TCO App: Telemonitoring and Control of Pediatric Overweight and Obesity

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Abstract  Continuous monitoring of the body condition of an overweight pediatric patient is of utmost importance for the success of his or her treatment. However, this represents a challenge after the first consultation because many parents present problems of time to attend the controls in the office, in addition to lack of tools to support monitoring from home, thus causing a high rate of dropout. There are telemonitoring applications for people with obesity that send data in real time, but they are focused on adults; they do not consider pediatric patients or their parents as agents of change. For this reason, TCO is presented as a mobile application for telemonitoring and control of overweight and obesity in pediatric patients, which facilitates the specialist in the communication, follow-up, and orientation of their patients through family members or caregivers, considering anthropometric indicators, automatic monitoring through rules, prescription of the food plan, and recommendation of foods and dishes of the season and region. A case study was carried out with two groups of 16 overweight and obese pediatric patients, one of them using TCO. The results show that the dropout rate was reduced by 38%, and both body mass index and average waist circumference improved by 4% and 3%, respectively. In addition, family members who did not dropout were surveyed, and satisfaction was obtained between “High” and “Very High” in the use of the application as an aid to monitoring and compliance with treatment.

Keywords  Telemonitoring · Control · Obesity · Overweight · Children

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1 Introduction

Pediatric obesity is a public health disease associated with having twice the risk of cardiovascular disease, type 2 diabetes, psychological problems, and early death in the future [20]. It is also a risk factor for COVID-19 [36]. In 2016, 124 and 213 million children were diagnosed as obese and overweight, respectively. According to the World Health Organization (WHO), there will be more children and adolescents struggling with obesity than with malnutrition in 2022 [8].

The tracking of overweight patients after the first consultation has become a challenge. Since specialists do not have periodic information on the progress of the patient regarding their anthropometric data (weight, height, waist circumference), they can’t identify if the treatment provided is working or not [10]. Also, many parents allege a lack of time to accompany their children to their periodic checkups, as well as a lack of tools to support them [35]. This causes a high early dropout rate without presenting improvements. Remote monitoring (telemonitoring) is a viable alternative to solve these issues.

On the other hand, the World Health Organization (WHO) raises among its strategic objectives to reduce childhood obesity, promote the development of technological solutions that facilitate the periodic control of body weight, and that bring together various components, focusing on the patient’s family [1, 31]. Telemonitoring solutions are currently in development for overweight people that contribute to overcoming distance and time barriers by sending data in real time to health providers. These applications will make it possible to assess the patient’s condition [28]. However, these solutions are focused on adults and other chronic diseases. Thus, no evidence of telemonitoring using anthropometric data has been found in overweight and obese children, counting on their parents as agents of change. On the other hand, there are mobile applications to support parents in the control of pediatric overweight and obesity, which also include videoconferences with specialists [23], however, these applications do not allow periodic monitoring or evaluation of the status of the pediatric patient.

Therefore, in this paper, we propose a TCO App, a web and mobile application for telemonitoring and control of overweight and obesity in pediatric patients. TCO considers three profiles: the nutritionist, the pediatric patient, and the patient’s family. The application allows the family member to register data such as weight, to be sent in real time to the nutritionist who receives alerts/notifications of the results and statistics. This way, after an evolutionary analysis, the dietitian can record or modify the diet plan, send comments, receive feedback, schedule sessions, have videoconferences, and maintain dialogs through a chat. The application is also based on monitoring rules that propose recommendations, depending on the results of the patient, for the family member to evaluate. In this way, the child adapts to the nutrition plan and weight improvement challenges are suggested for the child to apply.

This article is organized into five sections. The second section presents the literature review on telemedicine solutions, telemonitoring models, and existing mobile applications that support the control of pediatric overweight and obesity. In the third
section, the proposal for a telemonitoring and control of pediatric overweight and obesity application is detailed. In the fourth section, we present the validation performed through a case study at a health center in Lima, Peru. Finally, the fifth section culminates with the conclusions and results obtained from the validation.

2 Mhealth for Obesity in Pediatric Patients

MHealth is the use of mobile devices, telecommunications, and technology to promote education, remote monitoring, and communication for health care [26]. In [35], it is shown that 76% of overweight pediatric patients abandon treatment after 6 months, alleging a lack of time to attend checkups and a lack of tools to support their treatment from home. This problem is highlighted by the World Health Organization (WHO), which suggests that the development of telemedicine and mHealth, in that sense, should include parents or caregivers of children as agents of change during the treatment of patients [1, 30]; only in this way could be overcome the barriers of face-to-face visits, long distances and insufficient resources [18, 27].

In [20], a video conferencing program was implemented via mobile. On the other hand, in [33], a short messaging service (SMS) was used. Both showed improvements in parental satisfaction, considering these tools as effective, economical, and convenient. A survey in Pennsylvania perceived the need to have a web or a mobile application to increase the effectiveness of a successful program (accessibility, suggestions, recipes) [19, 24], and with this objective, parents of obese children could use these tools as a support for the treatment of their children [22]. Consequently, various mobile applications are in development.

In Table 1, an inventory of mobile applications to support the control of overweight and obesity in pediatric patients, with the participation of parents, is presented. This table includes characteristics such as profiles, anthropometric indicators (physical dimensions of the body at different ages and its comparison with reference standards [25]), patient ages, specialist interface, informative content, patient management module, appointments, reports, and videoconferences.

The tools present various characteristics, contents, as well as the use of video conferences. In addition, they use indicators such as the Body Mass Index (BMI), Waist Circumference (WC), and the Body Fat Index (BFI), which is considered effective in measuring overweight and obesity [29, 34]. However, specialists do not have an interface for monitoring. Therefore, most specialists send their comments through e-mails or social networks. In addition, the recommendations provided by the applications are usually generic and the only weight measurement is performed before and after the patient’s intervention. Likewise, these applications do not include remote monitoring that is essential for this type of diseases [11], on the contrary, for other diseases such as diabetes in adults, it has presented good results [38]. (See Table 1).
Table 1  App for the support and control of overweight and obesity in pediatric patients

| Characteristics       | MiniStop [32] | TeenPower [37] | Time2bHealthy [23] | AimBe [27] |
|-----------------------|---------------|----------------|--------------------|------------|
| Profiles              | Family        | Family         | Family             | Family, patient |
| Anthropometric indicator | BFI, BMI     | BMI, WC        | BMI                | BMI        |
| Patient ages          | 4–5           | 12–16          | 2–5                | 10–17      |
| Specialist interface  | No            | Website        | No                 | No         |
| Informative content   | Foods         | Foods, exercises, tips, recommendations, chat, notifications | Foods, exercises, tips, recommendations, screen time, notifications, e-mail reminders | Foods, exercises, tips, recommendations, notifications |
| Patient management    | Yes           | Yes            | Yes                | Yes        |
| Appointment management| No            | Yes            | No                 | No         |
| Videoconferences      | Yes           | Yes            | Yes                | Yes        |
| Report management     | Yes           | Yes, dashboards| No                 | Yes        |

3 TCO App

3.1 Model

A telemonitoring and control model of pediatric overweight and obesity is proposed, which allows remote monitoring automatically through rules and manually by a specialist, it also considers the prescription and participation of a family member or caregiver.

The family member registers the pediatric patient’s data in the application, where the overweight and obesity indicators (A. Capture) are calculated. All of these indicators are registered in a patient database stored in the cloud (B. Registration). Then, automatic monitoring is carried out through the monitoring rules (C. Automatic Monitoring), which, according to the evolution of the patient, automatically generate recommendations for food, exercises, and recipes. In critical cases, the specialist will be informed of the patient’s status via the application. Periodically, the specialist will evaluate the patient’s evolution (D. Manual Monitoring), and if necessary, will prescribe a treatment (meal plan and recommendations), through the prescription module (E. Prescription), which is sent in real time to the family member for posterior application to the pediatric patient (See Fig. 1).
Fig. 1  TCO model

Table 2  Profiles that intervene in the TCO model

| Profile                               | Description                                                                                                                                 |
|---------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------|
| Family member or caregiver of the patient | A family member or caregiver of the overweight or obese patient who performs the measurements of anthropometric data and manages the application of the treatment to the patient |
| Pediatric patient                     | An overweight or obese child whose indicators are evaluated and whose treatment is provided through their family member or caregiver          |
| Specialist (nutritionist)             | Nutrition professional also called a dietitian, who provides treatment and follow-up to overweight and obese pediatric patients                  |

The profiles that intervene in the TCO model are the family member, the specialist (usually, a nutritionist), and the pediatric patient (see Table 2).
### Table 3  BMI and its interpretation for children from 12 to 15 years old, adapted from [17]

| Age | Ideal | Normal (kg/m²) | Overweight (kg/m²) | Obesity (kg/m²) |
|-----|-------|----------------|-------------------|----------------|
| 12  | 17.5  | 15.8–19.9      | 20.0–23.5         | 23.6–30        |
| 13  | 18.2  | 16.4–20.8      | 20.9–24.8         | 24.9–3.7       |
| 14  | 19.0  | 17.6–21.8      | 21.9–25.9         | 26–33.1        |
| 15  | 19.8  | 17.6–22.7      | 22.8–27           | 27.1–34.1      |

### A. Capture

The family member, following the indications of the specialist (via Videoconferences) or the application (which uses the home protocol of the Centers for Disease Control and Prevention [27]), enters the following data in the application: weight in kilograms or pounds, height in meters, waist in centimeters, and other data such as age, gender, and region. Then, on the mobile device, the calculation of the Body Mass Index (BMI) is obtained from the formula: weight/(height x height) [3], which, together with the waist circumference, are the indicators used to identify the nutritional status of the patient.

### B. Registration

The captured data is stored in a database on a cloud server. Among the stored data is the historical Body Mass Index (BMI), Waist Circumference (WC), ideal weight (final goal), corrected weight (short-term goal), recommendations (exercise videos, recipes, and snacks), reports, meal plan, comments, messages, and scheduled appointments.

### C. Automatic Monitoring

Automatic monitoring is done by using rules that are based on the body mass index, waist circumference, regions, and seasons.

*Body Mass Index (BMI).* The following weight categories have been considered: ideal, normal, overweight and obese, based on the World Health Organization’s (WHO) growth table for children from 5 to 19 years of age. This table includes 410 records differentiated by gender and age [17]. Part of this table is presented in Table 3.

*Waist Circumference (WC).* The following waist circumference categories have been considered: ideal, normal, overweight and obesity, based on [21], for children from 2 to 18 years of age. This table includes 35 records differentiated by gender and age. Part of this table is presented in Table 4.

*Regions.* It refers to the regions that share the same physical and ecological characteristics, to take advantage of the food produced in each region. For example, in Peru, there are the coastal, Andean, and Amazonian regions.
Table 4  Waist circumference for children from 12 to 15 years old, adapted from [21]

| Age | Ideal | Normal | Overweight | Obesity |
|-----|-------|--------|------------|---------|
| 12  | 67.4  | 63.5–74.3 | 74.4–84.8 | +84.8 |
| 13  | 69.5  | 65.4–76.8 | 76.9–88.2 | +88.2 |
| 14  | 71.5  | 67.2–79.4 | 79.5–91.6 | +91.6 |
| 15  | 73.5  | 69.1–81.9 | 82–95     | +95    |

Seasons. It refers to the climatic seasons, which are useful for suggesting seasonal fruits and vegetables, as well as recipes based on these; since their nutritional properties remain intact, and they are usually cheaper. For example, in autumn, some of the coastal region’s seasonal fruits are the following: strawberries, pineapples, granadillas, tangerines, oranges, and grapes.

Monitoring rules have the following structure:

If ≪ combination (BMI, waist circumference, region, season.)≫ Then ≪ recommendation ≫

The combination is a result of the conditions for the four parameters. The recommendations refer to the suggestions given that correspond to a combination (for example, diets, food, exercises, advice, among others). Below is an example of a monitoring rule:

If BMI and waist circumference result in obesity, the patient’s region of residence is in the coastal region and the season is fall, then, only recommendations for foods that are lower in fat and sugar are shown, according to the National Heart, Lung, and Blood Institute Information Center (NHLBI) [16], recipes and snacks adapted to the foods that are most frequently produced in the autumn in the coastal region of that country.

D. Manual Monitoring

The results of the automatic monitoring, along with the evolution statistics, reports, and alerts are updated with each data capture in the specialist interface. The specialist can also access video calls and usage analytics for future decision-making through a PC or laptop.

E. Prescription

If deemed necessary, the specialist modifies the meal plan, schedules virtual appointments, sends recommendations or comments to the patient interface.
3.2 Development of the Application

The architecture used for the development of the TCO application was based on a cloud Backend as a Service model. The interface was programmed for Android devices. In Fig. 2, the integration architecture with the logical and physical components used is shown.

3.2.1 Application and Database Layer

A Mobile Backend as a Service (mBaaS) platform was chosen to link the application to backend storage in the cloud. This platform was also chosen because it allows user management, push notifications, and integration with social networks [13], which accelerates product development. The mBaaS platform used is Firebase, which is part of the Google Cloud, from which we used.

Cloud Firestore. It is a NoSQL database that allows data to be easily stored, synchronized, and consulted [4]. Here the information of the application was stored through collections and documents like the identifiable data of the users (names, surnames,
Fig. 3  Firebase: a Cloud firestore to store the application rules; b Firebase realtime database for the application messages

age, etc.), the information of the registered nutritional controls, reports, diets, and the monitoring rules.

In Fig. 3, a part of the collection of BMI growth tables [17] mentioned in Sect. 3.1 is shown. Documents were stored according to the gender and age of the patient, considering the following nomenclature: $M = \text{“Man”}$, $W = \text{“Woman”}$, $A = \text{“Years”}$, $M = \text{“Months”}$. For example, “M10A0M” is equivalent to a male patient of 10 years and 0 months. In each document, the fields corresponding to the percentiles that define whether the patient is overweight or obese were saved.

*Firebase Realtime Database.* It is a NoSQL database that stores and synchronizes messages between users in real time [6]. It was used for the integrated chat between the specialist and the family members. In Fig. 3, the different messaging transactions are displayed, which are broken down into the content of the message, the identifier of the sending user and that of the receiving user.

3.2.2 Presentation Layer

TCO App was implemented for Android devices because it is the predominant operating system with 70.68% of users worldwide [14], thus Android Studio 4.0.1 was used. The application is compatible with Android version 6.0 (marshmallow) and later. From this android version, is the most used according to StatCounter [12] covering 84.90% of users who use Android worldwide.
The programming was done with java using the Model View Controller (MVC) pattern so three different parts were obtained for the information classification, the interface, and the system logic. This allows the application to be maintainable and robust, as well as offering greater speed by being able to work on each part in parallel and reusing the views. Also, Google Analytics for Firebase was integrated as a web interface to display statistics on the use of the application.

TCO has interfaces for the pediatric patient’s specialist and family member profiles. The functionalities for the specialist are monitoring through the report of the patient’s improvement, prescription of the meal plan, consultation schedule, among others. In Fig. 4, an example of BMI monitoring is shown through a patient’s reports, her diet plan with the selected allowed foods, and the appointment schedule. The family member’s functionalities include the registry of checkups, such as weight, waist circumference, consultation of personalized recommendations, among others.

On the other hand, to monitor the use of TCO, Google Analytics was used, which allows identifying the most used functionalities, geographical areas of use, among other functionalities. In Fig. 5, the most used sections of the application and the country where most sessions are held are shown.
4 Validation

To validate the TCO App, a case study was conducted in Peru, a country that presented 19.3% of childhood obesity in the year 2018 [15].

4.1 Case Study

TCO App was validated in a nutritional office in a hospital in Lima, Peru, focused on pediatric care, which attends children from 5 to 16 years old, where they treat diseases such as obesity. In the office, approximately 20 children a month are cared for by a nutritionist who specializes in overweight and obesity. Monitoring is done in person when patients attend their medical appointment, which, on average, is monthly. Control and calculations are carried out manually and then transferred to the medical record system. The medical prescription is delivered to the family members in physical documents. Regarding the meal plan, it does not include typical dishes from the patient’s region. Also, there is a high dropout rate and little improvement in the child’s disease.

4.2 Adaptation of Rules

The parameters of the BMI, WC, region, and season established for the monitoring rules were adapted for the Peruvian population. There are 3 geographic regions that cover the territory: Coastal (Southeast to Northeast), Andean (Linked to the Andes mountain range), and Amazonian (part of the jungle) [9] In addition, the autumn season (the period between March 21 and June 21), 50 snacks, 90 fruits and vegetables, and 50 recipes were considered, with which 84 rules are obtained.
These rules were obtained from public sources such as the Ministry of Health [7], the National Heart, Lung, and Blood Institute Information Center [16], and all the images of the application interface were obtained from the Envato Elements platform [5] by paying an annual license fee. Some of these rules are shown below:

R01. If (Result of BMI Overweight + Result of WC Overweight) then (A green approval symbol is displayed and shows the message: “You are in your best nutritional state. Maintain your healthy style”).

R02. If (Result of BMI Overweight + Result of WC Overweight + Coast Region + Autumn) then (It is recommended to consume or acquire oranges, tangerines, strawberries, papayas, peaches, granadilla, apples, avocado, mango, soursop, etc., prepare recipes such as chicken liver or rice with chicken and snacks that include bread with an omelet, orange soda, hard-boiled eggs, etc. [2, 7]) (See Fig. 6).

R03. If (Result of BMI Obesity + Result of WC Obesity + Amazon Region + Autumn) then (It is recommended to consume or acquire aguaymanto, camu camu, star fruit, cocona, aguaje, taperiba, pineapple, blanquillo, granadilla, soursop, mango, etc., prepare recipes such as chicken juane or caigua stuffed with ground meat and

![Fig. 6 a Fruits and vegetables recommendations, b Snacks and recipes](image-url)
snacks that include inguirí with chicken, passion fruit soft drink, parboiled green banana, etc. [2, 7]).

4.3 Experimentation

Two groups of 16 patients were formed. The first group performed the traditional treatment (face-to-face visits and without an application) while the second group used the TCO App. In both cases, the trial period was eight weeks. For the other group, the father of the family was asked to record patient data every week (See Fig. 7). The fathers were trained in the use of the application modules and the proper form of measurement using the scale and measuring tape. Regarding the patients, it was considered that they did not present complications or were diagnosed with genetic disorders. Then, the informed consent was requested from their respective parents about their participation in the study.

4.4 Metrics

The dropout rate (patients who discontinue treatment), the BMI, and WC were determined before and after the intervention. Lastly, a questionnaire with questions about the use of the application (see Table 5) was presented to the parents of the TCO group.
Table 5 Usability and utility questionnaire

| N | Questions |
|---|-----------|
| Q1 | How much did the app help you monitor your child’s overweight/obesity? |
| Q2 | Do you think that the suggestions provided helped you to comply with the treatment? |
| Q3 | How easy was it for you to use the application? |
| Q4 | How useful do you think the “TCO App” is? |
| Q5 | How often would you use the app to monitor and control your child’s overweight/obesity? |
| Q6 | Would you recommend this application to other parents to monitor and control their child’s overweight/obesity? |

The questionnaire’s alternative responses followed the Likert scale (0: not at all, 1: very little, 2: a little, 3: moderately, 4: high; 5: very high).

4.5 Results

As can be seen in Fig. 8, the number of relatives and patients in both groups decreased over the weeks (dropout), which is usual in many treatments such as diabetes, hypertension, and other chronic diseases [28]. Some parents were called in order to ask the motives of the dropout in treatment. In the traditional group, parents commented that they did not have time to go to the hospital, the lack of results (note that the problem did not reduce), and few food options made them lose their motivation. On the other hand, in the TCO group, the lack of time and issues with their internet connection were mentioned. In the end, the dropout rate for the traditional group was 63%, while in the TCO group it was 25%. Ergo, TCO shows a dropout reduction of 38%.

After eight weeks, in the TCO group, the average BMI and WC improved by 6% and 4%, respectively; while the traditional group had improvements of 2% and 1% (See Table 6). Therefore, the group with the application obtained better results,
Table 6  Results of the overweight indicators

| Indicator       | Traditional Before | Traditional After | TCO APP Before | TCO APP After |
|-----------------|--------------------|-------------------|----------------|---------------|
| BMI average     | 21.23 kg/m²        | 20.87 kg/m²       | 21.63 kg/m²    | 20.26 kg/m²   |
| WC average      | 72 cm              | 71.7 cm           | 73.9 cm        | 71 cm         |
| BMI improvement | 2%                 | 6%                |                |               |
| WC improvement  | 1%                 | 4%                |                |               |

Fig. 9  BMI and WC for the TCO group, at the beginning and end of the study: a BMI; b CC

specifically, a 4% reduction of the BMI and a 3% reduction of the WC. Similar progress results were obtained in [29], where different behavior change techniques were applied in combination to nutritional interventions, obtaining as the main finding after 6 months an average difference of 0.53 kg/m² BMI and 1.45 kg weight between the groups that were part of their intervention compared to a control group to which they didn’t apply tests. Therefore, it is considered that, at the same time of validation, the results for TCO improve in comparison to those obtained. As additional data, there were significant improvements in 83% of patients in the TCO group. Also, those with higher BMI and WC were the patients who decreased their weight and girth the most when completing the validation (See Fig. 9).

The questionnaire (see Table 5) was applied to the relatives of the patients who remained in the TCO group (one of the parents was responsible for two patients). This way, the results obtained are shown in Table 7. The results show that 100% responded with “High” and “Very high” to questions about aid to monitoring (Q1), compliance with treatment (Q2), and perception of utility (Q4). On the other hand,
Table 7  Questionnaire results

| Family member | Questions |   |   |   |   |   |
|---------------|-----------|---|---|---|---|---|
|               | Q1        | Q2 | Q3 | Q4 | Q5 | Q6 |
| F1            | 5         | 5  | 4  | 5  | 4  | 5  |
| F2            | 4         | 5  | 5  | 4  | 4  | 4  |
| F3            | 4         | 5  | 3  | 5  | 4  | 4  |
| F4            | 5         | 5  | 3  | 5  | 5  | 5  |
| F5            | 5         | 5  | 4  | 5  | 4  | 5  |
| F6            | 4         | 4  | 4  | 5  | 4  | 4  |
| F7            | 5         | 4  | 4  | 5  | 5  | 5  |
| F8            | 4         | 4  | 4  | 4  | 5  | 5  |
| F9            | 5         | 5  | 5  | 5  | 4  | 5  |
| F10           | 5         | 4  | 3  | 5  | 5  | 5  |
| F11           | 4         | 5  | 4  | 4  | 4  | 4  |
| Average       | 4.55      | 4.64 | 3.91 | 4.82 | 4.27 | 4.64 |

regarding usability, the average responses for ease of use (Q3) and frequency of use (Q5) are between “High” and “Very high”. When asked, “Would you recommend TCO (Q6)?” 100% responded with “High” and “Very high”.

5 Conclusions

In this work, TCO was developed, a mobile application for telemonitoring and control of overweight in pediatric patients that facilitates the communication, monitoring, and guidance of their patients through family members or caregivers. The Android application was built on Firebase, a backend as a service model in the cloud that allowed quick development avoiding application and database server configuration, as well as making user management and push notifications easier. TCO considers anthropometric indicators that help to control and monitor, it performs automatic monitoring through rules established by the specialist, allows the prescription of a meal plan by the nutritionist, and recommends seasonal food and dishes from the region.

A case study was performed in a nutritional clinic of a health center in Lima, with two groups of 16 overweight and obese pediatric patients, one of them used the TCO application and the other followed traditional monitoring. The results show that the dropout rate was reduced by 38% for the group that used the application in relation to the traditional monitoring group. Additionally, the TCO group improved its average BMI and WC by 6% and 4%, respectively, while its counterpart had improvements of 2% and 1%. That is, TCO helped reduce dropout and improved treatment results.
In addition, a survey was conducted among the pediatric patients who did not abandon the treatment, obtaining results on the satisfaction aspect, between “High” and “Very High” to aid monitoring, compliance with treatment, and the perception of the utility, results that are repeated for the aspects of ease and frequency of use. Furthermore, 100% of respondents would recommend using TCO for monitoring and treating overweight and obese children.

For future works, it is proposed to develop a knowledge acquisition module that allows the automatic monitoring rules and the recommendations according to the context of the area and season to be kept up to date. Also, an integration between the application and the patient’s digital medical history is proposed.

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