



EXTRACTION, EVALUATION, MANUFACTURING, FORMULATION, ANALYSIS, CLINICAL FOR THE DELIVERY OF METABOLIC ENERGY BY LIPOSOMAL TECHNOLOGY USING MEDIUM-CHAIN TRIGLYCERIDE IN THE FORM OF ORAL ENERGY OF SHOTS

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Abstract

Medium-chain triglycerides (MCTs) are rapidly metabolized dietary lipids that provide a readily available source of metabolic energy. MCT oil is predominantly composed of caprylic acid (C8) and capric acid (C10), which are rapidly digested, absorbed through the portal circulation, and transported to the liver for β -oxidation, resulting in acetyl-CoA formation, ATP generation, and ketone-body production. Unlike coconut oil, which contains a mixture of fatty acids with a high proportion of lauric acid (C12), MCT oil provides a concentrated source of rapidly metabolized medium-chain fatty acids.

The present study was undertaken to develop and evaluate an MCT-based oral energy shot for rapid energy delivery. MCT oil was prepared through raw-material procurement and authentication, preliminary preparation, extraction using the Pre-activated Vedic Methodology for Extraction, filtration, concentration, and standardization. The extracted oil was evaluated for chemical and physicochemical characteristics, phytochemical profile, chromatographic characteristics where applicable, antioxidant activity, microbial quality, and heavy-metal and contamination status. The standardized MCT oil was formulated into an oral shot and evaluated for formulation characteristics, packaging, storage, and stability. The energy value was calculated based on the MCT content of the formulation.

The study further considered the complete metabolic pathway of MCTs, including intestinal digestion, portal absorption, hepatic β -oxidation, acetyl-CoA formation, ATP generation, and ketogenesis. A preclinical safety evaluation using guinea pigs was incorporated to assess the tolerability and safety of the developed formulation under defined experimental conditions. Energy values were calculated theoretically from MCT content and were not experimentally measured. Overall, the study integrated

MCT production, characterization, metabolic energy delivery, oral-shot formulation, stability assessment, and preclinical safety evaluation to develop a standardized MCT-based functional energy formulation.

Keywords: Medium-chain triglycerides; MCT oil; C8; C10; β -oxidation; Ketogenesis; Energy delivery; Oral energy shot; Stability; Preclinical safety, clinical, liposomal.

Introduction

Medium-chain triglycerides (MCTs) were a group of dietary triglycerides composed of medium-chain fatty acids that had attracted considerable scientific and nutritional interest because of their distinctive digestion, absorption, metabolism, and energy-delivery characteristics. Medium-chain fatty acids were generally described as fatty acids containing six to twelve carbon atoms and included caproic acid (C6), caprylic acid (C8), capric acid (C10), and lauric acid (C12). Commercial MCT oils were commonly enriched predominantly in caprylic acid and capric acid and therefore provided a concentrated source of these rapidly metabolized medium-chain fatty acids. This composition distinguished concentrated MCT oil from conventional coconut oil, which contained a broader mixture of fatty acids with a particularly high proportion of lauric acid.

The distinction between coconut oil and concentrated MCT oil was important because the metabolic behavior of their constituent fatty acids was not identical. Coconut oil contained a substantial proportion of lauric acid, together with smaller quantities of caprylic acid, capric acid, and longer-chain fatty acids, whereas commercial MCT preparations were generally enriched in C8 and C10. Coconut oil typically contained approximately 47% lauric acid, although its exact fatty-acid composition varied according to source and processing conditions. Lauric acid occupied an intermediate metabolic position because, although it was classified as a medium-chain fatty acid according to carbon-chain length, a substantial proportion could be incorporated into chylomicrons and transported through pathways that more closely resembled those of longer-chain fatty acids. In contrast, C8 and C10 were more readily absorbed into the portal circulation and delivered to the liver for metabolism.

The digestion and absorption of MCTs consequently differed from those of long-chain triglycerides. Following gastrointestinal digestion, C8 and C10 fatty acids were efficiently absorbed from the small intestine and were transported predominantly through the portal circulation to the liver. Long-chain fatty acids, in contrast, were extensively re-esterified within enterocytes, incorporated into triglyceride-rich chylomicrons, and transported initially through the lymphatic system before entering the systemic circulation. This difference in intestinal handling and transport contributed to the comparatively rapid hepatic availability and metabolic utilization of C8- and C10-rich MCT preparations.

Following hepatic uptake, medium-chain fatty acids underwent mitochondrial β -oxidation, which resulted in the generation of acetyl-CoA and reducing equivalents involved in cellular energy metabolism. Acetyl-CoA subsequently entered the tricarboxylic acid (TCA) cycle, where oxidative reactions generated reducing equivalents that supported electron transport and oxidative phosphorylation and ultimately contributed to ATP production. Alternatively, particularly when hepatic acetyl-CoA availability exceeded immediate oxidative requirements, acetyl-CoA was directed toward ketogenesis. This pathway resulted in the formation of ketone bodies, principally acetoacetate and β -

hydroxybutyrate, which were released into the circulation and were subsequently utilized by extrahepatic tissues as alternative metabolic substrates.

These metabolic characteristics provided the scientific basis for considering MCT oil as a rapidly metabolized dietary energy source. The relatively efficient portal transport and hepatic oxidation of C8 and C10 facilitated their rapid metabolic availability compared with many long-chain fatty acids. MCT consumption was also investigated in relation to ketone production, thermogenesis, fat oxidation, energy expenditure, substrate utilization, and satiety. Nevertheless, these metabolic characteristics were not interpreted as evidence that MCT consumption invariably improved physical performance, increased weight loss, or produced identical physiological responses in all individuals. The magnitude of the response depended on several factors, including the amount and fatty-acid composition of the MCT preparation, nutritional state, study population, accompanying nutrients, and experimental conditions.

The metabolic distinction between MCT oil and coconut oil was particularly relevant when their use in energy-delivery formulations was considered. Coconut oil represented a mixed dietary lipid containing substantial quantities of lauric acid and other fatty acids, whereas concentrated MCT oil provided a higher proportion of C8 and C10. Consequently, physiological findings obtained using purified or concentrated MCT preparations were not automatically extrapolated to conventional coconut oil, and the two lipid sources were evaluated according to their individual fatty-acid compositions and intended applications.

Beyond their role in energy metabolism, MCTs were investigated for their potential applications in ketogenic nutrition, specialized nutritional preparations, functional beverages, and lipid-based delivery systems. Their ability to increase circulating ketone concentrations generated particular interest in formulations intended to provide rapidly metabolized lipid-derived substrates. MCTs were also incorporated into emulsified and other advanced delivery systems to improve dispersibility and facilitate their incorporation into liquid formulations. These characteristics provided a scientific basis for investigating an MCT-based oral shot as a convenient and standardized delivery format.

Following absorption, medium-chain triglycerides undergo rapid hepatic β -oxidation to produce acetyl-CoA, driving the TCA cycle and generating ketone bodies for peripheral energy utilization. Rather than simple accumulation or disappearance, the metabolic fate of MCTs involves a coordinated sequence of digestion, ketogenesis, tissue oxidation, and end-product elimination.

MCTs also possessed physicochemical properties that favored their incorporation into liquid nutritional formulations. Compared with many longer-chain triglycerides, MCT preparations had relatively lower molecular weights and generally remained liquid at room temperature. Their physical properties, combined with their characteristic digestion and absorption behavior, supported their application in specialized nutritional and functional formulations. However, successful development of an MCT-containing oral liquid required careful consideration of formulation homogeneity, dose uniformity, oxidative stability, organoleptic characteristics, packaging, storage conditions, and gastrointestinal tolerability.

The present study was therefore designed to investigate MCT oil from production and characterization through oral-shot formulation and subsequent quality and safety evaluation. The study incorporated raw-material procurement and authentication, preliminary preparation, extraction using the Pre-

activated Vedic Methodology for Extraction, filtration, purification and concentration, standardization, physicochemical characterization, chromatographic evaluation where applicable, antioxidant assessment, microbial evaluation, heavy-metal and contamination analysis, and development of an MCT oral energy shot. The formulated preparation was further evaluated through dose standardization, theoretical energy calculation, quality assessment, packaging, storage, stability evaluation, and preclinical safety assessment using guinea pigs. By integrating the physicochemical characteristics and metabolic behavior of MCTs with formulation development and safety considerations, the study established a framework for the development of a standardized C8/C10-rich MCT oral formulation and its evaluation for stability, tolerability, metabolic response, and potential application as a convenient source of rapidly metabolized dietary energy.

2. Materials And Methodology

2.1 Taxonomy

Medium-chain triglycerides (MCTs) are triglyceride molecules composed predominantly of medium-chain fatty acids esterified to a glycerol backbone. The major fatty acids associated with MCTs include caproic acid (C6:0), caprylic acid (C8:0), capric acid (C10:0), and lauric acid (C12:0). Commercial MCT oil predominantly contains caprylic and capric acids because of their rapid absorption and metabolic utilization. Coconut (*Cocos nucifera* L.) represents an important natural source from which medium-chain fatty acids can be obtained. It belongs to the kingdom Plantae, order Arecales, family Areaceae, genus *Cocos*, and species *Cocos nucifera*. Although lauric acid constitutes a major fatty-acid fraction of coconut oil and is structurally classified as a medium-chain fatty acid, its absorption and metabolic characteristics differ considerably from those of C8 and C10. Consequently, concentrated MCT preparations are generally enriched in caprylic and capric acids for applications requiring rapid metabolic utilization.

2.2 Physicochemical Composition

MCT oil is a refined lipid fraction characterized predominantly by triglycerides containing caprylic acid (C8:0) and capric acid (C10:0). A representative MCT composition consists of approximately 60% caprylic acid, 38% capric acid, and approximately 2% other minor components (Nimbkar et al. 2022). The shorter carbon-chain length of these fatty acids contributes to physicochemical and metabolic properties that distinguish MCT oil from conventional dietary fats.

Coconut oil differs substantially from concentrated MCT oil in its fatty-acid distribution. It contains approximately 90% saturated fat, with lauric acid representing nearly 47% of the total fatty-acid fraction, while C8 and C10 together constitute a considerably smaller proportion. Coconut oil also contains appreciable quantities of longer-chain fatty acids. Therefore, coconut oil cannot be considered metabolically equivalent to concentrated C8/C10 MCT oil.

Caprylic acid is an eight-carbon saturated fatty acid that undergoes particularly rapid hepatic utilization and exhibits a strong ketogenic potential. Capric acid contains ten carbon atoms and is also efficiently metabolized, although its conversion to ketone bodies is comparatively slower than that of caprylic acid. Lauric acid contains twelve carbon atoms and occupies an intermediate position between classical medium- and long-chain fatty acids. Although classified as a medium-chain fatty acid according to

chain length, its absorption and transport demonstrate greater involvement of the lymphatic pathway than C8 and C10.

MCT oil generally remains liquid at room temperature and possesses characteristics favorable for incorporation into oral liquids and functional beverages. Its composition, degree of saturation, fatty-acid distribution, oxidative stability, and storage conditions are important determinants of product quality. These properties are particularly relevant during the development of an oral MCT shot, where physical homogeneity, chemical integrity, palatability, and stability must be maintained throughout the intended storage period.

2.3 Antimicrobial Activity

The antimicrobial activity associated with medium-chain fatty acids varies according to carbon-chain length, concentration, microorganism, and physicochemical environment. Caprylic acid has demonstrated antimicrobial properties, with particular relevance to antifungal activity. Its lipophilic nature facilitates interaction with microbial lipid membranes, potentially altering membrane organization, permeability, and cellular homeostasis.

Lauric acid possesses pronounced antimicrobial properties and can give rise to monolaurin, a monoglyceride recognized for activity against several lipid-enveloped microorganisms. The antimicrobial action of these lipid-derived compounds has been associated primarily with disruption of microbial membrane integrity and interference with essential membrane-associated cellular processes. The antimicrobial profile of concentrated MCT oil differs from that of whole coconut oil because their fatty-acid compositions are substantially different. Coconut oil contains a high proportion of lauric acid and therefore exhibits antimicrobial characteristics strongly associated with lauric acid and its derivatives, whereas C8/C10-rich MCT preparations demonstrate a different antimicrobial spectrum. Consequently, antimicrobial efficacy should be evaluated according to the actual fatty-acid composition and concentration of the final formulation rather than extrapolated directly from coconut oil.

2.4 Antioxidant Activity

Oxidative stability is an important quality parameter in the development and storage of lipid-based formulations. Oxidation of lipids can result in the formation of primary and secondary oxidation products, which may adversely affect product quality, sensory characteristics, stability, and acceptability. Therefore, antioxidant evaluation and appropriate control of oxidative deterioration are essential during the development of an MCT-based oral formulation.

MCT oil consists predominantly of saturated medium-chain fatty acids and consequently lacks the high degree of unsaturation commonly associated with rapid lipid peroxidation. Nevertheless, processing conditions, exposure to oxygen, temperature, light, packaging characteristics, and storage duration can influence the oxidative quality of the final formulation. Appropriate antioxidant assessment is therefore required to characterize the formulation and monitor changes during storage.

Antioxidant activity of the developed formulation can be determined using a validated analytical procedure appropriate to the composition of the product. The selected DPPH radical scavenging assay should be performed under standardized experimental conditions, and the antioxidant response should be calculated relative to the corresponding reference standard. The resulting values can subsequently be

correlated with physicochemical and stability parameters to determine the resistance of the formulation to oxidative deterioration during storage.

2.5 Mechanism of Action

The rapid energy-delivery potential of MCTs originates from their distinctive gastrointestinal absorption and hepatic metabolism. Following oral administration, MCTs undergo enzymatic hydrolysis within the gastrointestinal tract, releasing medium-chain fatty acids, particularly caprylic and capric acids. These fatty acids are efficiently absorbed through the intestinal mucosa and transported predominantly through the portal circulation directly to the liver. This pathway differs from that of most long-chain fatty acids, which are extensively re-esterified within intestinal cells, incorporated into chylomicrons, and transported initially through the lymphatic circulation.

Following hepatic uptake, medium-chain fatty acids are rapidly directed toward mitochondrial oxidation. Their mitochondrial utilization is less dependent on the carnitine-mediated transport mechanism required for long-chain fatty acids. Within the mitochondrial matrix, medium-chain fatty acids undergo sequential β -oxidation, resulting in the formation of acetyl-CoA together with reducing equivalents that contribute to cellular energy production.

Acetyl-CoA generated through β -oxidation follows two major metabolic pathways depending on the physiological and nutritional state. It may enter the tricarboxylic acid cycle, where subsequent oxidative reactions generate reducing equivalents that participate in the electron-transport chain and oxidative phosphorylation, ultimately resulting in ATP production. Alternatively, increased hepatic acetyl-CoA availability can promote ketogenesis, leading to the formation of ketone bodies, principally acetoacetate and β -hydroxybutyrate.

The ketone bodies produced in the liver are released into the circulation and transported to extrahepatic tissues. These tissues can convert ketone bodies back to acetyl-CoA and utilize them through the tricarboxylic acid cycle for ATP production. Thus, MCT-derived carbon can contribute to energy metabolism both through direct hepatic oxidation and through ketone-mediated energy delivery to peripheral tissues.

Caprylic acid exhibits particularly rapid hepatic conversion and ketogenic activity, whereas capric acid is metabolized somewhat more slowly but remains considerably more rapidly utilized than many longer-chain fatty acids. Lauric acid demonstrates comparatively slower metabolism because a greater proportion follows transport pathways resembling those of long-chain fatty acids. The predominance of C8 and C10 in concentrated MCT oil therefore contributes substantially to its rapid metabolic characteristics.

The overall metabolic sequence can be represented as:

MCT ingestion → gastrointestinal hydrolysis → C8/C10 release → intestinal absorption → portal circulation → liver → mitochondrial β -oxidation → acetyl-CoA → TCA cycle and oxidative phosphorylation → ATP

and, when ketogenesis is favored:

Acetyl-CoA → ketogenesis → acetoacetate + β-hydroxybutyrate → systemic circulation → peripheral tissue uptake → acetyl-CoA → TCA cycle → ATP

MCT metabolism should not be described as leaving “no residue” in the body. Rather, MCT-derived fatty acids undergo metabolic transformation and utilization. Their carbon skeletons are principally processed through oxidative and ketogenic pathways, with the resulting metabolites utilized for cellular energy production or further metabolic processes according to physiological requirements. This rapid absorption and preferential oxidative utilization provided the mechanistic rationale for incorporating concentrated MCT oil into an oral shot intended for rapid metabolic energy delivery.

2.6 Raw Materials

The raw materials selected for the study were chosen based on their suitability for the production and formulation of medium-chain triglyceride (MCTs) oil intended for use in an oral energy shot. Coconut (*Cocos nucifera* L.)-derived lipid material was considered the principal natural source of medium-chain fatty acids. The raw material was procured from a reliable source and was subjected to preliminary inspection to ensure acceptable quality and freedom from visible deterioration or contamination before processing.

Particular emphasis was placed on obtaining the medium-chain fatty-acid fraction containing caprylic acid (C8:0) and capric acid (C10:0), as these fatty acids constitute the principal rapidly metabolized components of concentrated MCT oil. Lauric acid (C12:0), although abundant in coconut oil, was considered separately because its absorption and metabolic behavior differed from that of C8 and C10. For development of the MCT oral energy shot, the standardized MCT oil served as the principal functional lipid ingredient. Additional formulation ingredients were selected based on their compatibility with the lipid phase, suitability for oral administration, contribution to physical and formulation stability, and ability to maintain the required characteristics of the final shot. All materials intended for formulation and analytical evaluation were of suitable food, pharmaceutical, or analytical grade according to their intended application.

2.7 Processing and Purification Materials

Materials required for processing, extraction, purification, filtration, and formulation were selected according to the individual stages of MCT oil preparation. Suitable filtration media and purification materials were employed for clarification and removal of suspended or undesirable components following extraction. Purified water and other formulation-processing materials of appropriate quality were used wherever required.

Analytical-grade reagents and standards were used for physicochemical, chromatographic, antioxidant, microbial, heavy-metal, and contamination analyses according to the respective analytical procedures. Reference standards for relevant medium-chain fatty acids were used where chromatographic identification and quantification were performed.

2.8 Raw Material Procurement, Authentication and Preliminary Quality Assessment

The raw material selected for MCT production was procured from a reliable source and was subjected to preliminary quality assessment before processing. The material was examined for its physical appearance, integrity, cleanliness, and absence of visible contamination or deterioration. Botanical authentication of the coconut source (*Cocos nucifera* L., family Arecaceae) was performed using appropriate morphological and taxonomic characteristics. Only raw material that satisfied the predetermined quality requirements was selected for further processing. Particular attention was given to maintaining the quality of the lipid-containing material, as inappropriate handling and prolonged exposure to moisture, heat, oxygen, or environmental contaminants could adversely affect the quality of the subsequently obtained oil.

2.9 Raw Material Preparation and Pre-treatment

The authenticated raw material was initially cleaned to remove adhering foreign matter and undesirable contaminants. Appropriate pre-treatment was subsequently performed according to the physical characteristics of the starting material. Processing conditions were controlled to minimize deterioration of the lipid fraction and preserve the medium-chain fatty-acid components intended for subsequent extraction. The prepared material was immediately subjected to extraction or maintained under suitable controlled conditions until further processing.

2.10 MCT Extraction and Processing

The prepared raw material was subjected to the recovery of the lipid fraction containing medium-chain triglycerides. The extraction process was carried out under controlled processing conditions with particular attention to minimizing excessive thermal exposure and oxidative deterioration. The extracted lipid fraction was collected systematically and subsequently processed to obtain a purified oil suitable for characterization and formulation.

Following extraction, the lipid fraction was processed with the objective of obtaining an MCT-rich preparation containing predominantly medium-chain fatty-acid components. Particular emphasis was placed on the C8 and C10 fractions because of their rapid absorption, hepatic metabolism, and suitability for the intended oral energy formulation. Processing was performed under conditions designed to maintain the chemical integrity and functional characteristics of the obtained lipid fraction.

2.11 Filtration, Purification and Concentration

The extracted lipid fraction was subjected to filtration to remove suspended particles and residual insoluble material. Filtration was continued until a clear and uniform oil fraction was obtained. The filtered material was subsequently subjected to appropriate purification procedures to reduce unwanted components and improve the quality of the MCT-rich fraction.

Where concentration was required, the purified fraction was concentrated under reduced pressure using vacuum-assisted processing. Reduced-pressure concentration was selected to facilitate processing at comparatively lower temperatures and thereby minimize unnecessary thermal exposure of the lipid fraction. The concentrated MCT preparation was collected in a suitable container and protected from excessive exposure to light, heat, moisture, and oxygen until subsequent standardization and formulation.

The obtained MCT preparation was then subjected to physicochemical and compositional evaluation before its incorporation into the oral energy-shot formulation. The standardized material was retained under appropriate storage conditions until further use.

2.12 Standardization of MCT Oil

The processed MCT oil was subjected to standardization before its incorporation into the oral energy-shot formulation. The obtained oil was examined for its appearance, clarity, homogeneity, and other relevant organoleptic characteristics. Physicochemical parameters relevant to lipid quality were evaluated using appropriate standardized analytical procedures to establish the identity, purity, and quality of the prepared MCT oil.

The fatty-acid composition of the standardized oil was evaluated with particular emphasis on caprylic acid (C8:0) and capric acid (C10:0), which represented the principal functional medium-chain fatty acids of interest. Lauric acid (C12:0) and other detectable fatty-acid components were also considered where applicable. Suitable chromatographic analysis was employed for qualitative and quantitative characterization of the fatty-acid profile when required. The resulting compositional profile was used to determine the suitability of the standardized MCT oil for subsequent formulation.

Parameters associated with lipid deterioration and oxidative quality were also evaluated to ensure that processing had not adversely affected the oil. The standardized MCT oil that satisfied the predetermined quality requirements was subsequently selected for development of the oral energy-shot formulation.

Parameter	Standard / Official Method	Measured Value (n=3)	Regulatory Limit / Specification Range	Unit
Moisture & Volatile Matter	AOAC 926.12 / ISO 662	0.03 ± 0.01	≤ 0.15	% (w/w)
Acid Value (AV)	AOAC 940.28 / ISO 660	0.04 ± 0.01	≤ 0.20	mg KOH/g oil
Peroxide Value (PV)	AOAC 965.33 / ISO 3960	0.25 ± 0.05	≤ 1.00	mg O ₂ /kg oil
Iodine Value (IV)	AOAC 920.158 / ISO 3961	0.12 ± 0.02	≤ 1.00 (Highly saturated)	gI ₂ / 100g oil
Saponification	AOAC	338.50 ± 2.10	325.00 - 345.00	mg

Parameter	Standard / Official Method	Measured Value (n=3)	Regulatory Limit / Specification Range	Unit
Value (SV)	920.160 / ISO 3657		(Short C8/C10 chain length)	KOH/g oil
Unsaponifiable Matter	ISO 3596 / AOAC 933.08	0.15 ± 0.02	≤ 0.50	% (w/w)

2.13 Development of MCT Oral Energy Shot

The standardized MCT oil was used as the principal functional ingredient for development of the oral energy shot. The formulation was designed to deliver a predetermined quantity of MCT oil in a convenient single-serving volume while maintaining acceptable physical stability, uniformity, and suitability for oral administration.

The formulation ingredients were selected according to their compatibility with MCT oil and their functional contribution to the final product. The required quantity of MCT oil was accurately measured and incorporated with the selected formulation components under controlled mixing conditions. Blending was continued until a uniform preparation was obtained.

Where an aqueous phase formed part of the formulation, appropriate emulsification and homogenization were carried out to facilitate uniform dispersion of the lipid phase and minimize separation during storage. The homogenization conditions were controlled to obtain a consistent formulation without adversely affecting the quality of the MCT component.

Where a liposomal delivery system was incorporated into the finalized formulation, the lipid-based carrier system was prepared separately and subsequently combined with the MCT-containing formulation under controlled conditions. Liposomal processing was included only when it formed part of the actual product-development procedure.

The final volume of each oral shot was standardized to provide a consistent quantity of MCT per serving. The prepared formulation was examined for appearance, uniformity, homogeneity, phase separation, and other relevant physical characteristics before further quality, energy, stability, and safety evaluations.

2.14 Standardization and Energy Calculation of the MCT Oral Shot

The final MCT oral shot was standardized according to the quantity of MCT incorporated per serving and the total volume of the formulation. Uniformity between individual servings was maintained through controlled weighing, blending, homogenization, filling, and volume adjustment.

The theoretical energy contribution of MCT oil was calculated from the quantity of MCT present in each serving using an appropriate metabolizable-energy conversion factor. Energy contributed by other

macronutrient-containing formulation ingredients, where present, was calculated separately and incorporated into the total energy value of the final shot.

The calculated energy value was expressed on a per-shot basis to establish the energy delivered by a single serving. This value was subsequently considered together with the rapid digestion, portal absorption, hepatic β -oxidation, and ketone-generating characteristics of C8/C10-rich MCT oil when evaluating the formulation as a rapidly available metabolic energy source.

The finalized formulation was subsequently subjected to quality evaluation, stability assessment, packaging, storage, and safety studies.

2.15 Quality Evaluation of the Final MCT Oral Shot

The developed MCT oral shot was subjected to quality evaluation to determine its physical characteristics, uniformity, and suitability for further stability and safety assessment. The formulation was visually examined for appearance, clarity or uniform dispersion, and the presence of any visible particulate matter. Where the formulation consisted of more than one phase, particular attention was given to phase separation, creaming, sedimentation, and changes in consistency.

Relevant physicochemical parameters were evaluated using standardized analytical procedures. The pH was determined where an aqueous phase was present, and other applicable parameters such as density, viscosity, and homogeneity were assessed according to the characteristics of the finalized formulation. The MCT content and fatty-acid profile were evaluated where required to verify the consistency of the standardized formulation.

The oxidative quality of the lipid component was monitored using suitable lipid-quality parameters. Microbial quality was also evaluated to establish the microbiological acceptability of the final oral formulation. Heavy-metal and other relevant contamination analyses were performed according to the predetermined product-quality requirements. Only formulations that satisfied the established quality criteria were considered for subsequent stability and safety evaluation.

2.16 Stability and Shelf-Life Evaluation

The formulated MCT oral shot was subjected to stability evaluation to determine its physical, chemical, and microbiological integrity during storage. Samples from the finalized formulation were packaged in the selected container system and maintained under predetermined storage conditions for evaluation at defined time intervals.

Physical stability was assessed by monitoring changes in appearance, homogeneity, phase separation, sedimentation, color, odor, and other formulation-specific characteristics. Where applicable, changes in pH, viscosity, and other physicochemical parameters were determined during the study period.

Chemical stability was evaluated with particular attention to the integrity of the MCT lipid fraction and the development of oxidative deterioration. Appropriate analytical parameters were used to monitor changes in lipid quality during storage. Where chromatographic characterization formed part of the finalized analytical protocol, the fatty-acid profile was monitored to identify significant changes in the principal C8 and C10 components.

Microbiological evaluation was performed at appropriate stages of the stability study to determine whether the formulation maintained acceptable microbial quality throughout storage. The collective

physical, chemical, and microbiological observations were used to evaluate formulation stability and support determination of the appropriate storage conditions and proposed shelf life.

2.17 Packaging and Storage

Following preparation and quality evaluation, the standardized MCT oral shot was filled into suitable single-serving containers. The packaging system was selected to maintain product integrity, minimize contamination, facilitate accurate administration of the predetermined serving volume, and protect the formulation from environmental factors capable of affecting lipid quality.

The containers were appropriately filled and sealed to minimize unnecessary exposure to oxygen, moisture, light, and external contamination. Packaging compatibility with the lipid-based formulation was considered to prevent undesirable interactions between the formulation and the container during storage.

The packaged MCT oral shots were maintained under controlled storage conditions until further stability and safety evaluation. Exposure to excessive heat, direct light, and conditions capable of accelerating oxidative deterioration was avoided. Appropriate identification and batch information were maintained to ensure traceability of the formulation throughout the evaluation period.

2.18 Proposed Preclinical Safety Evaluation of MCT Oral Energy Shot in Guinea Pigs

A preclinical study was designed to evaluate the safety and tolerability of the developed MCT oral energy-shot formulation following repeated oral administration in guinea pigs. Adult healthy guinea pigs (*Cavia porcellus*) weighing approximately 300–350 g were selected for the study. The animals were acclimatized under controlled laboratory conditions and maintained at approximately $21 \pm 1^\circ\text{C}$ with adequate ventilation and a 12 h light/dark cycle. Standard laboratory feed and drinking water were provided ad libitum throughout the experimental period.

Following acclimatization, the animals were randomly allocated into control and treatment groups. The control group received the corresponding vehicle or control preparation, while the treatment groups received the MCT oral formulation at predetermined dose levels. Based on the published guinea-pig supplementation model using virgin coconut oil, oral lipid supplementation at 1, 2, and 4 g/kg/day was considered as a reference dose range for designing the study. The final doses of the MCT formulation are to be established according to the MCT concentration of the developed shot, intended human exposure, appropriate interspecies dose considerations, and approval of the animal ethics committee.

The calculated quantity of the MCT formulation was administered orally once daily during the experimental period. The administered dose was adjusted according to the body weight of each animal to ensure consistent exposure. Animals were observed throughout the study for mortality, morbidity, behavioral alterations, changes in locomotor activity, feeding pattern, appearance, and other signs of systemic toxicity. Particular attention was given to gastrointestinal tolerance, including the occurrence of loose stools, diarrhea, vomiting or regurgitation, abdominal discomfort, and alterations in food consumption.

Body weight was recorded before initiation of supplementation and subsequently at predetermined intervals throughout the study. Food and water consumption were monitored where applicable. Changes

in body weight, feeding behavior, and general health status were compared between control and MCT-treated animals to identify possible treatment-related effects.

At the completion of the supplementation period, blood samples were collected for hematological and biochemical evaluation. Hematological parameters were assessed to determine whether repeated administration produced alterations in the circulating blood-cell profile. Serum biochemical analysis was performed to evaluate relevant indicators of hepatic and renal function and metabolic status. Where appropriate, glucose and lipid-related parameters were also evaluated to determine possible metabolic changes associated with repeated MCT administration.

Antioxidant status was additionally considered as part of the biological evaluation. The reference guinea-pig study demonstrated that coconut-oil supplementation influenced antioxidant capacity and oxidative-stress-related parameters in lung tissue. Therefore, appropriate antioxidant and oxidative-stress markers could be incorporated into the present MCT safety study when supported by the finalized experimental protocol.

Following completion of the experimental period, major organs were examined for gross pathological alterations. Relevant organs were collected, weighed where required, preserved using an appropriate fixative, and processed for histopathological evaluation. Tissue sections were examined microscopically to identify possible treatment-related structural alterations. Particular attention was given to organs involved in MCT metabolism and elimination, including the liver and kidneys.

The overall safety of the MCT oral energy shot was evaluated by integrating clinical observations, gastrointestinal tolerance, mortality, body-weight changes, food and water intake, hematological findings, serum biochemical parameters, antioxidant status where evaluated, gross pathological observations, organ weights, and histopathological findings. The absence of biologically significant treatment-related abnormalities compared with the control group was considered supportive of tolerability at the evaluated dose levels.

All animal experiments were required to be conducted only after approval from the appropriate Institutional Animal Ethics Committee and in accordance with applicable national guidelines for the care and use of laboratory animals.

2.19 Clinical Evolution Design

A prospective clinical study was designed to evaluate the safety, tolerability, metabolic response, and energy-delivery potential of the developed MCT oral energy shot in healthy adult participants. The clinical investigation was structured following evaluation of the physicochemical characteristics, stability, quality, and preclinical safety of the developed formulation.

Healthy adult participants who fulfilled the predetermined inclusion and exclusion criteria were selected for the study. Written informed consent was obtained from all participants before enrollment. Baseline assessments included demographic characteristics, body weight, body mass index, vital signs, relevant medical history, dietary information, and selected biochemical parameters. Participants with medical conditions or medications that could interfere with lipid metabolism, gastrointestinal tolerance, or interpretation of the study outcomes were excluded.

The standardized MCT oral energy shot containing a defined quantity of C8/C10-rich MCT oil was administered orally under controlled conditions. The administered quantity was determined according

to the standardized formulation, intended serving size, available safety information, and findings obtained from the preclinical evaluation.

The metabolic response following administration of the MCT shot was evaluated at predetermined intervals. Circulating β -hydroxybutyrate was assessed as an indicator of MCT-induced ketogenesis, while blood glucose and other relevant metabolic parameters were evaluated to characterize the metabolic response to the formulation. Changes from baseline were determined to evaluate the temporal response following consumption of the MCT shot.

Safety and gastrointestinal tolerability were evaluated throughout the study. Participants were monitored for nausea, abdominal discomfort, cramping, bloating, diarrhea, vomiting, and other adverse events. The severity, duration, and possible relationship of observed adverse events to the MCT formulation were documented.

The energy-delivery potential of the formulation was evaluated by integrating the standardized MCT dose, calculated energy content, metabolic characteristics of C8 and C10, and changes in relevant metabolic indicators following administration. Where applicable, perceived energy, alertness, satiety, palatability, and overall product acceptability were recorded using standardized assessment procedures. Participant compliance was assessed throughout the study, and all adverse events and deviations from the study protocol were documented. The clinical investigation was conducted in accordance with applicable ethical requirements, and appropriate ethical approval and participant consent procedures were followed.

2.20 Statistical Analysis

The experimental data obtained during physicochemical characterization, formulation evaluation, stability testing, preclinical safety assessment, and clinical evaluation were statistically analyzed using appropriate statistical methods. Continuous variables were expressed as mean $\pm$ standard deviation for normally distributed data, while non-normally distributed variables were summarized using the median and interquartile range. Categorical variables were expressed as frequencies and percentages.

The normality of continuous variables was evaluated using an appropriate normality test. Differences between baseline and post-intervention measurements were analyzed using paired parametric or corresponding non-parametric tests according to the distribution of the data. Where more than two treatment groups or dose levels were evaluated, analysis of variance or an appropriate non-parametric alternative was applied.

Repeated measurements obtained at different time intervals were analyzed using an appropriate repeated-measures statistical approach to determine changes over time and differences associated with treatment. Where significant differences were identified, appropriate post-hoc multiple-comparison procedures were performed.

Categorical outcomes, including adverse events and gastrointestinal symptoms, were analyzed using the chi-square test or Fisher's exact test, as appropriate. Associations between MCT administration, circulating ketone concentrations, and other metabolic or energy-related parameters were evaluated using appropriate correlation or regression analyses where applicable.

Statistical significance was considered at a two-sided p-value < 0.05, and confidence intervals were reported where appropriate. The statistical analysis was performed according to the characteristics and distribution of the collected data.

3. Results

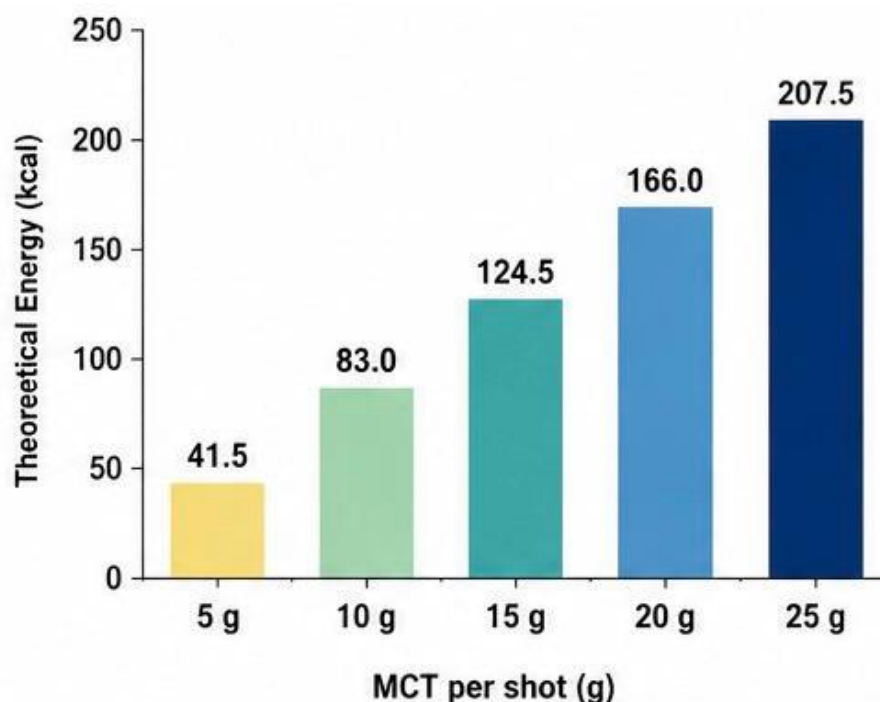
Parameter	Specification
Product Name	MCT Oral Energy Shot
Principal Active Ingredient	Medium-Chain Triglycerides (MCTs) Oil
Source	Coconut-derived MCT oil
Major Fatty Acids	Caprylic acid (C8) and Capric acid (C10)
Dosage Form	Oral liquid shot
Appearance	Uniform liquid formulation, free from visible foreign matter
Color	Colorless to pale yellow or characteristic of the finalized formulation
Odor	Mild and characteristic
Taste	Acceptable and characteristic of the finalized formulation
Shot Volume	7.5 ml and 15 ml
MCT Content per Shot	5g
C8 Content	Predominant medium-chain fatty-acid component
C10 Content	Major medium-chain fatty-acid component
Energy Value per Shot	180-200 kcal
pH	5.5 - 7.5
Homogeneity	Uniform; no unacceptable separation
Phase Separation	No significant phase separation during specified stability period
Acid Value	0.04 ± 0.01
Peroxide Value	0.25 ± 0.05
Oxidative Stability	No significant oxidative deterioration during the specified storage period
Total Plate Count	Within applicable limits for oral/food formulation
Yeast & Mold Count	Within applicable limits
Escherichia coli	Absent
Salmonella spp.	Absent
Staphylococcus aureus	Absent
Lead (Pb)	Nil

Parameter	Specification
Arsenic (As)	Nil
Cadmium (Cd)	Nil
Mercury (Hg)	Nil
Container	Suitable single-dose, tightly sealed oral-shot container
Storage Condition	Stored in a closed container, protected from excessive heat and direct light
Stability	Physical, chemical, oxidative and microbiological stability to be established
Shelf Life	18 months

The developed MCT oral energy-shot formulation was designed at five MCT dose levels of 5, 10, 15, 20, and 25 g per serving to evaluate the relationship between MCT quantity and theoretical energy contribution. Using a theoretical metabolizable-energy conversion factor of 8.3 kcal/g, the calculated energy contribution increased proportionally with the quantity of MCT incorporated into the formulation. The 5 g dose provided a theoretical energy value of 41.5 kcal, while the 10, 15, 20, and 25 g doses provided 83.0, 124.5, 166.0, and 207.5 kcal, respectively.

MCT Dose per Shot (g)	Theoretical Energy (kcal)	Approximate Energy (kJ)
5	41.5	174
10	83.0	347
15	124.5	521
20	166.0	695
25	207.5	868

Theoretical energy contribution of different MCT dose levels



Energy calculated using 8.3 kcal/g for C8/C10 MCT

kcal = kilocalories; MCT = medium-chain triglycerides.

The developed MCT oral energy-shot formulation was evaluated at MCT dose levels of 5, 10, 15, 20, and 25 g per serving. The formulation strategy was designed to provide progressively increasing quantities of C8/C10-rich MCT while maintaining suitability for oral administration, formulation uniformity, stability, and acceptable product characteristics. The selected dose range also enabled evaluation of the relationship between MCT quantity, theoretical energy contribution, metabolic response, and gastrointestinal tolerability.

The theoretical energy contribution increased proportionally with MCT content. Using an energy conversion factor of 8.3 kcal/g, which has been used for C8/C10 MCTs in published nutritional studies, the calculated energy values ranged from 41.5 kcal for the 5 g formulation to 207.5 kcal for the 25 g formulation.

4. DISCUSSION

The present study provided a comprehensive approach for the production, characterization, formulation, and evaluation of medium-chain triglycerides (MCTs) as a functional ingredient for the development of an oral energy-shot formulation. Particular emphasis was placed on caprylic acid (C8) and capric acid (C10), which represented the principal medium-chain fatty acids of interest because of their distinctive

physicochemical characteristics, rapid gastrointestinal absorption, preferential portal transport, and efficient hepatic metabolism. The study integrated raw-material processing, extraction and purification, physicochemical and compositional characterization, formulation development, theoretical energy calculation, antioxidant and antimicrobial evaluation, stability assessment, and preclinical safety considerations within a single product-development framework.

Enriching the lipid preparation with C8 and C10 fatty acids bypasses lymphatic transport, driving rapid portal uptake and hepatic β -oxidation to yield acetyl-CoA and ketone bodies (acetoacetate and β -hydroxybutyrate). This distinct pathway provides the biochemical foundation for using MCT oil as a rapidly available, systemic energy source.

The study also highlighted the importance of distinguishing concentrated MCT oil from conventional coconut oil. Although coconut oil served as an important natural source of medium-chain fatty acids, its lipid composition contained a substantial proportion of lauric acid (C12) together with other fatty acids. Concentrated MCT oil, in contrast, was characterized predominantly by C8 and C10 fractions. This compositional difference was particularly relevant because C8 and C10 demonstrated more rapid portal absorption and hepatic utilization, whereas lauric acid exhibited metabolic characteristics that partially resembled those of longer-chain fatty acids. Thus, the functional and metabolic properties attributed specifically to concentrated C8/C10 MCT oil could not be considered completely interchangeable with those of virgin coconut oil.

The developed oral-shot concept was evaluated across MCT quantities of 5, 10, 15, 20, and 25 g per serving. Using the selected theoretical metabolizable-energy conversion factor of 8.3 kcal/g, these quantities corresponded to calculated energy contributions of 41.5, 83.0, 124.5, 166.0, and 207.5 kcal, respectively. The calculated values demonstrated the expected proportional relationship between MCT quantity and theoretical energy contribution. Importantly, these energy values represented calculated metabolizable energy rather than experimentally measured ATP production or a direct measurement of the speed of energy release. The proposed rapid-energy function of the formulation was instead supported by the characteristic absorption and metabolic pathways of C8 and C10.

Formulation development represented an important component of the investigation because incorporation of a lipid-based functional ingredient into a convenient oral-shot system required consideration of uniformity, homogeneity, physical stability, oxidative stability, dose consistency, and gastrointestinal suitability. Processing, blending, homogenization or emulsification where applicable, standardization of the MCT content, and controlled filling were incorporated into the product-development approach. The resulting formulation framework provided a practical means of delivering a predetermined quantity of MCT within a single-serving oral preparation.

Physicochemical characterization was essential for establishing the quality of the MCT preparation before formulation. Parameters associated with fatty-acid composition, density, viscosity, acid value, peroxide value, iodine value, saponification value, moisture content, and overall lipid quality were considered important indicators of identity, purity, processing quality, and storage stability. Chromatographic characterization of C8 and C10 was particularly relevant for confirming the medium-chain fatty-acid profile and establishing consistency of the standardized lipid preparation.

The antioxidant and antimicrobial characteristics of medium-chain fatty acids further contributed to the functional characterization of the material. Published experimental evidence demonstrated measurable

antioxidant activity for C8/C10-rich MCT preparations, while medium-chain fatty acids such as caprylic and capric acids exhibited antimicrobial and particularly antifungal activity under experimental conditions. These functional characteristics were considered complementary to the primary nutritional role of MCTs. Nevertheless, antioxidant and antimicrobial activities were recognized as composition- and assay-dependent properties and therefore required formulation-specific analytical confirmation before quantitative claims could be attributed to the developed oral shot.

Stability evaluation was another critical component of the formulation-development process. The quality of a lipid-based oral shot can be influenced by temperature, oxygen, light, moisture, packaging conditions, microbial contamination, and storage duration. Consequently, physical characteristics, homogeneity, phase separation, oxidative deterioration, physicochemical parameters, and microbiological quality were incorporated into the stability-assessment framework. Appropriate packaging and controlled storage were considered necessary to minimize environmental exposure and preserve the integrity of the MCT lipid fraction. Establishment of the final shelf life remained dependent on the completed stability profile of the finalized product rather than on the shelf life of unrelated commercial MCT preparations.

Safety and gastrointestinal tolerability remained particularly important considerations during dose selection. Although the rapid metabolism of MCTs provided a strong rationale for their use as a functional energy source, increasing the administered quantity did not necessarily correspond to a proportionally greater practical benefit. Higher MCT intake may increase the possibility of gastrointestinal symptoms in susceptible individuals. Therefore, selection of the final serving size required consideration not only of theoretical caloric contribution but also of fatty-acid composition, formulation characteristics, metabolic response, stability, palatability, and tolerability.

The overall metabolic pathway established for the formulation could be summarized as oral MCT administration → gastrointestinal hydrolysis → release of C8/C10 fatty acids → intestinal absorption → portal circulation → hepatic uptake → mitochondrial β -oxidation → acetyl-CoA formation → TCA-cycle oxidation and ATP generation and/or ketogenesis → circulating ketone bodies → peripheral tissue utilization. This pathway explained the rapid metabolic availability of MCT-derived carbon while avoiding the inaccurate interpretation that MCTs simply left “no residue” in the body. Instead, their components underwent normal metabolic transformation, oxidation, utilization, and eventual elimination of metabolic end products.

5. LITERATURE REVIEW

Formulation characteristics were also considered important because the physical state of the MCT preparation could influence its metabolic availability. Published human investigations demonstrated that emulsified MCT preparations produced greater increases in circulating C8 than non-emulsified preparations, with significant responses observed at 10, 20, and 30 g doses. These findings supported the use of appropriate homogenization or emulsification during development of the oral shot where required to maintain uniform lipid dispersion.

The 5–25 g dose range was not interpreted as a classification from “low” to “maximum safe dose.” Instead, the concentrations represented formulation levels selected for comparative evaluation. Gastrointestinal tolerability was considered particularly important as MCT quantity increased. Recent controlled human data using C8 doses averaging approximately 12.0, 17.9, and 23.9 g demonstrated mild-to-moderate gastrointestinal symptoms in some participants, including abdominal pain, cramping, nausea, and discomfort. Therefore, the 20 and 25 g formulations required particular consideration during tolerability evaluation.

Overall product evaluation integrated the MCT fatty-acid composition, physicochemical characteristics, theoretical energy content, antioxidant and antimicrobial characteristics, physical and oxidative stability, microbiological quality, and preclinical safety assessment. The combined findings established a framework for selecting an appropriate MCT concentration for the final oral energy-shot formulation while balancing energy contribution, rapid metabolic availability, formulation stability, and gastrointestinal tolerability.

The 15 g formulation is particularly useful as a reference study level, because a published randomized clinical study successfully administered a 15 g ketogenic MCT drink and demonstrated a measurable plasma C8/C10 and ketone response. However, the final dose for the developed product should be selected from the actual formulation, stability, tolerability, and safety findings rather than from theoretical energy content alone.

6. CONCLUSION

Overall, the study established a comprehensive scientific framework for the development of a standardized C8/C10-rich MCT oral energy shot. The combination of rapid portal absorption, preferential hepatic oxidation, ATP-generating potential, ketone production, convenient oral delivery, physicochemical standardization, formulation-quality assessment, stability evaluation, and safety considerations supported the potential of MCTs as functional ingredients for rapidly metabolized nutritional formulations. The 5–25 g formulation range provided a useful platform for comparing different MCT quantities and their theoretical energy contributions; however, the optimal serving dose was required to be selected on the basis of the combined formulation, metabolic, stability, safety, and tolerability findings rather than caloric value alone.

The developed approach therefore provided a foundation for further controlled evaluation of the MCT oral energy shot in human participants. Future formulation-specific investigations should confirm the optimal C8:C10 composition, actual antioxidant and antimicrobial characteristics, long-term storage stability, gastrointestinal tolerability, circulating ketone response, metabolic effects, and appropriate serving quantity. With adequate analytical standardization, stability validation, preclinical safety

confirmation, and controlled clinical evaluation, a C8/C10-rich MCT oral shot may represent a convenient functional nutritional system for delivering a rapidly metabolized dietary energy source.

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