of the examined case group (n= 45)

|                      | No.              | Frequency (%) |
|----------------------|------------------|---------------|
| <b>Age (years)</b>   |                  |               |
| Min. – Max.          | 2.0 – 12.0       |               |
| Mean $\pm$ SD.       | $7.20 \pm 3.35$  |               |
| Median (IQR)         | 8.0 (4.0 – 10.0) |               |
| <b>Sex</b>           |                  |               |
| Male                 | 20               | 44.4          |
| Female               | 25               | 55.6          |
| <b>Consanguinity</b> |                  |               |
| Negative             | 15               | 33.3          |
| Positive             | 30               | 66.7          |
| <b>Birth order</b>   |                  |               |
| 1st                  | 13               | 28.9          |
| 2nd                  | 19               | 42.2          |

|                       |    |      |
|-----------------------|----|------|
| <b>3rd</b>            | 13 | 28.9 |
| <b>Family history</b> |    |      |
| <b>Negative</b>       | 18 | 40   |
| <b>Positive</b>       | 27 | 60   |

**IQR:** Inter quartile range, **SD:** Standard deviation

Regarding the etiology of CP, unidentified causes represented the highest proportion of cases (51.1%), followed by congenital causes accounting for 24.4%. Hypoxia was reported in 13.3% of the cases, while post-infectious cases accounted for 11.1%.

Regarding developmental milestones, only 11.1% of the studied cases achieved crawling. Walking without support was achieved by only 4.4% of the cases. Similarly, stair climbing was achieved by 11.1% of the cases. Other developmental milestones illustrated in table 2.

**Table (2): Developmental milestones among the examined cases (n = 45)**

|              | No.                | Frequency,% |
|--------------|--------------------|-------------|
| Sit          |                    |             |
| Min. – Max.  | 6.0 – 10.0         |             |
| Mean ± SD.   | 8.40 ± 1.36        |             |
| Median (IQR) | 9.0 (7.0 – 9.0)    |             |
| Stand        |                    |             |
| Min. – Max.  | 9.0 – 24.0         |             |
| Mean ± SD.   | 14.24 ± 4.44       |             |
| Median (IQR) | 12.0 (11.0 – 18.0) |             |
| Crawling     |                    |             |
| No           | 40                 | 88.9        |
| yes          | 5                  | 11.1        |
| Walk alone   |                    |             |
| No           | 43                 | 95.6        |
| yes          | 2                  | 4.4         |
| Climb stairs |                    |             |
| No           | 40                 | 88.9        |
| yes          | 5                  | 11.1        |

**IQR:** Inter quartile range, **SD:** Standard deviation

Regarding associated clinical symptoms, learning and visual difficulties were present in all cases. Movement disorders and hearing difficulties were reported in 91.1% and 62.2% of the cases respectively. Feeding difficulties and repeated respiratory tract infections were each observed in 68.9% of the studied cases.

Regarding topographical classification, our cases were classified as diplegic (53.3%), hemiplegic (26.7%), quadriplegic (20%) CP. According to the GMFCS classification, GMFCS level V represented the highest proportion of the studied cases, accounting for 26.7%. GMFCS levels I, II, and IV each accounted for 20.0% of the cases. The lowest proportion of cases was observed in GMFCS level III, which represented 13.3% of the cases studied.

**Table 3** showed a statistically insignificant variances among the two studied groups (Cases and Controls) regarding age and sex. The cases group exhibited significantly lower serum LC levels as compared with the control group.

**Table (3): Comparative analysis among the studied groups regarding Serum L-Carnitine level**

|              | Cases (n = 45)   | Control (n = 45) | U | p     |
|--------------|------------------|------------------|---|-------|
| Age          |                  |                  |   |       |
| Mean ± SD.   | 7.20 ± 3.35      | 7.22 ± 3.23      |   | 0.987 |
| Median (IQR) | 8.0 (4.0 – 10.0) | 7.0 (4.0 – 10.0) |   |       |

|                         |                           |                             |        |         |
|-------------------------|---------------------------|-----------------------------|--------|---------|
| Sex                     |                           |                             |        | 1.000   |
| Male                    | 20                        | 20                          |        |         |
| Female                  | 25                        | 25                          |        |         |
| Serum L-Carnitine level |                           |                             |        |         |
| Range (Min. – Max.)     | 280.0 – 5000.0            | 1200.0 – 6400.0             | 217.0* | <0.001* |
| Mean ± SD.              | 2071.78 ± 1841.91         | 4772.33 ± 1347.06           |        |         |
| Median (IQR)            | 790.0<br>(430.0 – 3900.0) | 5270.0<br>(4630.0 – 5600.0) |        |         |

**IQR:** Inter quartile range, **SD:** Standard deviation, **U:** Mann Whitney test, **p:** p value

**\*:** Statistically significant at p-value not more than 0.05 (All tests were two-tailed)

Serum LC level showed good diagnostic accuracy, with an area under the ROC curve of 0.893 (95% CI: 0.831–0.955), demonstrating a statistically significant discriminatory ability ( $p < 0.001$ ). At a cutoff value of  $\leq 4000$ , serum LC level achieved a sensitivity of 82.22% & a specificity of 77.78%. The positive predictive value (PPV) was 78.7%, even though the negative predictive value (NPV) was 81.4 % (Figure 2).

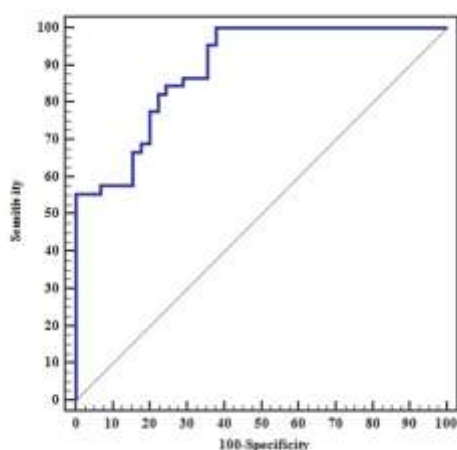


**Figure (2): ROC curve for Serum L- carnitine level to discriminate cases (n = 45) from control (n = 45)**

A highly significant difference was detected in serum LC levels among the different GMFCS levels in which the lowest serum LC levels were observed among patients classified as GMFCS level V. Serum LC levels did not significantly differ regarding the etiology ( $H = 2.337$ ,  $p = 0.505$ ) or the clinical type of CP ( $H = 4.464$ ,  $p = 0.107$ ) (Table 4).

**Table (4): Relation among Serum L-Carnitine level and different parameters in patient group (num. = 45)**

| Parameter             | Number | Serum L-Carnitine level |                 |                         | Test of Sig | P     |
|-----------------------|--------|-------------------------|-----------------|-------------------------|-------------|-------|
|                       |        | Min. – Max.             | Mean ± SD.      | Median (IQR)            |             |       |
| Sex                   |        |                         |                 |                         |             |       |
| Male                  | 20     | 280.0 – 4900.0          | 1910.5 ± 1709.4 | 880.0 (405.0 – 3520.0)  | U=215.000   | 0.424 |
| Female                | 25     | 360.0 – 5000.0          | 2200.8 ± 1966.6 | 700.0 (450.0 – 4000.0)  |             |       |
| Cause of CP           |        |                         |                 |                         |             |       |
| Congenital            | 11     | 360.0 – 3960.0          | 1826.4 ± 1504.0 | 1000.0 (540.0 – 3350.0) | H=2.337     | 0.505 |
| Unidentified/ Unknown | 23     | 280.0 – 4900.0          | 1934.8 ± 1888.1 | 630.0 (390.0 – 3950.0)  |             |       |
| hypoxia               | 6      | 420.0 – 5000.0          | 2911.7 ± 1996.2 | 3190.0 (700.0 – 4970.0) |             |       |

|                                   |    |                 |                 |                          |            |         |
|-----------------------------------|----|-----------------|-----------------|--------------------------|------------|---------|
| Post-Infection                    | 5  | 400.0 – 4900.0  | 2234.0 ± 2389.6 | 610.0 (460.0 – 4800.0)   |            |         |
| Type of CP                        |    |                 |                 |                          |            |         |
| Diplegia                          | 24 | 280.0 - 5000.0  | 2007.1 ± 1836.0 | 745.0 (435.0 – 3850.0)   | H= 4.464   | 0.107   |
| Hemiplegia                        | 12 | 400.0 – 4970.0  | 2801.7 ± 1880.6 | 3190.0 (645.0– 4625.0)   |            |         |
| Quadriplegia                      | 9  | 360.0 – 4900.0  | 1271.1± 1603.9  | 460.0 (380.0– 1000.0)    |            |         |
| Classification according to GMFCS |    |                 |                 |                          |            |         |
| 1                                 | 9  | 4000.0 –5000.0  | 4735.6 ± 307.0  | 4800.0 (4650.0 – 4900.0) | H= 35.205* | <0.001* |
| 2                                 | 9  | 3000.0 – 4000.0 | 3624.4 ± 347.1  | 3700.0 (3380.0 – 3900.0) |            |         |
| 3                                 | 6  | 500.0 – 3000.0  | 993.3 ± 984.8   | 600.0 (580.0 – 680.0)    |            |         |
| 4                                 | 9  | 390.0 – 2000.0  | 642.2 ± 519.9   | 430.0 (400.0 – 590.0)    |            |         |
| 5                                 | 12 | 280.0 – 1000.0  | 520.8 ± 261.5   | 385.0 (350.0 – 710.0)    |            |         |

IQR: Inter quartile range, SD: Standard deviation, U: Mann Whitney test

H: H for Kruskal Wallis test, p: p value for comparing among the two examined groups

A significant negative association was recorded between serum LC level and age of sitting, age of standing, and GMFCS classification. On the contrary, a significant positive correlation has been found among serum LC level and the ability to walk independently. (table 5, figure 3).

**Table (5): Correlation among Serum L-Carnitine level and different variables in patient group (num. = 45)**

|                                   | Serum L-Carnitine level |         |
|-----------------------------------|-------------------------|---------|
|                                   | $r_s$                   | P       |
| Age (years)                       | -0.241                  | 0.111   |
| Developmental milestone           |                         |         |
| Age of Sitting                    | -0.561                  | <0.001* |
| Age of Standing                   | -0.492                  | 0.001*  |
| Crawling                          | 0.245                   | 0.105   |
| Walk alone                        | 0.295                   | 0.049*  |
| Climb stairs                      | 0.245                   | 0.105   |
| Classification according to GMFCS | -0.865                  | <0.001* |

\*: Statistically significant at p-value not more than 0.05,  $r_s$ : Spearman coefficient

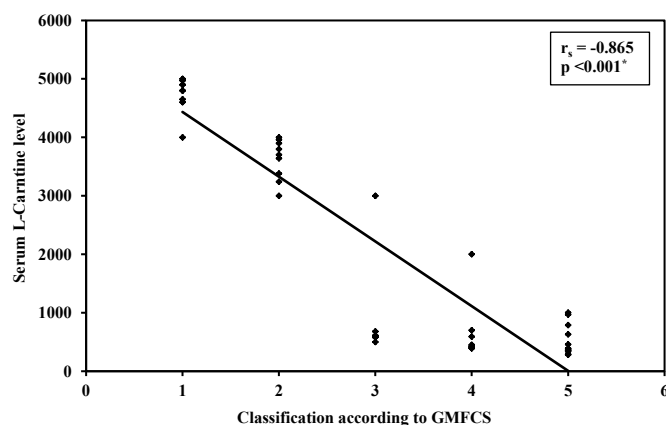


**Figure (3): Association among Serum L-carnitine level (ng/ml) and GMFCS levels in patient group**

## Discussion

Spastic CP was identified in all our cases. Spastic CP is regarded as the predominant type of CP, around 80% to 90% of all individuals affected by CP demonstrating varying degrees of spasticity (14-15).

In most of our cases, the etiology of CP was still unknown (51.1%). The identification of CP has traditionally occurred late, typically among twelve and twenty-four months in affluent nations and at five years of age in low to middle-income countries (16-18). Employing a variety of evaluations such as Prechtl's General Movements Assessments (GMA), neuroimaging, Hammersmith Infant Neurologic Examination (HINE), & motor function assessments, the average age for diagnosing CP can currently be decreased to under ten months (19-21). Integrating MRI with preliminary genetic assessments may improve diagnosis precision. Identifying the fundamental etiology of CP can greatly enhance genetic counselling, influence treatment choices and evaluating the likelihood of recurrence in the family (22).

Approximately 60% of patients exhibited a positive family history, with consanguinity present in 66.7%. Recent genetic research has revealed a diagnostic yield of twenty-eight to thirty-one percent in instances with CP, primarily due to single nucleotide variants (~25 %) and to a lesser extent from copy number variants (~5 %) (23). Moreover, diminished mitochondrial DNA (mtDNA) was linked to CP (24).

The developmental milestone assessment highlighted significant delays across the study which exceeded the expected ages for normal developmental milestones. Our outcomes were corresponded to those of Begum et al. (25), who claimed that 55% of children achieved sitting, 48% achieved crawling, whereas only 19% achieved independent walking. These discrepancies could be explained by disparities in the age groups of the children under study, the severity of the disease, and sample size.

Excessive muscular tone and resistance to passive movement are characteristics of spastic CP. The opposition to passive motion generally escalates as the speed of movement rises (26). Himmelmann et al. (27) and Wright et al. (28) concluded that spasticity adversely impacts gross motor skills in CP cases, particularly during motor tasks. Employing the GMFCS, Eiseigbe et al. (29) found that about 70% of children having spastic CP necessitated an assistive device for mobility. Research conducted by Park et al. (30) similarly revealed that over 60% of children having spastic CP necessitated a handheld mobility aid for ambulation.

The subjects had diverse related comorbidities. In children having CP, motor impairments frequently correlate with sensory, perceptual, cognitive, communicative, and behavioral issues, in addition to epilepsy and subsequent musculoskeletal complications (31-32), intellectual disability, autism, epilepsy, and visual deficits (33-36).

CP can be categorized according to the specific brain regions affected and the timing of the lesions, the nature of the movement disorder (spasticity, dyskinesia, or ataxia), the distribution of involved limbs (hemiplegia, quadriplegia, or diplegia), the degree of motor impairments assessed by tools like GMFCS, and the muscular tone of the afflicted limbs (hypotonic, hypertonic, or isotonic) (37-41).

Based on topographical categorization, our cases have been identified as diplegic (53.3%), hemiplegic (26.7%), and quadriplegic (20%) CP. Research conducted by Begum et al. (25), utilizing a distinct sample size, indicated that the predominant proportion (51%) of participants were identified with spastic quadriplegic CP, while 20.3% were diplegic, 10.4% were hemiplegic, 7.6% were triplegic, and 1.6% were monoplegic CP. Howard et al. (42)

asserted that quadriplegic CP is more prevalent both domestically and globally. However, an additional investigation examined that diplegic CP is more prevalent (43).

A study conducted by Trezol et al. (44) corroborated our findings, revealing that individuals identified with GMFCS levels II, III, IV, and V involved 26%, 12%, 20%, and 42% respectively, according to the GMFCS classification.

Conversely, research conducted by Huroy et al. (45) indicated that level I accounted for 45.7%, with level II at 16%, level III at 12%, level IV at 13.4%, and level V at 12.9%. The discrepancy in sample size could be the reason. The GMFCS has been applied to categorize children having CP according to the intensity of their motor impairment. The GMFCS is a dependable & reliable tool that employs a five-tiered easy ordinal classification system that holds significance for both healthcare professionals and caregivers (46-47). It delineates the manner in which the child moves and utilizes assistive devices, offering a broad understanding of the severity of CP, which aids healthcare providers and carers in assessing the child's rehabilitative prospects (48).

Beyond its function in energy metabolism, LC may also provide cytoprotective benefits. It possesses many neuroprotective, neuromodulatory, and neurotrophic characteristics (49). LC is essential in fulfilling the brain's significant energy demands. It serves as a crucial transporter for long-chain fatty acids (FAs) in the mitochondrial membrane, allowing for their beta-oxidation, which is the main process that produces energy. Notably, LC possesses the capacity to pass through the blood-brain barrier, thereby facilitating cerebral function and energy metabolism (50).

Our study demonstrated that serum LC levels effectively discriminated children with CP from healthy controls. The analysis produced an AUC of 0.893 ( $p$ -value < 0.001), demonstrating good diagnostic performance. Despite patients on anticonvulsants being excluded from our study, feeding difficulties represented 68.9% of our patients. The potential for malnutrition exists because of dysphagia, increased energy requirements, feeding dependence and oropharyngeal disorders (51). Roughly 75% of carnitine in the body is obtained from dietary consumption, especially red meat and dairy products, and the other 25% is produced domestically (52-53).

Carnitine can be acquired through dietary sources and synthesized in the kidneys, brain, and liver; however, it is regarded as a 'conditionally essential' nutrient for humans in particular situations when cellular concentrations are diminished (e.g., premature infants, diabetes, elderly cases, & genetic disorders leading to 1<sup>IV</sup> or 2<sup>IV</sup> carnitine deficiency) (54-55).

Lower serum LC levels were significantly negatively correlated with later achievement of sitting and standing, whereas higher serum LC levels were significantly associated with independent walking, the ability to crawl and climb stairs.

LC fulfils numerous critical activities within intracellular processes, with its primary functions being a supporter of cellular energy metabolism. It conveys long-chain FAs to the mitochondrial matrix & preserves equilibrium of coenzyme A (CoA) in the mitochondria (56). CoA is essential for the induction & oxidation of adipose tissue FAs for production of ATP in the mitochondria (12).

Skeletal muscle contains more than 95% of the total carnitine in the body, where it is essential for the translocation of long-chain FAs across the mitochondrial membrane for beta-oxidation (57). Skeletal muscles lack the capability to synthesize it; therefore, they must obtain it from plasma (58). Moreover, LC exerts a beneficial effect on critical pathways associated with detrimental skeletal muscle wasting. This modulation could be fundamental to some documented anti-catabolic advantages & enhancements in fatigue-related results noted in chronic illness cases taking LC (59).

A notable finding from the present research was the remarkably negative correlation among serum LC levels and GMFCS categorization ( $r$  equal to -0.865,  $p$  < 0.001). The preclinical investigations indicated that administering LC following perinatal hypoxic-ischemic damage or pediatric traumatic brain injury enhanced motor capabilities and both short- and long-term memory (60-61); taking LC post-injury can augment mitochondrial activity (62), reduce cerebral swelling after injury (61,63), and avert tissue loss in pediatric injury models (60,61,63).

Our study's strength was investigating the relation between LC and motor disabilities in non-epileptic spastic CP children in which few research studies had focused on despite the enthusiasm of this topic. The single-centered design of our study, small sample size, and the lack of monitoring were our study's limitations. Future research should focus on multicenter, well-designed, randomized controlled trials to determine whether correcting LC deficiency can improve motor performance, nutritional status, & health-related quality of life in spastic CP cases, particularly those with severe functional impairment (GMFCS IV– V). Such studies should also establish the optimal dosage, duration of supplementation, and the relationship between changes in serum LC concentrations and clinically meaningful functional outcomes.

## Conclusion

Serum LC levels are significantly reduced in children having spastic CP than healthy controls, and that these levels are strongly and inversely correlated with the degree of motor function impairment as determined via GMFCS.

#### List of Abbreviations

| Abbreviation | Full form                                   |
|--------------|---------------------------------------------|
| AUC          | Area under the curve                        |
| CoA          | Coenzyme A                                  |
| CP           | Cerebral palsy                              |
| ELISA        | Enzyme-Linked Immunosorbent Assay           |
| FA           | Fatty acid                                  |
| GMA          | General Movements Assessment                |
| HINE         | Hammersmith Infant Neurologic Examination   |
| GMFCS        | Gross Motor Function Classification System  |
| LC           | L-carnitine                                 |
| MRI          | Magnetic resonance imaging                  |
| mtDNA        | Mitochondrial DNA                           |
| NPV          | Negative predictive value                   |
| IQR          | Interquartile range                         |
| PPV          | Positive predictive value                   |
| ROC          | Receiver operating characteristic           |
| SPSS         | Statistical Package for the Social Sciences |
| SD           | Standard deviation                          |

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#### Authors' contributions

Rana Moustafa contributed to information collection, clinical assessment, and drafting of the manuscript. Ahmed Saad supervised the study design, clinical evaluation, and manuscript revision. Walid Saber performed physical therapy assessments, including GMFCS classification, and contributed to data interpretation. Hala Zeidan and Fatma Hussein. conducted the biochemical analyses (serum L-carnitine measurement by ELISA) and contributed to laboratory data interpretation. Sarah Abdelrashid contributed to statistical analysis, information interpretation, & writing and revision of the manuscript. All authors read & approved the final manuscript.

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#### Declarations

#### Ethics approval and consent to participate

Ethical consent has been secured from the Research Ethics Committee at October 6 University, Egypt. Written informed consent was acquired from the caregivers (parents or legal guardians) of all subjects following a comprehensive elucidation of the research's aims, methodologies, potential advantages, and associated hazards.

#### Consent for publication

Not applicable.

#### Competing interests

The authors declare that they have no competing interests.

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