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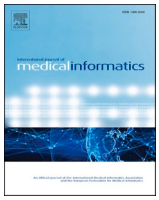

Review article

Smartphone applications for nutrition Support: A systematic review of the target outcomes and main functionalities

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ABSTRACT

Introduction: A proper nutrition is essential for human life. Recently, special attention on this topic has been given in relation to three health statuses: obesity, malnutrition and specific diseases that can be related to food or treated with specific diets. Mobile technology is often used to assist users that wish to regulate their eating habits, and identifying which fields of application have been explored the most by the app developers and which main functionalities have been adopted can be useful in view of future app developments.
Methods: We selected 322 articles mentioning nutrition support apps through a literature database search, all of which have undergone an initial screening. After the exclusion of papers that were already reviews, not presenting apps or not focused on nutrition, not relevant or not developed for human subjects, 100 papers were selected for subsequent analyses that aimed at identifying the main treated conditions, outcome measures and functionalities implemented in the Apps.
Results: Of the selected studies, 33 focus on specific diseases, 24 on obesity, 2 on malnutrition and 41 on other targets (e.g., weight/diet control). Type 2 diabetes is the most targeted disease, followed by gestational diabetes, hypertension, colorectal cancer and CVDs which all were targeted by more than one app. Most Apps include self-monitoring and coaching functionalities, educational content and artificial intelligence (AI) tools are slightly less common, whereas counseling, gamification and questionnaires are the least implemented. Body weight and calories/nutrients were the most common general outcome measures, while glycated hemoglobin (HbA1c) was the most common clinical outcome. No statistically significant differences in the effectiveness of the different functionalities were found.
Conclusion: The use of mobile technology to improve nutrition has been widely explored in the last years, especially for weight control and specific diseases like diabetes; however, other food-related conditions such as Irritable Bowel Diseases appear to be less targeted by newly developed smartphone apps and their related studies. All different kinds of functionalities appear to be equally effective, but further specific studies are needed to confirm the results.

1. Introduction

Nutrition is a fundamental part of everyone's everyday life. Proper food intake is essential for all humans during every time of their life to ensure well-being and a proper healthcare status. Incorrect eating habits have been in fact demonstrated to be related to several health problems, such as obesity, hypertension, cardiovascular conditions, and even mental distress [1]. In the last years, attention to this topic has gradually increased, especially in the contest of three situations: obesity, which is a public health problem with increasing burden in several parts of the world [2], malnutrition, which is often related to advanced age, social inequalities and illness, and specific diseases that can be related to food intake in various ways. In details, some subjects can suffer from diseases that are directly caused by food (e.g., food intolerance and allergies) and therefore need to avoid certain kinds of nutrients, whereas special diets can be necessary to treat conditions that are not directly related to food, such as diabetes or the epilepsy syndrome caused by GLUT1 deficiency [3], or even to support other conditions such as cancer [4,5], multiple

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sclerosis [6], and depression [7].

Besides the preexistence of conditions that require special dietary regimes, nutrition necessities can vary significantly from person to person depending on sex, age, and other life habits. Therefore, maintaining a proper diet can sometimes be a difficult task, although necessary to stay in good health and improve quality of life. Thanks to the continuous development of digital and mobile technology, smartphones can play an important role in assisting users in meeting their nutrition needs, both through direct support and as a telemedicine tool to make the communication between patients and physicians easier.

Due to the fast development of technology, numerous Apps for nutrition support have been developed and tested in the last years, serving users with different needs that range from the use of tailored diets to treat specific diseases to the promotion of healthy eating in the general population. Currently, a generic user can choose among a vast range of Apps depending on specific needs and characteristics (age, sex, health status, etc.).

The aim of this systematic review is to try to understand on which topics the development and use of smartphone technology has been focusing in the nutrition context over the last years, through an analysis of the main targeted conditions, the age of the users for which the Apps are intended, and an overview of the main functionalities that are implemented and outcome measures that are used to evaluate the Apps. Besides providing an interesting point of observation on the state of the art of Apps usage to assist nutrition, the results of our analyses are also intended for the researchers that wish to undertake new investigations involving the development of mobile technology with nutrition control/monitoring purposes.

Indeed, the results provide an informative overview of the physiological and pathological conditions that have been investigated extensively in studies involving the use of mobile technology, the outcomes that are mostly used for monitoring such conditions, and the general effectiveness of the strategies that are most commonly used in app development.

Numerous systematic reviews have been already made on this topic [8–11], however this study differs from the previous ones mainly for thee aspects: 1) systematic reviews on nutrition usually focus on the use of apps for one particular aim and not on a broader spectrum of usage; 2) Most reviews focus on reviewing the apps themselves instead of their use and utility in clinical studies; 3) technological development is really fast and there could be differences from the results of previous reviews written even a few months or years ago from one written now.

1.1. The ONFOODS project

This review has been written in the context of the ONFOODS project [12], which is an Italian National project that involves 26 partners to undertake research in several topics related to food, with the aim of increasing sustainability, safety, security, and health related to nutrition. The project is divided into seven main subject areas, named *spokes*, that focus on individual targets. Spoke 6 is led by the University of Pavia, Italy, and it is focused on developing nutritional strategies targeting the most vulnerable categories of the national population (i.e., families in the condition of financial hardship, people affected by pathologies, or elderly people), in order to ensure adequate nutrition and limit the onset of malnutrition situations that would end up reducing resilience and aggravating conditions of frailty. One of the procedures that will be carried out to reach this target is the development of a smartphone App, which will function as an instrument to support vulnerable patients and also to help the doctors to monitor them. For better tailoring this App, we decided to perform an extensive literature review to discover which conditions can be already tackled using smartphone Apps, which age groups can benefit from a high availability of apps tailored for them, which outcomes are mostly used to monitor specific conditions and which kind of functionalities are commonly the most effective.

2. Methods

2.1. Research Question and query

The scope of this review is relatively broad, as it consists in an exploration of the main studies related to the development of recent smartphone Apps that are designed to provide support to users who want/need to control their diet. The final aim of this exploration is twofold: on the one hand, we wish to identify the main fields of application in the use of mobile technology for nutrition support, so that the interested reader can have an opportunity to identify consequently also the diseases or conditions for which a proper availability of technological tools is still lacking; on the other hand, we aim at summarizing the main strategies that have been mostly used to create the Apps that are currently available, including testing methods, outcome measures and successes in helping the users.

From a formal point of view, the research question can be written as follows: *"Which nutrition-related conditions have been targeted the most for the development of smartphone Apps to support patients and users in the last 5 years? How do these Apps usually work?"* Answers to this question can be useful to identify possible gaps in the current availability and design of nutrition support-related Apps.

We searched for relevant studies on *Scopus* using the following query:

"TITLE-ABS-KEY ((diet OR nutrition) AND smartphone AND app) AND (LIMIT-TO (PUBYEAR, 2023) OR LIMIT-TO (PUBYEAR, 2022) OR LIMIT-TO (PUBYEAR, 2021) OR LIMIT-TO (PUBYEAR, 2020) OR LIMIT-TO (PUBYEAR, 2019)) AND (LIMIT-TO (SUBJAREA,"MEDI") OR LIMIT-TO (SUBJAREA,"COMP") OR LIMIT-TO (SUBJAREA,"ENGI") OR LIMIT-TO (SUBJAREA,"ENVI"))"

This query selects all papers that contain the words *diet* or *nutrition* and *smartphone, app* in either the title, the abstract, or the keywords. Considering that technology progresses extremely quickly and thousands of new apps are developed every year, we limited the research to the last four and a half years (from 2019 to June 2023, when the papers screening started) in order to avoid the inclusion of apps that had become obsolete. Plus, we limited the research to the medical or engineering-related fields, as this literature review focuses on the apps involved in studies that aim at treating medical conditions related to food and nutrition.

This query selected 322 papers that underwent a first screening performed by all the authors of this paper. The aim of the first screening was to decide which papers were suitable for inclusion in the review pool and which were to be excluded, according to several parameters listed in the rest of this chapter. The included articles were then analyzed in order to extract the most important features to find an answer to our research question.

2.2. Exclusion criteria

Several exclusion criteria were used to perform the first screening of the articles that were selected by the query. In particular, a paper was excluded if it was:

- already a systematic review.
- not presenting an App or a group of Apps.
- not focused on food, diet, or nutrition
- not relevant, i.e., not aiming at improving eating habits or treating a medical condition (e.g., papers focused on assessing the use of technology among different socio-demographic groups).
- not developed for human subjects
- not a paper (the query selected a few corrections and a master thesis), not written in English, or not available through institutional access using the credentials of the University of Pavia or the University of Pennsylvania.

The excluded papers were read and analyzed as thoroughly as the

selected ones, and some of them were taken into consideration to help inform the discussion of this review or to better tune the analysis criteria used to catalog the included papers. Fig. 1 reports the flowchart of the screening and selection process, following the PRISMA paradigm.

2.3. Categorization parameters

The selected papers were carefully read and analyzed, and they were catalogued based on the following features: year of publication, typology of the paper (e.g. randomized controlled trial, study protocol, research article, conference paper, etc.), description of the main methods, description of the results, comments to add (if any), App names and current availability on the Android and Apple stores, age and disease targets, sample size (in case of a pilot study), and main outcome measures.

2.4. Analysis

Once the categorization was complete, an analysis was performed to identify the most used apps and functionalities, and the target conditions.

The papers were first grouped according to their main targets, with particular attention to those focusing on obesity, malnutrition and specific diseases. The targeted diseases and the other targets that do not fall in any of these categories were analyzed as well, as were the age of the target users. Afterwards, we analyzed the published studies and the related Apps in order to characterize the most common features and report how many times their use was associated to a positive result in the selected studies. We identified the following common features:

- Gamification: the App features some game-like strategies, for example prizes that are given upon reaching a certain target, daily challenges etc.
- Self-monitoring: the user can input his/her data on a regular basis and monitor some variables, also through measures that are calculated based on several inputs.
- Educational content: the App presents at least one section where the user can learn about a medical condition or the suggested diet in order to make more informed decisions.
- Coaching/Motivational content: The app features an active motivational part (e.g. through push notifications, alerts and personalized advice related to calculated scores) that aims at improving the user's behavior.
- Artificial Intelligence: the App presents consistent AI-based functionalities, notable examples are the analysis of food pictures through neural networks, NLP-based chat-bots and machine learning algorithms to compute personalized scores from complex data.
- Monitoring/Counseling with a Physician: the App allows the patient to be in contact with a physician that can monitor their condition and provide counseling either upon patient's request or upon noticing dangerous events.
- Questionnaires: the App contains validated questionnaires that are used to collect patients' information and help the physician monitor the patient, possibly through the calculation of scores related to his/her condition.

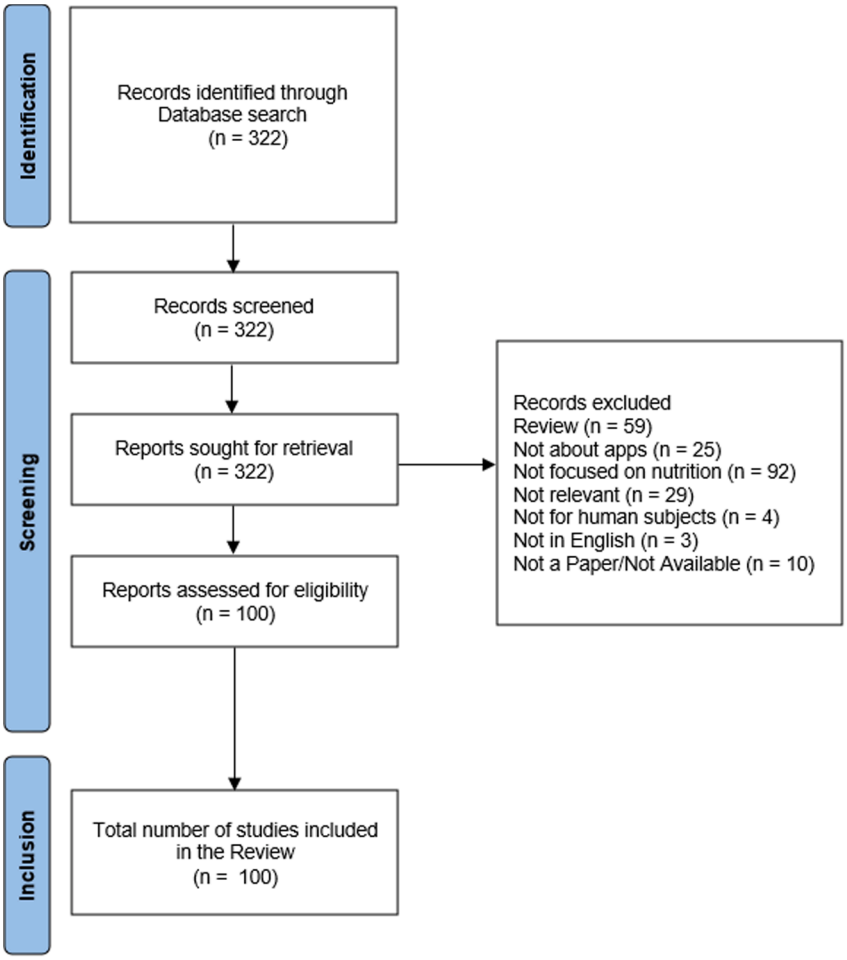


Fig. 1. PRISMA flowchart of the paper screening and selection process.

Lastly, we provide an analysis of the main outcome measures monitored by the apps reported in the selected studies.

3. Results

Out of the 322 papers that were extracted by the query, 100 were selected by our screening process and categorized based on the criteria presented in the Methods section. Most papers present the development or the application of an App or case-control studies to test Apps' efficacy, and some of them present the comparison of the performances of 2–5 Apps for a specific aim. 72 different apps were discussed in these papers, but only 11 were discussed in at least 2 different papers, as shown in Table 1. All the Apps in this table are currently available both on the Android Play Store and on the Apple Store for iOS users. Noom is the most cited App.

Not all papers present apps that are currently available, as even though most papers can be classified as Research Articles (65), 23 are clinical trials (22 of which are randomized control trials and only one describes a non-randomized trial), 7 contain study protocols and 5 are conference papers. Most conference papers and several clinical trials and protocols present studies about smartphone Apps that are currently under development or awaiting for approval. Table 4, at the end of the manuscript, contains all the 100 selected studies with the related references and information about Apps and targets.

3.1. Targeted conditions

Fig. 2a shows the main targets of the studies presented in the selected papers. While numerous studies aim at providing support to nutrition in the context of a disease or are focused on the treatment of obesity, the majority focus on other targets, which were generic diet or weight control, pregnancy, support during cancer treatment, support during hemodialysis, support after breast cancer surgery, and well-being during the lockdown related to the COVID-19 pandemic. Results related to these targets are visible in Fig. 2b. Only 2 papers focused on malnutrition. It should be noted that the distinction between studies targeting obesity and those targeting general diet/weight control was made on the basis of what was specified in the objectives of the selected papers.

As shown in Fig. 3, most papers focused on the treatment of people of all ages or on adults, whereas 4 papers focused specifically on children, 4 on the elderly, 3 on young adults, and 2 on adolescents. Interestingly, 9 papers were focused on adults and 1 on adolescents exclusively of female sex. This number is higher than the number of papers that focus on pregnancy or gestational diabetes, as the article [13] focuses on presenting an app that has the aim of aiding the treatment of obesity only on women without a coexisting female-specific condition.

The majority of the 35 papers that focus on supporting nutrition in a disease is focused on type 2 diabetes (10 papers), plus 4 papers that were focused on gestational diabetes and 2 on diabetes in general. No studies were focused on type 1 diabetes specifically. Other diseases were targeted by the selected studies: Hypertension and Colorectal Cancer were aimed by three studies each, Cardiovascular Diseases were targeted by two, whereas one paper was found for Breast Cancer, Pancreatic Cancer, Celiac Disease, Depression,

Irritable Bowel Syndrome, Metabolic Abnormalities, Women Infertility, and Spina Bifida. These results are shown in Fig. 4.

These results show that most Apps and studies related to Apps are focused on diet and weight control, and they mostly target adults or all ages.

The papers were heterogeneous in scope and typology, so we analyzed the main methods in order to find the most commonly used approaches, categorizing the described Apps according to several features: sample size (general and per target), presence of gamification strategies, self-monitoring, coaching, motivational content, monitoring and counseling with a physician, data collection through questionnaires. Effectiveness of the Apps in the presented studies, when described, was also evaluated, in order to explore whether there are some approaches for which Apps appear to be more effective than others.

Table 1
Apps named in more than 2 papers.

App Name	Counts
EVIDENT 3	2
HealthyMoms	2
KELA.AE	2
Keenoa	2
MINISTOP 2.0	2
MyFitnessPal	2
Noom	4
PEARS	2
Pregnant+	2
VeggieBook	2
Well-D	2

3.2. Common features and effectiveness

Most of the Apps discussed in the selected papers are currently available in the stores, or are described by the papers themselves in association with a validation study or a feasibility study, where acceptance or usability were assessed.

The average sample size of the selected studies is 159, with high variability. For example, one paper presenting an App for type 2 diabetes management performed an evaluation with a cohort of 1000 people, while another study related to an App used for diabetes (all types) has been evaluated only on 6 people. This reflects the heterogeneity of the papers' scopes and types, on average RCTs comparing two cohorts in a case-control study had the highest sample sizes, whereas studies focused on the evaluation of feasibility or acceptability of the Apps used smaller cohorts. It is also worth mentioning that relatively low sample sizes related to some diseases could reflect difficulties in enrolling a large number of patients due to the rarity of the disease or related factors.

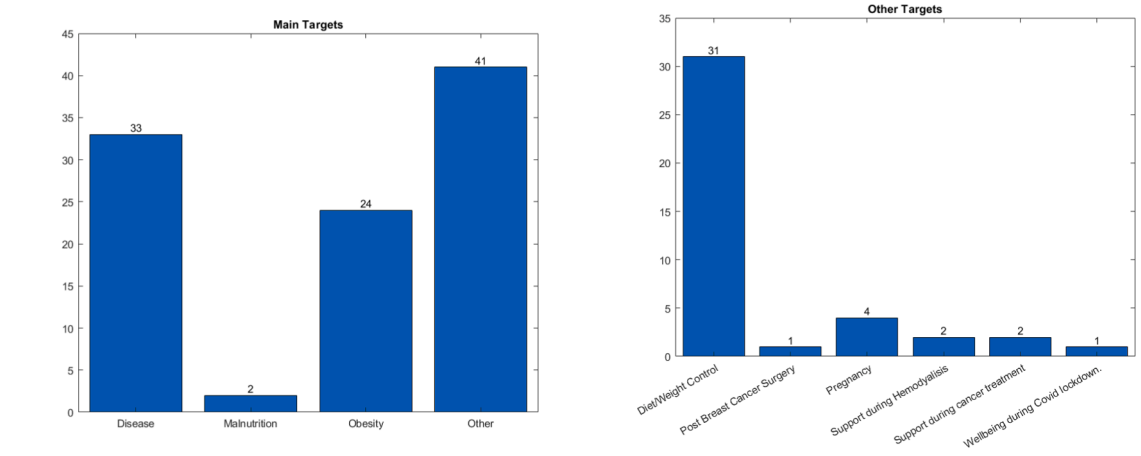
In order to characterize the effectiveness of the apps' features, we analyzed the results reported by the published studies and based them on the common features reported in the Methods section.

The results are reported only for papers that clearly specify both the Apps' functionalities and the results of the associated study. Table 3 reports these results. In particular, each column of the table indicates respectively:

- The total number of times the feature was mentioned among the Apps' functionalities in the selected paper.
- The number of times the feature was associated to a study where the App was used to achieve all the intended goals/results.
- The number of times the feature was associated to a study where the App was used but did not achieve any of the intended goals/results.
- The number of times the feature was associated to a study where the App was used to achieve several intended goals/results but only some of the goals were actually achieved.
- The number of times the feature was associated to a study where the App was used to achieve the intended result in an evaluation of its feasibility and acceptance of use.

Multiple mention of the same feature within a selected paper were counted only once if they were related to the same app.

From the results reported in Table 2, it appears that the main features utilized in the Apps discussed in the selected studies are user self-monitoring functionalities and the presence of coaching and motivational content, whereas counseling with a physician, gamification and questionnaires are less mentioned. A qualitative evaluation seems to show that the rate of failure of apps using AI tools is generally lower than those implementing other features. However, applying a Chi-square test



(a) Bar graph of the main targets of the selected studies.

(b) Bar graph of the targets of studies that were not focused on either a specific disease or malnutrition or obesity.

Fig. 2. Main targets of the selected papers. (a) Bar graph of the main targets of the selected studies. (b) Bar graph of the targets of studies that were not focused on either a specific disease or malnutrition or obesity.

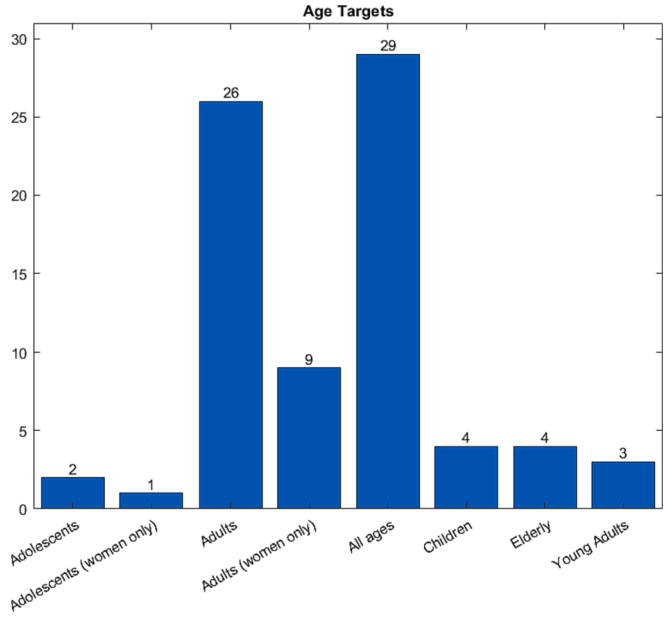


Fig. 3. Age targets of the selected studies.

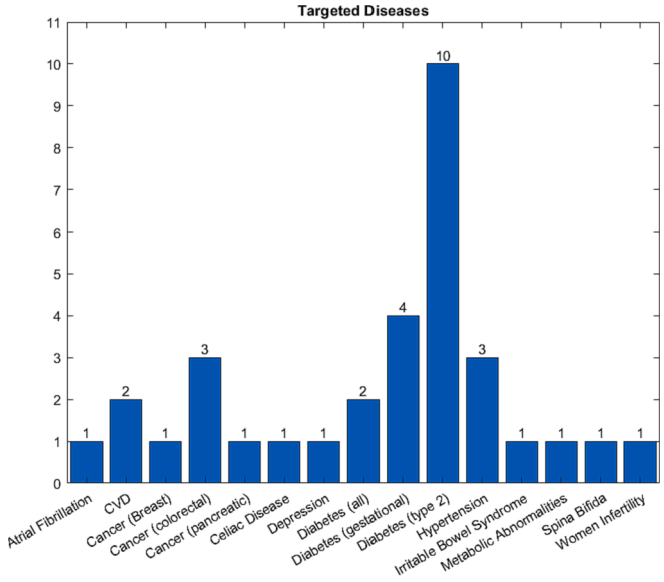


Fig. 4. Counts of the diseases that are targeted by the selected studies.

using these results as contingency table, no statistically significant differences were reported in the proportion of effective counts for the different features (P-Value = 0.827, six degrees of freedom). This could be due in part to the relatively small number of samples and the development of further analyses including more apps could be worth exploring.

3.3. Outcome measures

Several outcomes were identified in the selected papers, that can be subdivided into different categories as shown in Table 3: Dietary Intake (e.g. calories and/or nutrients, vegetable intake, frequency of eating events etc.), Weight-related measures (e.g. weight itself, BMI, waist circumference), Clinical Outcomes (i.e. outcomes that can be measured during a medical examination such as glycohemoglobin, blood pressure etc.), Physical Activity, Adherence to Diet, Mental Health and indicators of Satisfaction, Engagement, Quality of Life and Feasibility of App usage.

Table 2
Main features and counts of the times the selected studies reported whether the Apps using them were effective, not effective, partially effective or effective in a usability/acceptance study.

Feature	Counts	Effective	Not Effective	Partially Effective	Usability Study
artificial intelligence	22	13 (59 %)	3 (14 %)	4 (18 %)	2 (9 %)
coaching/ motivational	40	23 (57.5 %)	12 (30 %)	1 (2.5 %)	4 (10 %)
counseling	13	7 (54 %)	3 (23 %)	3 (23 %)	0 (0 %)
educational	23	14 (61 %)	4 (17 %)	2 (9 %)	3 (13 %)
gamification	4	2 (50 %)	0 (0 %)	1 (25 %)	1 (25 %)
questionnaires	9	5 (56 %)	1 (11 %)	1 (11 %)	2 (22 %)
self-monitoring	45	25 (56 %)	10 (22 %)	6 (13 %)	4 (9 %)

Outcomes related to dietary intake and obesity-related measures are the most common, in particular body weight is the most used outcome measure followed by measurements of calories or specific nutrients. This

Table 3
Outcome Measures.

Category	Count	Outcome	Count
Dietary Intake	23	Calories/Nutrients	7
		Vegetable Intake	2
		MDS (Mediterranean Diet Score)	2
		Frequency of Eating Events	3
		Food Images Recognition	1
		Salt/Sodium Content	1
		Availability of Healthy Food	1
		Food Purchase	1
		Dietary Risk Score	1
Weight-related	15	Body Weight	14
		BMI	2
		Waist Circumference	2
		Height in Children	1
Clinical	11	HbA1c	4
		Blood Pressure	2
		Skeletal Muscle Index	2
		Glucose	1
		Lipids	1
		Visceral Fat Area	1
		Gastrointestinal Symptoms	1
		Inflammatory Markers	1
Feasibility	5	Feasibility of Study	5
Satisfaction	5	Satisfaction Indexes	4
		Willingness to buy product	1
Physical Activity	5	Frequency of Physical Activity	5
Acceptability/ Engagement	4	Acceptability Rate or Engagement Indicators	4
Quality of Life	4	Various QoL Questionnaires	4
		Cancer-related Distress	1
Mental Health	3	Indication of Depression/Anxiety	3
Adherence to Diet	2	Adherence to Gluten-free Diet	1
		MDS (Mediterranean Diet Score)	1

result is compatible with the majority of the Apps being related to diet control and obesity risk.

Clinical parameters that are usually measured during a medical examination are often used as well, both related to obesity control (visceral fat area and skeletal muscle mass) and to specific conditions that can be controlled through specific nutrition regimens. For example glucose and Glycohemoglobin (HbA1c) that are typical parameters for diabetes, which is the most studied disease among the ones found in the selected papers, and blood pressure is typically controlled by low-sodium diets. Finally, gastrointestinal symptoms and inflammatory markers are typically used in relation to IBDs and cancer.

4. Discussion

Maintaining a proper nutrition could be a complex task, especially in some contexts such as people that require specific food regimens due to the presence of a pathology or other conditions. In particular, patients that lack proper medical training may need to be helped managing their diets and in some cases be provided with psychological support to increase motivation and improve mental health. For these reasons, a smart- phone app needs to be tailored precisely to the target users, considering their needs, choosing the parameters that have to be monitored and the most effective strategies that can be used to reach the aim of improving health. A nutrition support App should be also designed in a way that ensures acceptability and engagement from the users, as the production and maintenance costs on a mobile health delivered intervention, although more effective, can be significantly higher than a standard care-based approach [14].

The scope of this review is to analyze and categorize the studies that have involved the description or use of a smartphone App to support nutrition in the last five years. We tried to determine several aspects of these studies. The first aim was to understand which health conditions have been mostly targeted, with a particular focus on obesity, malnutrition and several diseases. This choice is related to the aims of the ONFOODS project, presented in the Introduction section, that has several branches that focus on designing interventions on these topics that are currently part of the main health issues in Italy, for example obesity has a higher occurrence on Italian children compared to the rest of Europe [15]. After finding which conditions were mostly targeted, we focused on identifying the age and sex characteristics of the targeted populations, and then analyzed the main features and outcome measures used to achieve practical interventions on them. The results show that most nutrition apps have been used to focus on assisting in the improvement of dietary habits and keeping body weight under control, although numerous Apps have been developed to assist patients that are affected by specific diseases, the most common being type 2 diabetes. Both the types of targets and the age of the targeted population reflect to some level the potential availability of App users, e.g. App use is easier for adults who are interested in keeping a healthy food regime than for diet control in children who need to be supervised by adults. Apps related to these topics are also probably the most successful in commerce, as they have the largest set of potential users. However, children obesity and malnutrition are serious public health problems, and the development and use of more technologies that can help reducing it could still be beneficial. To this aim, app design should be carefully chosen, as there are some studies that suggest that when the target user is a caregiver (e.g. parents for their children), interactive features and validated educational information coming from credible sources are extremely important [16]. Gamification and engaging graphical features have been also demonstrated to be effective in apps for children [17,18].

The sample sizes of participants in the selected studies are largely variable, depending mainly on the type of study (e.g. feasibility study vs. clinical study) and the disease/condition targeted (e.g. type 2 diabetes is much more common than Spina Bifida). It should be noted that the results reported here have the sole purpose of providing a general overview of the selected studies, but further investigation is required to define whether there are statistically significant differences in the study sample sizes among the different conditions, considering also that there could be geographical biases.

Looking at the most treated diseases, it can be seen that some conditions that are notably treated with special diets, such as Irritable Bowel Diseases, Crohn's Disease and Ulcerating Colitis, appear not to be targeted by studies involving the use of an app in the last five years. Type 1 diabetes is also not widely supported by mobile health technologies, in contrast with type 2 diabetes and gestational diabetes, which are more common and often relatively easier to manage.

It should be specified that this result does not imply that smartphone apps developed for the treatment of these conditions do not exist, but they could mean that they have not been used in the time frame of the selected studies or that they are not focused on supporting nutrition. For example, through a Google Scholar research of articles that mention the use of apps for the management of Type 1 diabetes it could be noticed that there are numerous apps reviewed in literature that have been used in the context of this disease, but the studies are generally either older than 5 years or not focused specifically on this type of diabetes, but rather on diabetes in general with results related also to type 1 diabetes [19,20]. A recent *meta*-analysis by Pi et al. [21] performed in 2023 evaluates the effectiveness of some apps developed for type 1 diabetes, some of them mentioned in recent studies, however those apps usually focus on glucose or insulin control and not on nutrition control. The same happens for IBD, a recent review shows that some apps have been developed [22], but they are either not recent or they do not focus on providing support on nutrition, as they focus on symptoms and treatments and their support on nutrition is generally limited to a dietary log functionality. There are also other recently developed IBD-focused apps, but they also do not provide support on nutrition, for example Peters et Al. [23] present a recent app that aims at helping to reduce IBD symptoms using hypnotherapy.

Generally speaking, it seems more common for Apps to implement coaching, self-monitoring and educa- tional content rather than services

Table 4
All selected studies and related targets.

Authors andRefer- ence	Year	App Name	Main Target	Age Tar- get	Disease Target	Other Target	Features	Effective
Alexandrou C. et Al. [26]	2023	MINISTOP 2.0	Obesity	Children			Question- naires, Coaching	Yes
Hilbert A. et Al. [27]	2023	trEATsmart	Obesity	Adults				NA
Shatwan I.M. et Al. [28]	2023	MyPlate	Other	Adolescents			Coaching	No
Lim J.Y. et Al. [29]	2023	Breast Can- cer by Sec- ond Doctor	Other	All ages		Post Breast Cancer Surgery	Coaching	Yes
Recio- Rodŕıguez J.I. et Al. [30]	2022	EVIDENT 3	Other	Elderly		Dietor Weight Control	Coaching	No
Muth A.-K. et Al. [31]	2022	FoodApp	Other	Adults		Wellbeing during Covid lock- down.	Question- naires	Yes
Haukur Gud- mundsson G. et Al. [32]	2022	Sidekick	Other	Adults		Support during cancer treat- ment	Educational content, Self- monitoring	Yes
Nguyen P.H. et Al. [33]	2022	FRANI	Other	Adolescents (women only)		Dietor Weight Control	Self- monitoring, AI	Yes
Ahmadi M. et Al. [34]	2022	NA	Disease	Adults	Cancer (Breast)		Self- monitoring	Yes
Silva A.R.C.S. et Al. [35]	2022	RotulApp	Other			Dietor Weight Control	Educational content, AI	Yes
Dias S.B. et Al. [36]	2022	PROTEIN	Other	All ages		Dietor Weight Control	Coaching, educa- tional, Self- monitoring	Yes
Mönninghoff A. et Al. [37]	2022	FutureMe	Other	All ages		Dietor Weight Control	Coaching, educa- tional, Self- monitoring	No
Burke L.E. et Al. [38]	2022	SMARTER	Other	Adults		Dietor Weight Control	Self- monitoring, Coaching	No
Okaniwa F. et Al. [39]	2022	NA	Other	All ages		Dietor Weight Control	AI	NA
Mohanty S. et Al. [40]	2022	RFMx	Obesity	All ages	Atrial Fib- rillation		Self- monitoring, Coaching	Yes
Kavanagh M.E. et Al. [41]	2022	PortfolioDiet	Disease	All ages	CVD		Gamificat- ion,Self- monitoring, Question- naires	Yes
Salmani H. et Al. [42]	2022	ColorectAlong	Disease		Cancer (colorec- tal)		Coaching	NA(us- ability)
Kondo M. et Al. [43]	2022	DialBeticsLite	Obesity	All ages			AI, Coach- ing,Self- monitoring	Yes
Kwan Y.H. et Al. [44]	2022	EMPOWER	Disease	All ages	Diabetes (type 2)		Gamificat- ion,Self- monitoring, Coaching	NA (pro- tocol)
Rageliene˙ T. et Al. [45]	2022	Food Boss	Obesity	Children			AI	Yes
Lugones- Sanchez C. et Al. [46]	2022	EVIDENT 3	Obesity	All ages			Question- naires	Yes
Lim S.L. et Al. [47]	2022	nBuddy Di- abetes	Disease	Adults	Diabetes (type 2)		Couseling, educa- tional	Yes
Fanca A. et Al. [48]	2022	NA	Other	All ages			AI, Coach- ing,Self- monitoring	Yes
NabovatiE. et Al. [49]	2022	NA	Disease	All ages	Diabetes (type 2)		AI, educa- tional	Yes
Vu B. et Al. [50]	2022	STOP KM- EP	Obesity	All ages			Gamificat- ion, Coach- ing	NA(No results yet)
Bangamuarachc W. et Al. [51]	h2i 022	NA	Other			Dietor Weight Control	AI	Yes
Sasaki Y. et Al. [52]	2022	CALO mama	Other	All ages		Dietor Weight Control	AI	No
Ayyoubzadeh S.M. et Al. [53]	2022	NA	Disease		Cancer (colorec- tal)		NA	NA
Harrington K. et Al. [54]	2021	LifeData	Malnutritio	nAll ages			AI, Question- naires	Yes
Nuruddin R. et Al. [55]	2021	NA	Other			Pregnancy	Educational, Coaching	NA(in progress)
Riches S.P. et Al. [56]	2021	SaltSwap	Disease	All ages	Hypertension		Coaching	No

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Table 4 (*continued*)

Authors andRefer- ence	Year	App Name	Main Target	Age Tar- get	Disease Target	Other Target	Features	Effective
Vaz C.L. et Al. [57]	2021	NA	Obesity	Adults			Coaching, AI	Yes
Bouzo V. et Al. [58]	2021	Keenoa	Other	All ages		Dietor Weight Control	AI	Yes
Tsunemi A. et Al. [59]	2021	Calomeal	Disease		Diabetes (type 2)		AI,Self- monitoring	Yes
Keum J. et Al. [5]	2021	Noom	Disease		Cancer (pancre- atic)		AI, coun- seling, educa- tional, Self- monitoring	Yes
Ruf A. et Al. [60]	2021	APPetite	Other			Dietor Weight Control	Self- monitoring	Yes
Lim S.L. et Al. [61]	2021	NA	Disease	Adults	Diabetes (type 2)		Coaching, counsel- ing,Self- monitoring	Yes
Huntriss R. et Al. [62]	2021	Oviva	Obesity	Adults			Coaching, counsel- ing,Self- monitoring	No
Khoury C.F.E. et Al. [63]	2021	KELA.AE	Other			Support during Hemodyal- isis	Counseling, Self- monitoring	Yes
Hunt M. et Al. [64]	2021	Zemedy	Disease	All ages	Irritable Bowel Syndrome		Counseling, Coaching, educa- tional	Yes
Greene E.M. et Al. [65]	2021	PEARS	Obesity	Adults (women only)			Coaching, Question- naires	Yes(ac- ceptance)
Lancaster R. et Al. [66]	2021	Research Food Diary	Other	Adults		Dietor Weight Control	Self- monitoring	Yes
Young C.L. et Al. [67]	2021	My Food & Mood	Disease		Depression		Self- monitoring, Coaching	Yes
DeBezieux H.R. et Al. [68]	2021	Whole Biome	Disease	All ages	Diabetes (all)		Self- monitoring	Yes(ac- ceptance)
SandborgJ. et Al. [69]	2021	HealthyMoms	Other	Adults		Pregnancy	Educational, Coaching, Self- monitoring	No
SandborgJ. et Al. [70]	2021	HealthyMoms	Other			Pregnancy	Educational, Coaching, Self- monitoring	Yes(ac- ceptance)
Jung H. et Al. [71]	2021	FRADA	Disease	Elderly	Diabetes (type 2)		AI	Yes(ac- ceptance)
MahmudN. et Al. [72]	2021	NA	Disease		Cancer (colorec- tal)		Educational, Coaching	Yes
Buendia R. et Al. [73]	2021	BALANCE	Disease	Adults	Diabetes (type 2)		Coaching, educa- tional, Self- monitoring	No
Elkhodr M. et Al. [74]	2021	NA	Disease		Diabetes (gesta- tional)		Coaching, Self- monitoring, counseling	NA
Vasiloglou M.F. et Al. [75]	2021	goFOOD	Other	All ages		Dietor Weight Control	AI	NA
Henriksson H. et Al. [76]	2020	MINISTOP 2.0	Obesity	Children			Educational, Coaching, Self- monitoring	NA
Seward M.W. et Al. [77]	2020	NA	Obesity	Adults			Counseling	NA
Doddaiah S.K. et Al. [78]	2020	Diaguru	Disease	Adults	Diabetes (type 2)		Coaching, Self- monitoring, counseling	Yes
Lagerros Y.T. et Al. [79]	2020	HAPPY	Disease	Adults	Diabetes (type 2)		Coaching, Self- monitoring	NA
Garnweidner- Holme L. et Al. [80]	2020	Pregnant+	Disease	Adults (women only)	Diabetes (gesta- tional)		AI, Coach- ing,Self- monitoring	No
Cho S.M.J. et Al. [81]	2020	Noom	Disease	Adults	Metabolic Abnor- malities		Self- monitoring, AI	Partially
Ji Y. et Al. [82]	2020	Keenoa	Other	Adults		Dietor Weight Control	Self- monitoring, AI, Coun- seling	Partially
Duncan M.J. et Al. [83]	2020	Balanced	Obesity	Adults			Self- monitoring, educa- tional, counseling	Partially
Fuemmeler B.F. et Al. [84]	2020	Mila Blooms	Other	Adolescents		Dietor Weight Control	Gamificat- ion	Yes(ac- ceptance)
Baik S.H. et Al. [4]	2020	MyGuide, My Health	Other	Adults		Support during cancer treat- ment	Self- monitoring	Yes
Khoury C.F.E. et Al. [85]	2020	KELA.AE	Other			Support during Hemodyal- isis	Self- monitoring, educa- tional	Yes
Browne S. et Al. [86]	2020	myBigO	Obesity	Children			Self- monitoring, Question- naires	Partially

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Table 4 (*continued*)

Authors andRefer- ence	Year	App Name	Main Target	Age Tar- get	Disease Target	Other Target	Features	Effective
Keshen A. et Al. [87]	2020	Recovery Record	Malnutritio	nAdults			Self- monitoring	No
Khosla S. et Al. [88]	2020	Nutri- Mentak	Other	All ages		Dietor Weight Control	NA	NA
Lanzola G. et Al. [89]	2020	Ketty	Other			Dietor Weight Control	AI, educa- tional	NA
Weerahandi H. et Al. [90]	2020	DASH	Disease	Elderly	Hypertension		Self- monitoring, counseling	No
Zou P. et Al. [91]	2020	mDASHNa- CC	Disease	Elderly	Hypertension		NA	NA
Burke L.E. et Al. [92]	2020	NA	Other	Adults		Dietor Weight Control	NA	NA
Herńandez- Reyes A. et Al. [93]	2020	Nutricion Sur	Obesity	Adults (women only)			NA	NA
Ainscough K.M. et Al. [94]	2020	PEARS	Obesity	Adults (women only)			Coaching, Question- naires	Yes
Hildebrandt T. et Al. [95]	2020	Noom	Other	Adults		Dietor Weight Control	AI, coun- seling, educa- tional, Self- monitoring	Yes
Whitelock V. et Al. [96]	2020	NA	Other			Dietor Weight Control	Self- monitoring	Yes
Ahn J.S. et Al. [97]	2020	Well-D	Obesity	All ages			Coaching	No
Alturki R. et Al. [98]	2020	NA	Obesity	All ages			NA	NA
Moguel E. et Al. [99]	2020	foodScan	Other			Dietor Weight Control	NA	NA
Dowd A.J. et Al. [100]	2020	MyHealthyGut	Disease	Adults	Celiac Disease		Coaching, Self- monitoring, educa- tional	Yes
Borgen I. et Al. [101]	2019	Pregnant+	Disease	Adults (women only)	Diabetes (gesta- tional)		AI, Coach- ing,Self- monitoring	No
Lim K. et Al. [102]	2019	SPAROW	Disease	Adults (women only)	Diabetes (gesta- tional)		Coaching, Self- monitoring	NA
Ahn J.S. et Al. [103]	2019	Well-D	Other			Dietor Weight Control	Coaching	NA
Muralidharan S. et Al. [104]	2019	mDiab	Disease	Adults	Diabetes (type 2)		Educational, Self- monitoring	NA
Garvin T.M. et Al. [105]	2019	Cooking Matters	Obesity				Coaching	Yes
Sahoo D. et Al. [106]	2019	FoodAI	Other	All ages		Dietor Weight Control	AI	Partially
Stiles-Shields C. et Al. [107]	2019	MyDiet Coach	Disease	Young Adults	Spina Bi- fida		Coaching, Self- monitoring	Yes
Prapkree L. et Al. [108]	2019	Snackability	Obesity	Young Adults			AI, Coach- ing	Yes(ac- ceptance)
Alnasser A. et Al. [13]	2019	Twazon	Obesity	Adults (women only)		Dietor Weight Control	Coaching, Self- monitoring	Yes
Jeon E. et Al. [109]	2019	NA	Disease	All ages	Diabetes (all)		Educational, Coaching, Self- monitoring	Yes
Nour M. et Al. [110]	2019	NA	Other	Young Adults		Dietor Weight Control	Gamificat- ion,Self- monitoring	Partially
Chen J. et Al. [111]	2019	EasyDiet Diary	Other			Dietor Weight Control	Educational, Coaching	Partially
Clarke P. et Al. [112]	2019	VeggieBook	Other	All ages		Dietor Weight Control	Coaching, educa- tional	Yes
Fallaize R. et Al. [113]	2019	Samsung Health, My- FitnessPal, FatSe- cret, Noom Coach, Lose It!	Other	All ages		Dietor Weight Control	NA	NA
Patel M.L. et Al. [114]	2019	MyFitnessPal	Obesity	Adults			Self- monitoring, educa- tional, Coaching, Gamificat- ion	Yes
Evans S.H. et Al. [115]	2019	VeggieBook	Other			Dietor Weight Control	NA	NA
Huang C.-Y. et Al. [116]	2019	SWITCHes	Obesity	All ages			NA	NA

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Table 4 (*continued*)

Authors andRefer- ence	Year	App Name	Main Target	Age Tar- get	Disease Target	Other Target	Features	Effective
Alturki R. et Al. [117]	2019	Akser Waznk	Obesity	All ages			Coaching, educa- tional, Self-monitoring	Yes(ac- ceptance)
Jain P. et Al. [118]	2019	NA	Other			Dietor Weight Control	AI	Partially
Choi B.G. et Al. [119]	2019	EXP	Disease	Adults	CVD		Educational, Coaching, counsel- ing,Self-monitoring, Question- naires	No
Langarizadeh M.etAl. [120]	2022		Disease	Adults (women only)	Women Infertility		Educational, Question- naires, Self-monitoring	Yes(ac- ceptance)
Koivuniemi E. et Al. [121]	2022	Dottli, Dot- tli Oy	Other	Adults (women only)		Pregnancy	Self-monitoring, counseling	Partially
Wunsch K. et Al. [122]	2020	SMARTFAMILY	YOther	All ages		Dietor Weight Control	NA	NA

that allow counseling with physicians or feature validated questionnaires. Artificial Intelligence is also integrated in a consistent number of cases. It is also interesting to notice that most Apps monitor or calculate outcome measures that are easy to measure individually, such as body weight, or easy to calculate from data inserted by the user, such as quantities of calories or nutrients. Questionnaires are usually implemented when the outcome is a validated score, for example the MDS (Mediterranean Diet Score) and the various QoL (Quality of life) ones. A few Apps, however, monitor clinical parameters, and they are usually the same Apps that contain functionalities that allow for monitoring by the physician.

The results of this review can be useful both to identify the current gaps in the availability of Apps for nutrition support and to have an overview of the current state of the art, looking at the most used strategies that can be followed to create a useful tool to help patients. Arguably, this study suffers also from some limitations. First of all, the results of the statistical analysis on the main App functionalities are intended to be taken qualitatively, as more precise studies are required to better identify the most effective strategies in the development of an App. Plus, most RCTs were developed on restricted populations, all coming from the same limited geographic area (country, region, or even city), and the potential of generalization is not easy to evaluate. Possible biases could also be present considering that socio-demographic factors can influence the willingness of the users to buy and use an App [24,25]. Despite these difficulties, mobile technology still has generally promising results in the assistance of patients that require support on nutrition, although a feasibility study before the deployment of an App and a trial study to assess the real efficacy are recommendable. Finally, it should be noted that this review does not focus on the evaluation of the apps themselves, but rather on their use in the context of academic research. It could be possible for the same App to be tested for different purposes (e.g. a general nutrition app that provides support to contrast obesity can be used also to monitor the diet of a patient who is treating cancer), therefore the effectiveness of the approach can be different depending on the target for which an App is used. Plus, not all apps are available in the Google and/or Apple stores, as some studies refer to apps that have not been commercialized yet or apps that are available only in specific countries or for selected groups. For this reason, in future developments, it could be useful to evaluate the users' perception of the different features and the consequent possible relation between the store evaluations and the apps' measurable effectiveness, and to evaluate the possible relations between the use of an app in research studies and the users' evaluations and number of downloads of the same app in the different countries.

5. Conclusion

Maintaining a proper nutrition is fundamental for human health and quality of life, yet it can be a difficult task, especially for people that require special dietary regimens due to obesity, underlying malnutrition or the presence of a disease. In this context, mobile technology can provide support through tools that help managing diets, provide educational contents, facilitate self-monitoring and foster the communication with clinicians. In this review, we selected 100 recent studies that describe or evaluate the use of mobile apps to support nutrition in the last five years, analyzing their characteristics, the targeted conditions, the outcome metrics and their effectiveness. Of the selected studies, 33 focus on specific diseases, 24 on obesity, 2 on malnutrition and 41 on other targets (e.g., weight/diet control). Type 2 diabetes is the most targeted disease, followed by gestational diabetes, hypertension, colorectal cancer and CVDs which all were targeted by more than one app. Other food-related conditions such as Irritable Bowel Diseases appear to be less targeted by newly developed smartphone apps and their related studies. The most implemented functionalities are self-monitoring and coaching, educational content and artificial intelligence (AI) tools are also relatively common, whereas counseling, gamification and questionnaires are the least implemented. Body weight and calories/nutrients were the most common general outcome measures, while glycated hemoglobin (HbA1c) was the most common clinical outcome. No statistically significant differences in the effectiveness of the different functionalities were found. This study helps to understand the current state of the art concerning nutrition smartphone apps and can be the starting point for new app development, however more studies can be beneficial to better evaluate the apps themselves considering also their availability in the stores for each country, and more targeted studies are required to better quantitively identify the most effective strategies in the development of an app.

6. Summary Points

What was already known on the topic.	What this study added to our knowledge.
• A proper nutrition is essential for human life, but maintaining it can be a difficult task, especially for people needing special diets in relation to a preexisting condition. • Mobile technology is often use to provide support to users who wish/need to control their diets. • Apps development is vary fast and currently a large number of apps for nutrition support are available,	• This review analyzes the studies that mention the use of Apps for smartphone designed to provide support for nutrition in the last years. We summarized the main functionalities, targeted conditions/users and outcome measures of all the Apps that were described in the selected studies. • Most Apps focus on general weight and diet control, but a significant

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What was already known on the topic.	What this study added to our knowledge.
therefore identifying which fields of application have been explored and which main functionalities have been adopted the most can be useful in view of future app developments.	number of Apps is focused on treating specific diseases. • Type 2 diabetes is the most common disease target. Self-monitoring and coaching are the most implemented features.

CRediT authorship contribution statement

Daniele Pala: Study Design, Data curation, Formal analysis, Writing – original draft, Writing – review & editing. **Giorgia Petrini:** Formal analysis, Data curation. **Pietro Bosoni:** Formal analysis, Data curation. **Cristiana Larizza:** Supervision, Formal analysis, Data curation. **Silvana Quaglini:** Validation, Supervision, Resources. **Giordano Lanzola:** Writing – review & editing, Project administration, Funding acquisition, Formal analysis, Data curation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Authors' Contribution

All authors made substantial contribution to this paper. DP, GL and SQ designed the study, DP and GP extracted and prepared the data. Articles' screening was performed by DP, GP and GL. DP and PB wrote the paper and performed the analyses, which were supervised by GL, SQ and CL. All authors read and approved the final version of the manuscript.

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