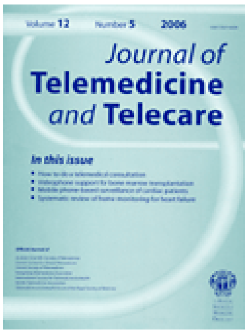

High Altitude Mountain Telemedicine

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Keyword:	teleconsultation, acute mountain sickness, healthcare, ICT

High Altitude Mountain Telemedicine

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Abstract

Introduction: An innovative teleconsultation platform has been designed, developed and validated between Summer 2017 and Winter 2018, in five mountain huts and in three remote outpatients clinical centres of the Italian region Valle d'Aosta of the Mont Blanc massif area. **Methods:** An ad hoc video-conference system was developed within the framework of the *e-Rés@mont* (Interreg Alcotra) European project, to tackle general health problems and high altitude diseases (such as acute mountain sickness, high-altitude pulmonary and cerebral edema). The system allows contacting physicians at the main hospital in Aosta to perform a specific diagnosis and to give specific advice and therapy to the patients in an extreme environment out-hospital setting. At an altitude between 1500 and 3500 meters, five trained nurses performed clinical evaluations (anamnesis, blood pressure, heart rate, oxygen saturation), electrocardiographic and echography monitoring on both tourists and residents as necessary; all the collected data were sent to the physicians in Aosta. **Results:** A total of 702 teleconsultation cases were performed: 333 dismissed (47%), 356 observed (51%), 13 immediate interventions (2%). In 30 cases the physicians decided there was no need for helicopter and ambulance rescue intervention and hospital admissions. The main physiological measures, the classified pathologies, the severe cases, and cost savings are described. **Discussion:** The *e-Rés@mont* teleconsultation platform has been discussed in terms of treated cases, feasibility, proactivity in reducing complexities, direct and indirect advantages, and diagnostics help; moreover general and specific pros and cons have been debated, and future steps have been exposed.

Keywords: teleconsultation, acute mountain sickness, healthcare, ICT

Introduction

Technology plays a vital role in further improving the healthcare sector. Digital technologies and the evolution in communication are changing the approach in the practice of medicine. Telemedicine has quietly become a part of healthcare and of everyday practice[1]. Recently, the potential for remote patient management through evolving technologies has increased patients monitoring as well as advice to physicians. Infact, a physician, is now able to assist from a distance, and this is crucial in a mountain environment[1,2]. Telemedicine offers a pragmatic, convenient and low-cost solution for high altitude and expedition medicine[3,4,5,6].

In order to improve healthcare for both tourists and residents in a mountain environment, and to manage Acute Mountain Sickness (AMS) and general health problems, an innovative teleconsultation system has been developed within the EU Interreg V-A ALCOTRA 2014 - 2020 *e-Rés@mont* project (code 492, start date 2016-08-31, end date 2018-03-01).

Mainly, the aim of the *e-Rés@mont* project was to design, develop, perform and experiment an innovative healthcare service to support mountain populations. The development of this project not only helped people who live in mountain areas but also improved the attractiveness of such areas for tourists. A network of structures and professional operators was built around Mont Blanc (Italy, France and Switzerland). *e-Rés@mont* ended on March 2018 and the project was realized in collaboration with a group of 5 nurses trained in emergency setting and mountain medicine before they started their activity.

It was designed and implemented a specific Web platform accessible via ~~a~~ tablet with a mobile connection, providing:

- a user friendly interface customized for the 2 groups of users, nurses and physicians;
- a multimedia text chat-audio-video real-time conference system, built on purpose for privacy reasons, allowing a connection with a medical doctor in a remote hospital;
- methods for storing images and videos for clinical evaluation;
- a tool for the risk assessment of acute diseases which was accessible via Web and via a mobile App, based on a modified version of the National Early Warning Score (NEWS)[7] adapted in order to monitor oxygen saturation (SaO_2) and blood pressure (BP) at different altitudes;
- a survey for individual lifestyles;
- an automatic evaluation of AMS based on the Lake Louise Score (LLS)[8] version 1993;
- an automatic evaluation of High Altitude Pulmonary Edema (HAPE) and High Altitude Cerebral Edema (HACE)[9];
- an automatic evaluation for severity Glasgow Coma Scale (GCS) to measure the consciousness of the patients[10].

When the Internet connection was unavailable, a Decision Support System (DSS) application on tablet provided the nurses with the risk scores necessary to assess the severity of the patient and allowing them to decide whether to call the emergency system directly.

Once the Internet connection was restored, all data recorded and saved locally were automatically sent to the hospital.

At the hospital, the physicians on duty checked all the data, if necessary they would require a video consultation with the nurse and the patient, and once the diagnosis was made it would be stored within the platform and sent to the nurse who in turn would have to confirm the reading and communicate it to the patient.

A healthcare model, the first of this kind in Europe to our knowledge, based on a telecooperation and virtual teleconsultation service in mountain environment has therefore been developed and employed with both the locals and the people who spend time in a mountain environment episodically (tourists, hikers, climbers, etc.).

This model of teleconsultation is uncommon, at least in Italy; as a matter of fact, the Italian Law recently (July 12nd, 2012) defines the goals of telemedicine: secondary prevention, diagnosis, care, rehabilitation and monitoring, rules are transferred to future integrations. In the meantime, the Italian Autonomous Region of Valle d'Aosta, in concordance with the Italian Government defined their guidelines for the use of telemedicine.

Methods

A platform of teleconsultation was designed and developed by the Institute of Information Science and Technologies (ISTI) in collaboration with the Institute of Clinical Physiology (IFC) part of the National Research Council (CNR) of Italy. The platform allowed to access a Web system (Figure 1A), via a tablet equipped with a mobile 3G/4G connection. The trained nurses from remote mountain huts in the Italian Northern mountain area, at an altitude between 1533 and 3500 meters, were enabled to send multimedia data (physiological parameters: BP, heart rate (HR), SaO_2; electrocardiogram (ECG), and echography) to the hospital in Aosta where a doctor would make a diagnosis.

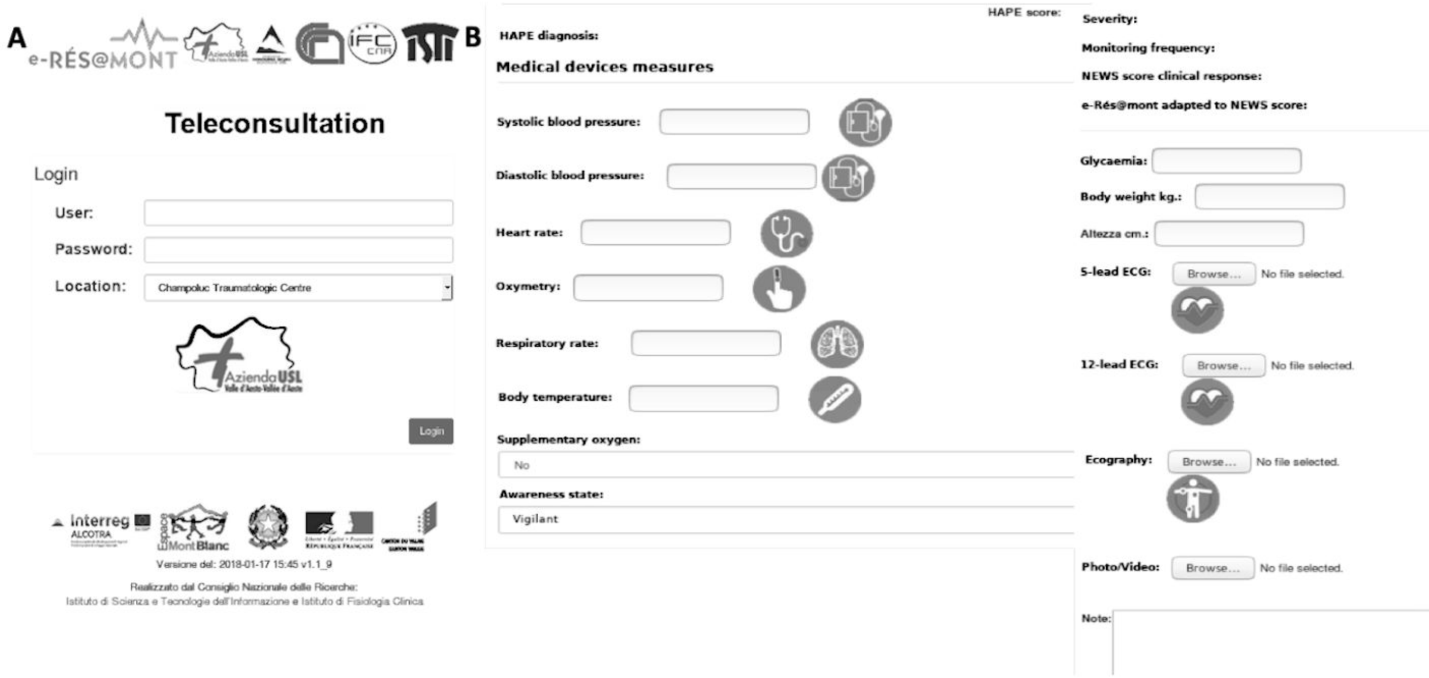


Fig. 1 - The login page of the *e-Rés@mont* teleconsultation Web system (A); and the medical devices measures page (B)

This platform provided an ad hoc videoconference system built using the most recent technologies with auto-adapting video-band. When the connection was unavailable, a decision support system, in the form of an offline Web app, provided scores and suggestions to the nurses which allowed them to evaluate the clinical severity, to dispense emergency aids and to call rescue services when needed. When the connection become available again, the locally stored data were sent to the hospital. Based on the acquired information, the presence of AMS was also automatically assessed. Doctors and nurses chose the validated scales readjusted physiological parameters according to the altitude, defined tools, drugs and identified a protocol to follow. As of symptoms, the patients were submitted to clinical evaluation (i.e. vital parameters, SaO_2, body mass index (BMI), LLS questionnaire for AMS scoring); moreover, a 5 or 12 lead ECG and lung ultrasound could be performed. Based on the data received, doctor on call would take medical decision, and nurse/s who provided care to the patient/s would receive the appropriate instructions.

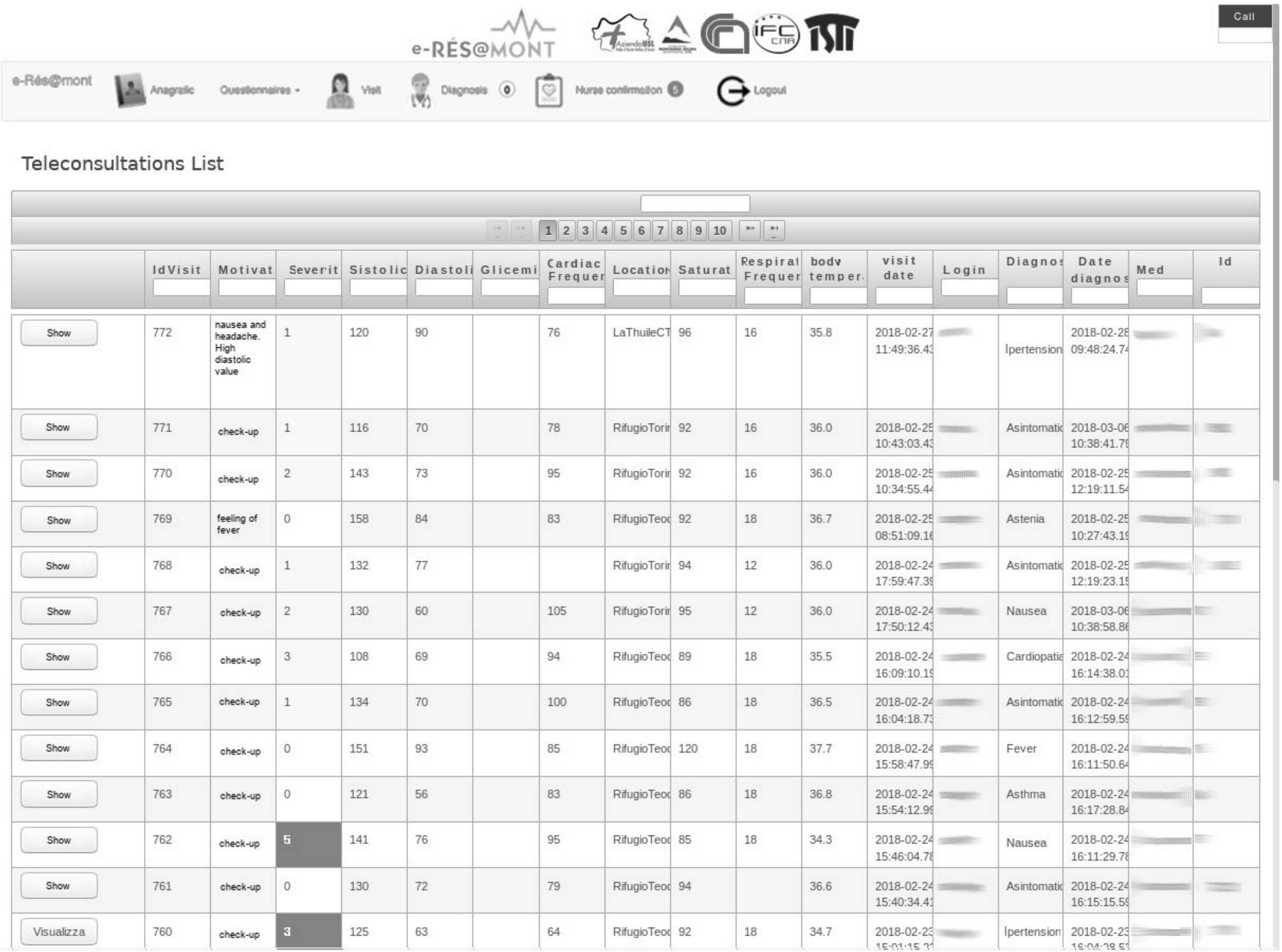
All the subjects needing evaluation for AMS or any other symptoms were submitted to a standardized clinical evaluation: anamnesis, state of consciousness, BP, HR, respiratory rate (RR), body temperature and SaO_2 monitoring. When necessary, the nurses would also perform ECG monitoring and ultrasound examination with a portable appliance.

Figure 1B shows the Web page dedicated to the collection of parameters obtained through medical devices for the teleconsultation.

The National Early Warning Score (NEWS) was used to determine the disease level of severity in patients and to solicit critical care intervention. In this study, the NEWS score was adapted on the basis of the altitude therefore the SaO_2 and systolic blood pressure (SBP) parameters were normalized[11]. The system, depending on the NEWS, can classify the subjects based on colour codes for diseases level of severity: white stands for mild diseases, yellow for medium-severity diseases that need a medical consultation in a short time, red for a level of severity that requires a direct call to the emergency system by phone (European emergency number 112).

In case of a yellow code and the simultaneous lack of Internet connection, the nurses should check the patient again within half an hour for new clinical evaluation.

Figure 2 shows the teleconsultation list page accessible to the physicians: an immediate visual comprehension of the situation utilising the severity codes is presented, offering the possibility to search by single or multiple fields and globally on all the collected data.



	IdVisit	Motivat	Severit	Sistolic	Diastoli	Glicemi	Cardiac Frequer	Locatior	Saturat	Respirat Frequer	body temper	visit date	Login	Diagnos	Date diagnos	Med	Id
Show	772	nausea and headache. High diastolic value	1	120	90		76	LaThuileCT	96	16	35.8	2018-02-27 11:49:36.43		Ipertension	2018-02-28 09:48:24.74		
Show	771	check-up	1	116	70		78	RifugioTorir	92	16	36.0	2018-02-25 10:43:03.43		Asintomatic	2018-03-06 10:38:41.79		
Show	770	check-up	2	143	73		95	RifugioTorir	92	16	36.0	2018-02-25 10:34:55.44		Asintomatic	2018-02-25 12:19:11.54		
Show	769	feeling of fever	0	158	84		83	RifugioTeoc	92	18	36.7	2018-02-25 08:51:09.16		Astenia	2018-02-25 10:27:43.19		
Show	768	check-up	1	132	77			RifugioTorir	94	12	36.0	2018-02-24 17:59:47.39		Asintomatic	2018-02-25 12:19:23.15		
Show	767	check-up	2	130	60		105	RifugioTorir	95	12	36.0	2018-02-24 17:50:12.43		Nausea	2018-03-06 10:38:58.86		
Show	766	check-up	3	108	69		94	RifugioTeoc	89	18	35.5	2018-02-24 16:09:10.19		Cardiopatie	2018-02-24 16:14:38.01		
Show	765	check-up	1	134	70		100	RifugioTeoc	86	18	36.5	2018-02-24 16:04:18.73		Asintomatic	2018-02-24 16:12:59.59		
Show	764	check-up	0	151	93		85	RifugioTeoc	120	18	37.7	2018-02-24 15:58:47.99		Fever	2018-02-24 16:11:50.64		
Show	763	check-up	0	121	56		83	RifugioTeoc	86	18	36.8	2018-02-24 15:54:12.99		Asthma	2018-02-24 16:17:28.84		
Show	762	check-up	5	141	76		95	RifugioTeoc	85	18	34.3	2018-02-24 15:46:04.78		Nausea	2018-02-24 16:11:29.78		
Show	761	check-up	0	130	72		79	RifugioTeoc	94		36.6	2018-02-24 15:40:34.41		Asintomatic	2018-02-24 16:15:15.59		
Visualizza	760	check-up	3	125	63		64	RifugioTeoc	92	18	34.7	2018-02-23 [illegible]		Ipertension	2018-02-23 [illegible]		

Fig. 2 - The Teleconsultation list page

Cutting-edge Web technologies were adopted: users had to open a browser (e.g. Firefox, and Chrome), from a tablet and access a Web page. Behind the Web page there was a persistence module deputy with the aim to handle all the data, a logic module, also including the DSS providing risk scores and suggestions, a signalling module which can put in contact the nurse tablet with the physician tables (on activation, the connection continued peer to peer, without intermediary).

The video conference data-rate was auto-adapted depending on the internet band.

The system is developed at Pisa, by a team from CNR-ISTI, as a prototype, and is connected to the Internet backbone (server) via cable.

In each mountain hut involved in this study, there were tablets equipped with a Subscriber Identity Module (SIM) card, or a satellite connection with a Wi-Fi router providing a local area connection.

The final system has been deployed in the hospital and connected via cable to the Internet. In the Aosta hospital, a router was programmed to provide a secure connection for the tablet of the physicians (Figure 3).

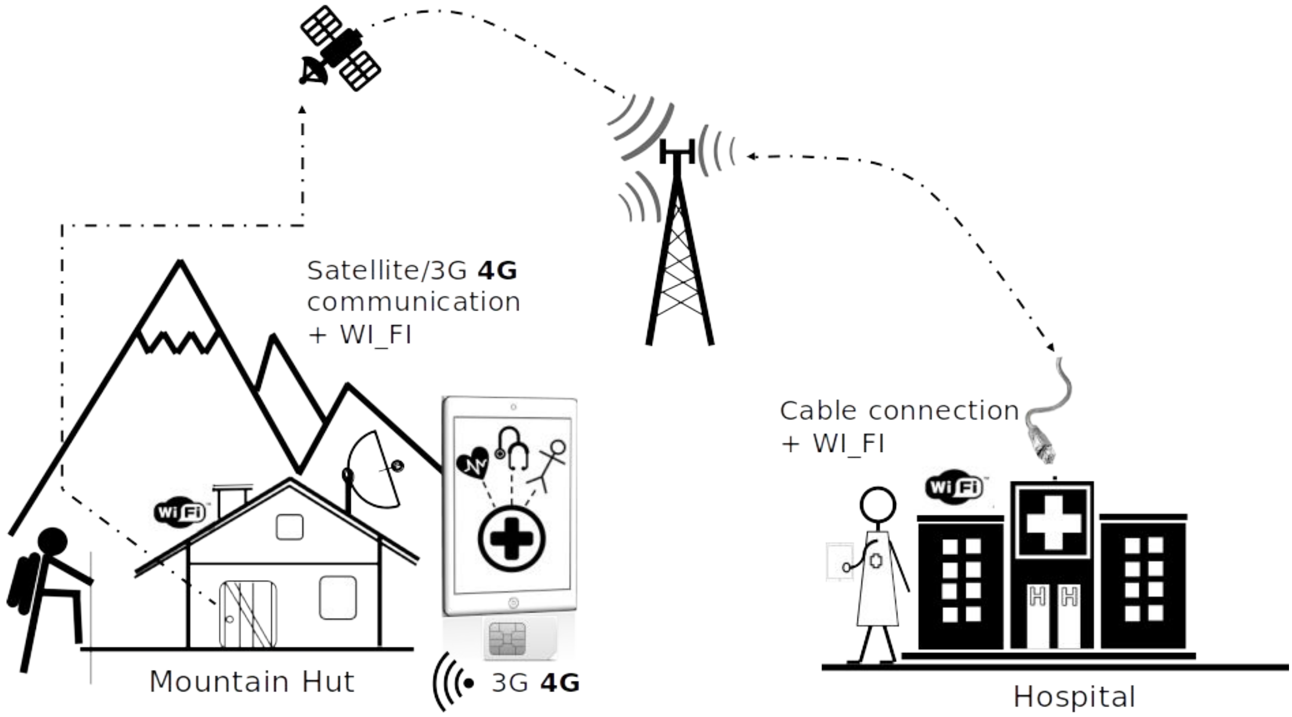


Fig. 3 - Connections' schema

To build our ad-hoc video-conference, Web Real-Time Communications (WebRTC)[12] was adopted, an open source project created to enable secure real-time communication of audio, video and data in Web and native apps (Figure 4). It had multiple Application Programming Interfaces (APIs) related to capturing, recording and streaming audio and video, and also for streaming data between users. It is usable through a recent browser (i.e. Firefox, Chrome) on desktop and mobile apps.

Fig. 4 - An example of video teleconsultation test via WebRTC
between the ISTI-CNR headquarters in Pisa and one of the participating mountain huts

For storing data locally in the offline teleconsultation App, Localstorage[13] was used, a technology providing new methods to store information securely and locally in a browser. It has bandwidth, speed and security advantages compared to the old cookies technology providing even more space. Moreover, information stored using local storage cannot be accessed from a different host.
For sending data between the remote mountain huts and the hospital, Websocket[14] was used, a new full-duplex communication protocol that can remain permanently active, enabling the exchange of information between the client and the server.

Results

Between Summer 2017 and Winter 2018, 702 teleconsultations were performed with the Aosta hospital within 5 mountain huts and in 1 remote outpatient clinical centre with the Aosta Hospital (males 61%; females 39%; average age 49±17 yrs).
The system performed the functions designed for mountain areas adequately: all data were correctly received at the hospital and teleconsultations allowed the specialists to check all the measurements in order to give their advice and to decide the final diagnosis and treatment. Figure 5 shows the teleconsultations by age groups: distribution is almost normal, although no sample selection was made.

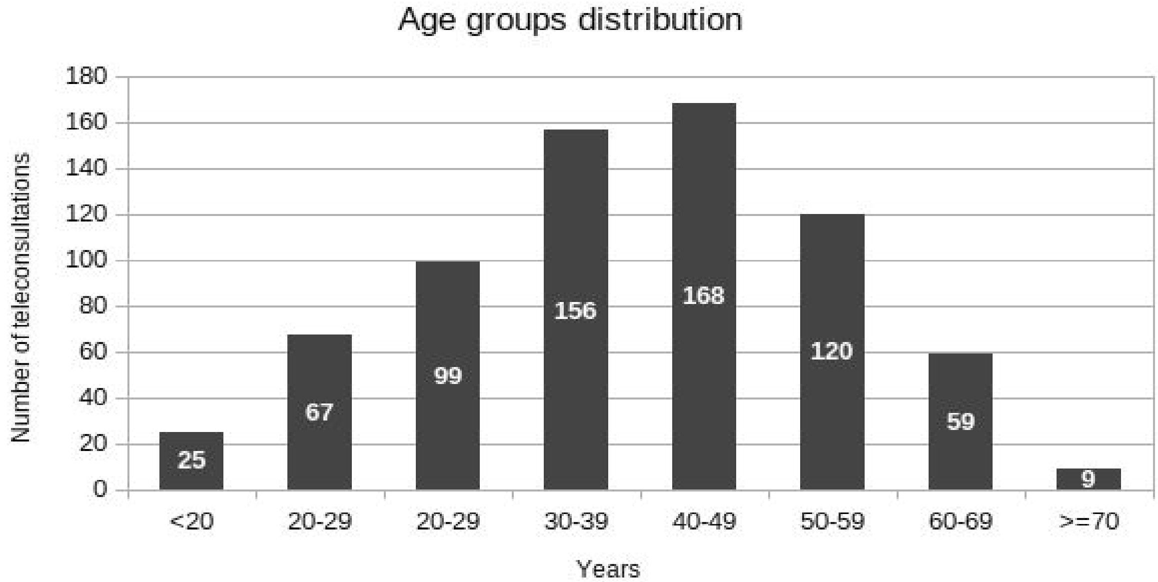


Fig. 5 - Age groups distribution of teleconsultations

In Table 1 the primary measures of age in years, SBP and DBP, HR, RR beats per minute (bpm), and the SaO_2, grouped by location, altitude and gender are reported.

	Height Above Mean sea level (altitude)	Gender	Age (years)		Systolic Pressure (mmHg)		Diastolic Pressure (mmHg)		Hearth Rate (bpm)		Respiratory Rate (mean per minute)		Oxigen Saturation (SaO_2)	
			Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Cogne Center	1396	female	61.5	18.7	130.8	19.5	74.8	11.0	77.2	11.7	16.4	1.5	96.6	1.5
		male	54.8	18.0	133.8	14.5	76.4	8.8	73.2	11.4	16.5	1.6	96.6	1.3
ColDeLaSeigne Hut	2365	female	45.7	14.4	**119.7***	13.6	**75.2***	9.2	83.0	12.8	14.8	2.2	**94.5***	2.0
		male	46.4	17.5	**127.5***	16.1	**79.2***	10.7	82.1	13.0	14.3	2.1	**93.4***	2.1
Arbolle Hut	2507	female	51.4	14.5	**117.9***	18.1	**70.1***	10.8	**77.4***	12.5	16.7	1.3	94.1	1.7
		male	51.8	15.7	**127.4***	16.4	**78.1***	12.5	**84.0***	16.7	16.7	1.5	94.3	1.9
Teodulo Hut	3317	female	37.1	12.0	**118.4***	17.7	**68.8***	7.3	83.8	18.5	14.8	2.6	93.6	1.9
		male	45.0	11.3	**132.9***	15.8	**74.2***	9.4	82.2	12.4	15.7	2.8	92.3	5.5
Torino Hut	3375	female	45.9	14.9	**126.2***	21.7	75.4	13.2	79.5	11.5	16.8	1.9	91.0	3.0
		male	44.6	16.4	**136.2***	17.8	79.7	12.7	81.4	14.3	17.1	2.0	89.9	5.0
Mantova Hut	3498	female	**36.2***	13.6	**118.1***	12.5	**67.7***	7.2	84.3	14.3	**15.5***	2.1	90.8	1.7
		male	**49.6***	13.7	**129.2***	17.8	**72.5***	9.1	80.9	16.2	**17.0***	2.0	90.8	3.2

* p-value < 0.05, Independent T-Test

Table 1 - Main physiological measures grouped by location, altitude and gender

As expected, SaO_2 decreased as altitude rose, while the mean age, BP and HR were lower in females. Moreover, in Cogne the average age was higher, probably because the healthcare centre supplies the entire local population in addition to the tourists.

Out of 702 consultations, a total of 203 resulted in an identified pathology (Figure 6): the most frequent pathologies were AMS (8,0%), headache (4,0%), minor trauma (2,3%), (which represented the 70% of the entire pathologies), and gastrointestinal disorders (1,3%).

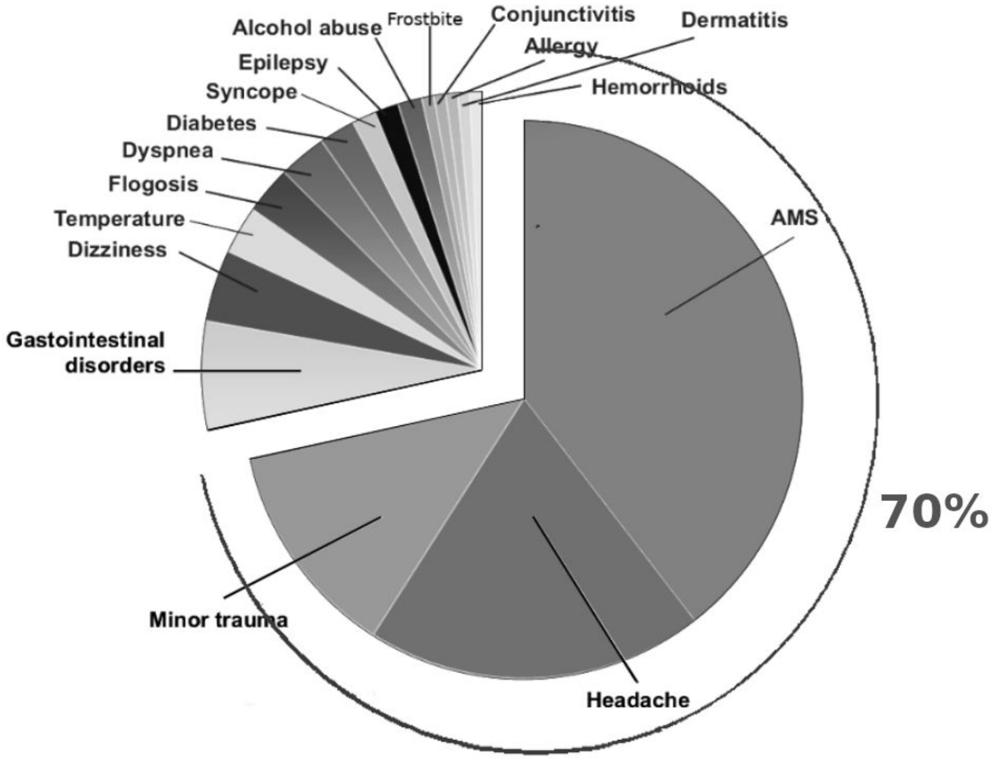


Fig. 6 - Classified pathologies in *e-Rés@mont* project

In Figure 7 the macro-categories of pathologies have been grouped by the mountain huts. The total percentage of AMS was 15.25%. As expected, AMS diagnosis increased at higher altitudes, but some differences have to be acknowledged: at the Mantova mountain hut (3498 m.) the AMS percentage was lower if compared with the others at similar altitude: Teodulo (3317 m.) and Torino (3375 m.) huts. On the contrary, at the Torino and Teodulo mountain huts the AMS diagnosis was higher (41% and 26,5% respectively).

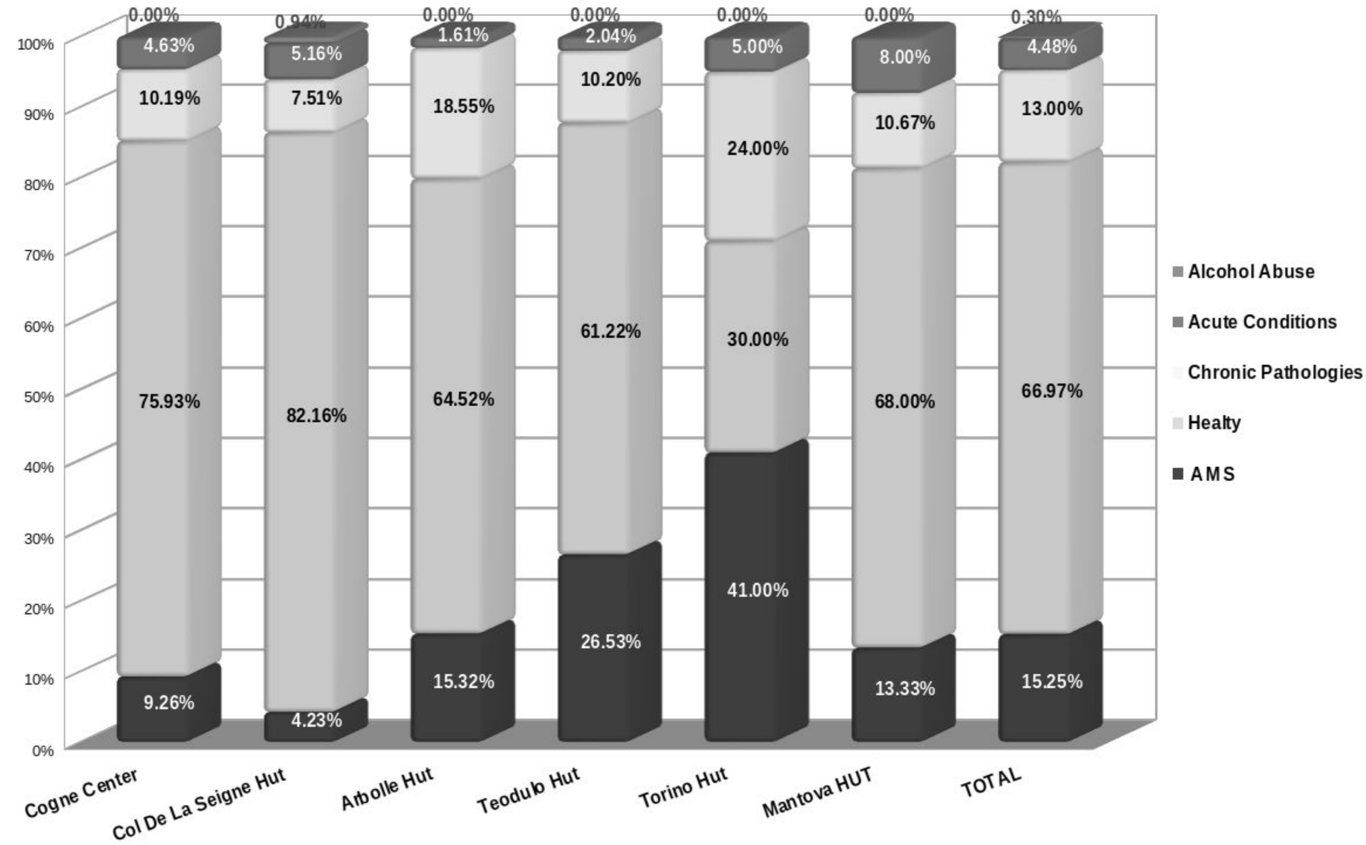


Fig. 7. - Macro-categories of pathologies: grouped by mountain hut and total

The teleconsultation system allowed us to reach a final diagnosis and treatment decision with an average time of 32 minutes. The subjects evaluated by the system were classified as 333 white codes (47%), 356 yellow codes (51%), 13 red codes (2%)[15,16].

Figure 8 shows the distribution of the severity codes grouped by sites: mountain huts at high altitude and wherever the patients' average age was higher, and red codes were common.

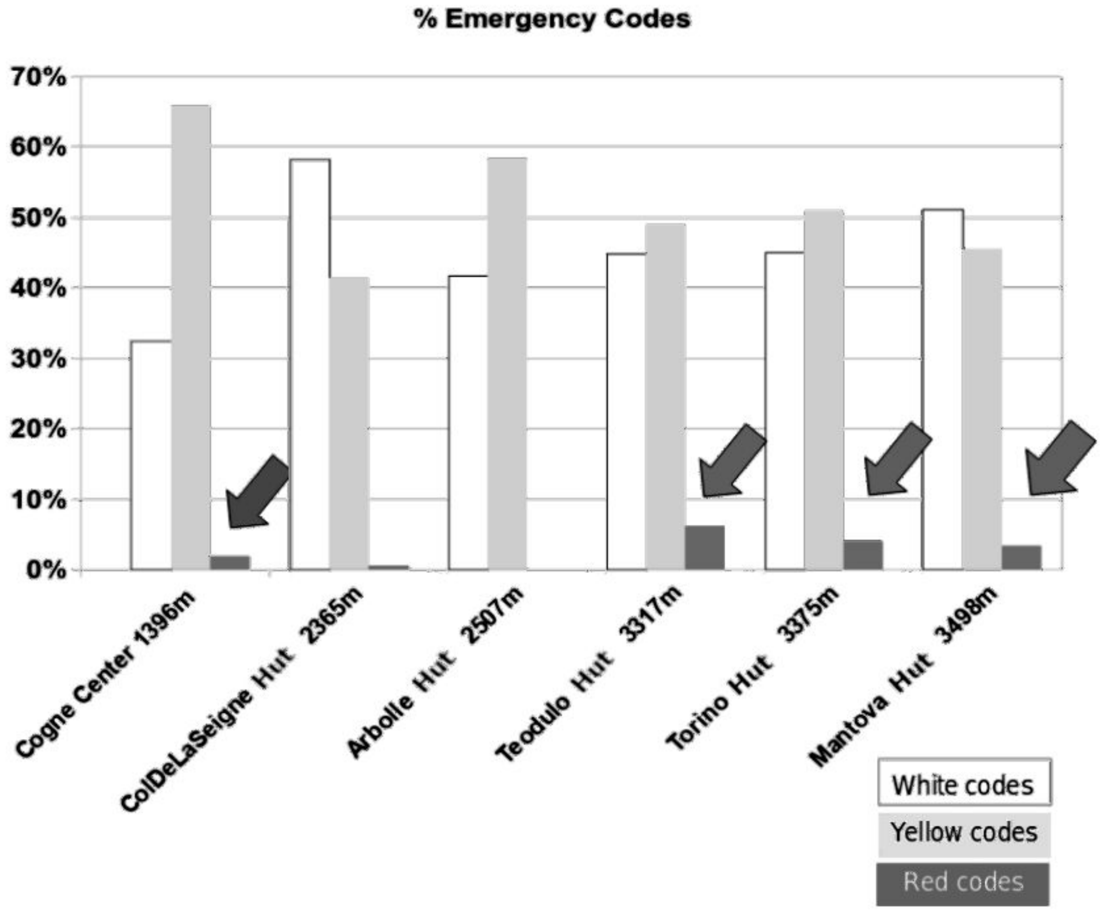


Fig. 8 - Emergency codes by location

Figure 9 shows the macro-categories of all the pathologies: red and yellow codes versus red codes only (13 red, 17 yellow).

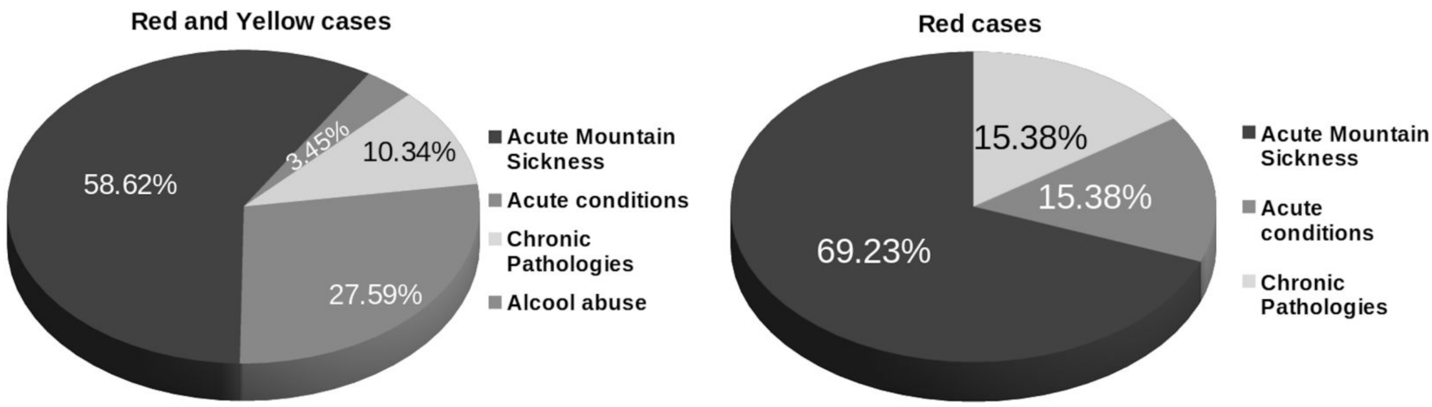


Fig. 9 - Macro-categories of pathologies for the 30 most severe cases:
A: red and yellow codes, B: red codes

In all sites where the *e-Res@mont* teleconsultation was used the AMS represented the most common pathology (58,2%) if we take into account together red and yellow code cases and even more if we

consider only the red code cases (69,2%).
Specifically, the diagnosis labelled as red code cases was:

- AMS macro-category: severe AMS, vertigo, headache, syncope;
- Chronic Pathologies macro-category: hypertensive crisis;
- Acute Conditions macro-category: hypotension and trauma.

In these 30 cases (yellow and red), the physicians on call in Aosta hospital decided to treat the patient on the spot and in most cases subjects were treated and then taken to a lower altitude as soon as possible on foot. As matter of fact 30 inappropriate rescue interventions were avoided: 18 ambulance trips and 12 helicopter flights, and consequently the related admittance to emergency and specialized hospital departments were avoided too. On the basis of these data the global savings achieved amounted to 75,489€ as detailed in Table 2.

voice	costs (€)	cost function	details
avoiding helicopters call: direct saving	43.200	12 * 30 * 120	12 flights; 30 minutes hypothetical average duration of a helicopter intervention; 120€/minute is the cost of a helicopter flight without a nurse nor a physician
emergency treatment	7.230	30 * 241	30 cases evaluated 241€ is the average cost for emergency department treatment in the Regione Autonoma della Valle d'Aosta[17]
inappropriate use of helicopter rescue service	20.400	800 * 8 + 3500 * 4	800€ for 8 Italian citizens, up to 3.500€ for 4 foreigners[18] to be paid to the Mountain Rescue service
supplement ticket for non local resident	4.659	$\frac{(120*30*11+241*29)*10}{100}$	10% extra charge for non resident fee applied by the regional health system: 29 non-resident, 1 resident red code
TOTAL	75.489		

Table 2 - Global savings achieved

Moreover there were other direct savings for the additional cost for hospital department and indirect savings for leaving helicopters, ambulances, structures and personnel free where needed, reducing traffic and pollution.

Discussion

While on the mountains and rural areas of other parts of the world, such as the Himalayas and other regions[19,20,21], telemedicine has spread non-sporadically in the last few years, on the European Alps telemedicine is still not common, and, in Italy, it is not even fully regulated and practicable, apart from provinces and regions with special status. In this scenario, the teleconsultation platform proposed in this paper has been the first of this kind on the Alps, tackling AMS and general health problems of both tourists and residents.
Technology plays a crucial role in the further development of the patient-centred healthcare[22], and the *e-Rés@mont* platform can help to shorten the distance between patients and medical staff, and improve the timeliness of monitoring, diagnosis and treatment.

Examinations of 702 persons were collected and analysed, partly automatically and partly verified by physicians and by specialists when needed through the teleconsultation model proposed by the *e-Rés@mont* project. The proposed platform has offered many advantages, not only the direct economic one (saving about 75,500€), which is certainly noteworthy but also the indirect ones. The advantages can be listed as (i) reduction of the waiting list (decision on treatment taking an average time of 32 minutes), (ii) monitoring of multiple different pathologies (203 cases resulted in an identified pathology), (iii) performing patient follow up, (iv) opportunities for checking daily parameters in acute and chronic diseases, (v) providing teleconsultation everywhere, also from the doctors home, therefore reducing car traffic, and thus, the carbon footprint. With the results of the *e-Res@mont* teleconsultation system, it was possible to prevent the deterioration of the different emergencies. Based on the physiological parameters measured, a score risk for the acute diseases was built: the subjects that were diagnosed as a moderate risk were invited to rest and their follow-up was always performed.

Regarding the cons of the system: barriers remain in adopting these new technologies[23,24,25] and it is essential to acknowledge that physicians actually prefer a face-to-face contact with with patients[26] when they need to perform a clinical evaluation. However, often not all consultations require a complete physical examination. Moreover, in this project, the teleconsultation was carried on by expert nurses who had also been trained to use ultrasound devices. From the perspectives of information and communication technology (ICT), one of the possible significant problems of this teleconsultation system regarded connectivity, especially in the extreme and challenging environment where the project was meant to operate. An offline app with a clinical decision support system was provided with the aim to reduce the need of a connection to solve the relevant potential issues and, in case of a red code case, the nurses should call the emergency system as soon as possible. Privacy was dealt with by encrypting any exchange of information and any sensitive information in the database. Rights to access the stored information were customized by group of users and by location.

From an economic point of view, initial costs for acquiring devices and training the medical staff could be influential, but operatively cost will be adequately recouped.

Correct diagnosis and treatment are defined as quality of care: telemedicine helps to provide the two main dimensions of quality of care, that are access and effectiveness[27].

The *e-Rés@mont* platform also allowed to make an AMS diagnosis and to give to the subjects the right indication whether to keep staying at high altitude or to descend. In the results, as expected the number of AMS cases increased at higher altitudes, but at the Mantova mountain hut, the AMS diagnosis percentage was lower compared to others mountain huts at a similar altitude (the Torino and Teodulo mountain huts). These results could be probably associated with the fact that mountaineers at the Mantova mountain hut were generally more expert and to get the refuge they took the cableway up to 2980 m and after they walked up to the Mantova mountain hut (3498 m). It's well known that a slow ascent avoiding as much as possible mechanical transportation to climb a mountain is considered more appropriate for AMS prevention[28.]. Appropriate preventive strategies should be adopted, i.e. warnings of acute high altitude disease risk should be visible at the starting point of the cable car, and should be useful in particular for tourists that decide to spend a night at high altitude without previous acclimatization.

Conclusions

The *e-Rés@mont* multiparametric platform has been:

- feasible
- less time consuming (compared to the usual emergency system in a mountain environment)

It can be self-financing with a low-cost sanitary ticket: a hypothesis provided by the Valle d'Aosta Region would be of about 35 euros.

With appropriate training, the platform could be used by the staff of the mountain huts without nurses or by the mountaineers themselves while staying in a bivouac, thanks to the video contact between doctors and subjects/patients.

e-Rés@mont telemedicine platform can also be used for medical tourism not only to improve healthcare in a challenging environment but also to save patients from the hassles of identifying and connecting with an appropriate health services provider while removing language and cultural barriers[29]. Further studies are needed to assess the impact on health costs on the waiting lists. Moreover innovative machine learning techniques can be used to classify diseases[30]. Non-availability of emergency healthcare services in mountainous, isolated, and sparsely populated regions is a universal problem[31]. In this regard, on October 26th 2017, a teleconsultation between rescue point in Pheriche (फेरिचे), a village in the Khumbu region of eastern Nepal, situated at an altitude of about 4,371 m, and Pisa, Italy, was made using the *e-Rés@mont* platform. A male Sherpa of 50 years old was diagnosed with a case acute respiratory insufficiency: the clinical evaluation was performed in about 30 minutes and all the data were shared through the platform. Finally we can say that, *e-Rés@mont* telemedicine platform could also be used in other situations, for example disaster relief, emergency situations, and high altitude expeditions, because of its ease of use, flexibility, adoption of innovative technologies, has applications API, and above all because it is within everyone's reach thanks to mobile apps. Furthermore, the proposal platform may form a guide to practice in the field of high-altitude telemedicine.

Acknowledegments

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