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Efficacy of Remote Hearing Aids Programming Using Teleaudiology: A Systematic Review

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Abstract

Telemedicine is defined as a system that allows healthcare workers to deliver their services and consultations to the patients remotely without the need of their physical presence within academic institutions, hospitals, and medical clinics aiming to reduce the personal contact and limiting it to the need only. The field of telemedicine is growing every day and facilitating more flexible services for patients around the world especially during COVID-19 pandemic. **Methods:** This systematic review was conducted according to the Cochrane Handbook for Systematic Reviews. Database search was made on several databases including PubMed/Medline, Scopus, Web of Science, Publons, EMBASE, and Google Scholar using the relevant keywords. Inclusion criteria for articles in our study included the following original research (primary research articles), addressing the efficacy of teleaudiology for hearing aids programming and satisfaction of patients. **Results:** Seven studies were included in this systematic review article. Included studies were assessed using Cochrane handbook guidelines. **Conclusions:** The results of this work based on the currently available literature denote that remote programming for the hearing aids using modern technology is effective and provide comparable results with the standard face-to-face clinic programming, even for patients with no previous experience in hearing aids fitting in either of in-person physical presence programming or remotely over the internet using teleconferencing which is known as teleaudiology. Most of the results were positive and support the continuity to develop better facilities to improve the teleaudiology to be an essential part of hearing aids programming with its different types. Minimal results provided negative impact from the participating patients, this resulted because of the non-upgraded infrastructure and facilities of the audiology clinic or the personal computer of the patient in his home/workplace or both sides don't have enough specifications to smoothly perform this modern approach.

Keywords

Telemedicine, Teleaudiology, Hearing Aids and COVID-19 Pandemic

1. Introduction

Telemedicine is defined as a way that allows healthcare workers to deliver their services and consultations to the patients remotely without the need of their physical presence within academic institutions, hospitals, and medical clinics aiming to reduce personal contact and limiting it to the need only [1]. The field of telemedicine is growing every day, and facilitating more flexible services for patients around the world [2]. In general, this approach of medical communication between the physician and the patient is made through a computer in the working site, personal computer for the patient, stable network connection for both the provider and the patient, and the proper facilities needed according to the service that is being offered [1]. The history of modern telemedicine communications began in 1905 by the Dutch physician-scientist Dr. Willem Einthoven, who specialized in medicine and physiology. Dr. Einthoven invented the electrocardiograph (ECG) in 1895 [3] [4], and later on, in 1905, he applied the world's first modern paradigm in this field by attempts to remote trans-telephonic transfer of ECG waves from his physiology laboratory to the university hospital of Utrecht University [5]. Later on, in the 1920s, the idea of Dr. Einthoven became popular around Europe, and several of the medical centres and healthcare wards in France, Italy and Norway. A few years later, in the 1930s and up to the 1940s, it has been used for the ships located in remote areas to facilitate communications between the captain, ship workers and the station [6]. The first usage of telemedicine in the United States of America was done in the early 1950s, for the transmission of radiographies, and later on, in the late 1950s, it was approved for medical purposes, especially for medical consultations through radio channels [6]. With the modern advances in the fields of technology, the applications of telemedicine have been spread to different medical specialties, including the field of audiology [6].

The abbreviation of teleaudiology refers to the usage of telemedicine facilities in the field of audiology to deliver its services including video endoscopy, programming/fitting of the hearing aids and cochlear implants, and following up of audiology clinic patients without the need of their physical presence in the clinic [7]. The history of using teleaudiology began in the mid-1990s for research purposes without the approval for being used on human patients; the first approval to use teleaudiology services for patients was in the early 2000s in East Carolina University by Dr. Givens [8]. This first application for teleaudiology was used for the assessment of auditory threshold through a computer located in the audiology laboratory at the university campus and linked to a remote audiometer controlled over the internet [8]. This was conducted as a double-blind randomized

controlled trial comparing the standard face-to-face audiometer to the new approach of remote audiometer. The results of this world's first trial about this topic presented comparable results denoting that teleaudiology can be feasible and safely used and with the advances and development of technology, it will be better used on wider access with more applications [8]. In 2006, a Brazilian physician-scientist named Dr. Ferrari conducted a randomized controlled trial on 30 patients to test the efficacy of using teleaudiology in hearing aids fitting, also known as hearing aid programming [9]. However, the results of this trial were neutral, because some of the users had network connection disturbances due to the low internet speed at that time. Three years later in 2009, Dr. Ferrari and his colleagues [10] conducted another trial for teleaudiology with a larger sample size (n = 60 patients), but this time to measure the feasibility of ear measurements remotely. The results of his trial were positive and denoted that teleconsultation for audiology was effective and helpful for the patients, with positive impact and satisfaction [9].

The same situation and advancements continued at this rate until 2016, Dr. Campos and his colleagues conducted a mixed-methods trial to assess the communications between healthcare workers and the patient for hearing aid fitting consultations with those face-to-face hearing aid fitting consultations [11]. The trial was conducted on overall 60 patients, 30 on the teleaudiology group and 30 on the face-to-face group. While the aim of this study wasn't about the efficacy or the safety of using teleaudiology for hearing aids programming, and was limited to testing the teleconsultations after face-to-face programming of the hearing aids. The trial resulted in lower percentage of technical errors (27%) compared with other past trials (40% - 50%) that have been conducted from 2003 to 2015. The reason behind the advancements of delivering smoother and more stable services was the development of technologies at the time of the study (2016) compared to the time of the previous trials (2006 and 2009), both hardware and software capabilities have been developed majorly, including computer specifications and internet connection speed and bandwidth [11].

With the emergence of COVID-19 pandemic at the end of 2019 and early months of 2020, many countries around the world applied the lockdown in an effort to reduce the number of infections. With the application of this policy, many in-person services have been delayed and replaced with remote-based services [12]. This included the usage of telemedicine in medical clinics [12]. However, to the moment in the published literature, there isn't available evidence about using teleaudiology for the purposes of COVID-19 lockdown yet. But, since the concept of telemedicine has been widely used for medical services during the current pandemic, it will be possible to use it as a part of the routine it the infrastructure of the hospital and the patient home is sufficient to conduct this type of over the network communication.

The aim of this systematic review article is to review the currently available evidence about the efficacy of using teleaudiology for hearing aids programming

or as known as hearing aids programming fitting. This will provide the readers with an evidence-based article including all published literature about this topic. To our knowledge, this is the first systematic review article investigating the efficacy of hearing aid programming remotely through teleaudiology without the essential need of in-person programming for the patients in academic institutions, hospitals, medical clinics or healthcare wards.

2. Methods

This systematic review was conducted according to the Cochrane Handbook for Systematic Reviews [13].

2.1. Database Search

Database search was made on several databases including PubMed/Medline, Scopus, Web of Science, Publons, EMBASE, and Google Scholar using the relevant keywords "Teleaudiology AND hearing aid OR Teleaudiology AND hearing aid programming OR Teleaudiology and hearing aid fitting OR Telemedicine AND hearing aid OR Telemedicine AND hearing aid programming OR Telemedicine and hearing aid fitting OR Remote AND Hearing Aid OR Remote AND Hearing Aid programming OR Remote and hearing aid fitting" up to the date of 10th of August at 2021. The Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) checklist for 2020 was used to conduct this systematic review [14]. Screening methodology was made as to the following according to three phases consequently. In the first phase, we conducted a screening process for the titles of the articles which have been included from the databases search using the applicable keywords. This was done through reading the title of the article, and deciding whether the topic is related to our aim or not, therefore we exclude it. The second phase was completed after the titles were screened and non-relevant articles were excluded. Abstracts of the included studies from the first phase were screened carefully to determine the eligibility of the articles, in the abstract screening phase we mainly determined the eligibility based on the methods and results sections. For the last phase, a full-text screening for the included articles from the abstract screening phase was conducted. Each eligible article was read critically from the introduction section to the conclusions section, and those articles that didn't report the outcomes needed were excluded. We did not apply a filter for the publication year to include all eligible articles in the current published literature.

2.2. Studies Eligibility

Inclusion criteria for articles in our study included the following original research (primary research articles), addressing the efficacy of teleaudiology for hearing aids programming and satisfaction of patients. Original research, also known as primary research articles includes prospective clinical trials, retrospective clinical trials, quasi-trials, randomized controlled trials, quasi-randomized

controlled trials, cohort studies, matched-cohort studies, case reports and case series including at least two patients. We included articles with patients at least 18 years old and older (adults-only), or samples with patients combining subjects who were under and over 18 years old (mixed-sample). Studies that only include underaged patients (paediatrics-only) were not included in our eligibility criteria. We restricted our eligible articles to English language only.

Exclusion criteria for the studies included non-original research articles (secondary research articles), namely review articles (narrative reviews, systematic reviews, and meta-analysis), short communications, editorials, commentary articles, expert opinion, letter to the editor, case reports and case series with less than two patients, pediatrics-only research articles, studies which didn't use teleaudiology for hearing aids programming, studies which used teleaudiology for other purposes rather than hearing aids fitting, studies which didn't report the efficacy neither the satisfaction of the patients from the delivered services, studies with high-rate of missing data and outcomes, and articles in other languages rather than English.

2.3. Outcomes

We aim to present two major outcomes in our systematic review, first to track the efficacy of remote programming for hearings aids using teleaudiology in comparison to standard in-person (face-to-face) programming. This includes reviewing both of the advantages and disadvantages of this emerging technology in the field of union between audiology and telemedicine and resulting with what is known as teleaudiology, and tracking its development over the years from the available published literature, as extracted from the included studies according to our eligibility criteria. Secondly, we aim to follow up on the satisfaction rate of the patients who experienced remote programming and their impression of this new experience.

3. Results

3.1. Baseline Characteristics

Following PRISMA 2020 guidelines [14], our research strategy included seven studies **Figure 1**. Baseline characteristics of the included studies are listed in **Table 1**.

The first study which was published in 2006 by (Ferrari, 2006) [9] is a randomized controlled trial, which included an overall of 30 patients, 15 patients in the teleaudiology hearing aids fitting group and 15 patients in the in-person (face-to-face) hearing aids fitting group. Ten patients from the 15 in the teleaudiology group were males (66.6%), and the other five patients from the 15 were females (33.3%). Nine patients from the 15 in the face-to-face group were males (60.0%), and the other six patients from the 15 were females (40.0%). For both teleaudiology and face-to-face programming groups, the mean age and standard deviation (SD) for the participants are 59.5 (14.8). The authors didn't report the results of pure-tone audiometry (PTA) for both groups.

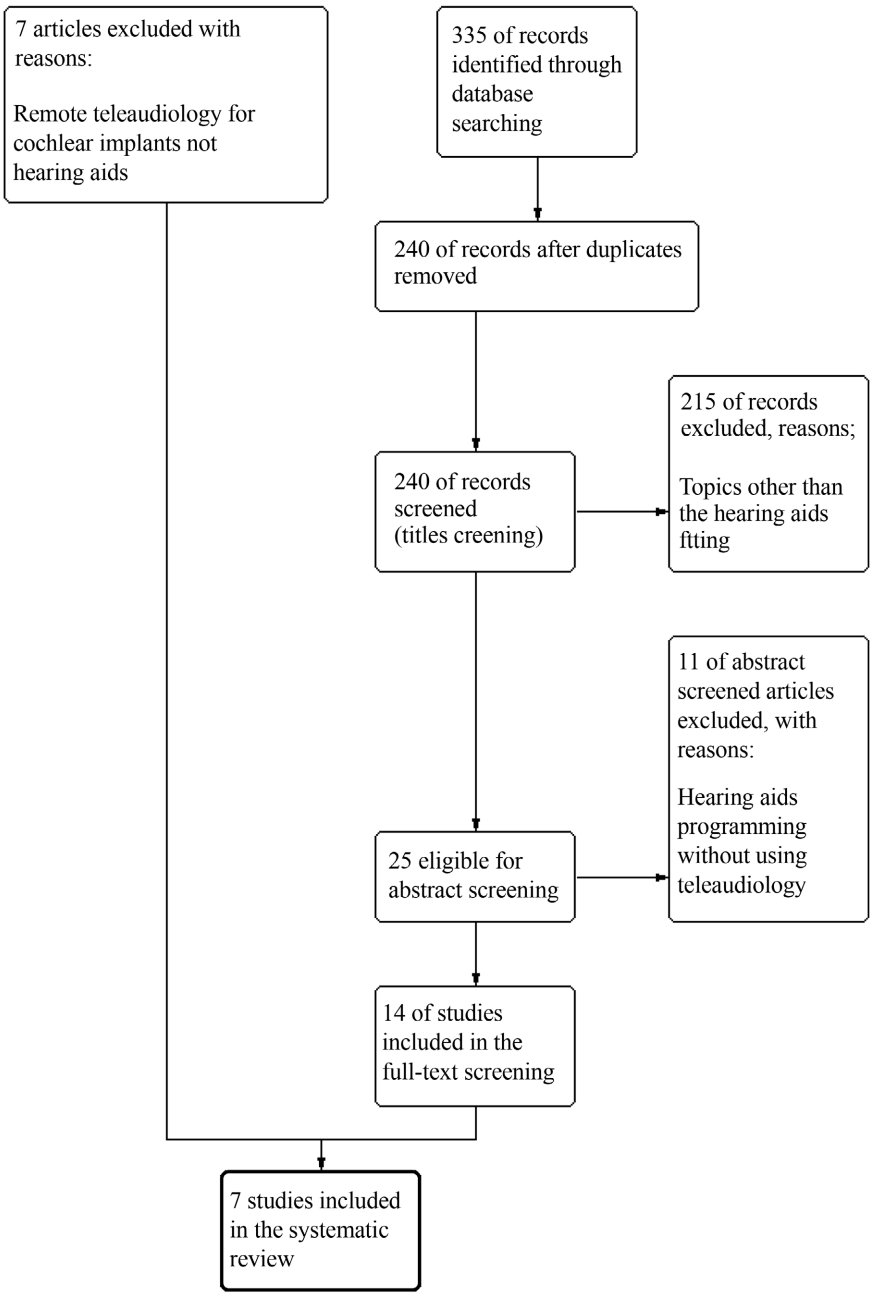

Figure 1. PRISMA flow chart for studies inclusion eligibility.

The second study which was published in 2012 by (Campos & Ferrari, 2012) [15] is a randomized controlled trial, which included an overall number of 50 patients, 25 patients in the teleaudiology hearing aids fitting group and 25 patients in the face-to-face hearing aids fitting group. 17 patients from the 25 in the teleaudiology group were males (68.0%), and the other eight patients from the 25 in the teleaudiology group were females (32.0%). 13 patients from the 25 in the face-to-face group were males (52.0%), and the other 12 patients from 25 were females (48.0%). The authors didn't report the mean age or the PTA for both groups.

Table 1. Baseline characteristics of the included studies.

	TA group (n)	F2F group (n)	TA group males (%)	F2F group males (%)	Mean TA group age (SD)	Mean F2F group age (SD)	Mean TA PTA right ear dB HL (SD)	Mean TA PTA left ear dB HL (SD)	Mean F2F PTA right ear dB HL (SD)	Mean F2F PTA left ear dB HL (SD)
(Ferrari, 2006) [9]	15	15	66.60%	60%	59.5 (14.8)	59.5 (14.8)	N/A	N/A	N/A	N/A
(Campos & Ferrari, 2012) [15]	25	25	68.00%	52.00%	N/A	N/A	N/A	N/A	N/A	N/A
(Penteado, Ramos *et al.*, 2012) [16]	3	N/A	66.00%	N/A	68.66 (20)	N/A	N/A	N/A	N/A	N/A
(Penteado, Bento *et al.*, 2014) [17]	8	N/A	37.50%	N/A	71.63 (42)	N/A	N/A	N/A	N/A	N/A
(Pross, Bourne *et al.*, 2016) [18]	169	338	100%	96%	74 (9.8)	76 (10.3)	N/A	N/A	N/A	N/A
(Venail, Picot *et al.*, 2019) [19]	26	26	53.80%	65.40%	66.8 (16.0)	70 (11.1)	52.8 (10.2)	54.7 (10.9)	52.7 (8.8)	54.8 (11)
(Tao *et al.*, 2021) [20]	28	28	60.70%	64.30%	74.2 (9.2)	75.2 (10)	48 (16.79)	45.14 (12.83)	45.75 (7.17)	48.34 (18.45)

The third study which was published in 2012 by (Penteado *et al.*, 2012) [16] is a single arm trial that reports the results for teleaudiology hearing aids programming without a comparator to a face-to-face group. This study is a case series which included three patients for teleaudiology fitting. Two of the three patients were males (66.6%), and the other one was female (33.33%). The mean age and SD for the patients are 68.22 (20). The authors didn't report the results of PTA for the included patients.

The fourth study which was published in 2014 by (Penteado *et al.*, 2014) [17] is also a single arm trial that reports the results for teleaudiology hearing aids programming without a comparator to a face-to-face group. An overall number of eight patients were allocated to the teleaudiology group, three from the eight patients were males (37.5%), while the other five patients were females (62.5%), as they represented the larger number. The mean age and SD for the patients are 71.63 (42). The authors didn't report the results of PTA for the included patients.

The fifth study which was published in 2016 by (Pross *et al.*, 2016) [18] is a randomized controlled trial, which included an overall 507 patients. A total of 169 patients were in the teleaudiology hearing aids fitting group, and 338 in face-to-face programming group. This study was done on veterans, and most of its sample are male patients. All of the participants in the teleaudiology group were males, while in the face-to-face group 373 patients were males (96.1%) and the other 15 from 388 were females (3.86%). The mean age and SD for teleaudiology group are 74 (9.8), while the mean age and SD for the face-to-face group are 76 (10.3). The authors didn't report the results of PTA for the included patients.

The sixth study which was published in 2019 by (Venail *et al.*, 2019) [19] is randomized controlled trial, which included an overall number of 52 patients. A total of 26 patients were in the teleaudiology hearing aids fitting group, and 26 patients were in the face-to-face group. A sum of 14 patients from 26 in the teleaudiology was males (53.8%), while the other 12 patients from 26 were females (46.2%). For the face-to-face group, 17 patients from 26 were males (65.4%), while the other nine patients from 26 were females (34.6%). The mean age and SD for teleaudiology group are 66.8 (16), while the mean age and SD for the face-to-face group are 70 (11.1). The mean PTA for both ears is 53.75 in both of teleaudiology and face-to-face groups.

The seventh study which was published in 2021 by Tao, Brennan-Jones *et al.* (2021) [20] is a randomized controlled trial, that included an overall number of 56 patients. A total of 28 patients were included in the teleaudiology hearing aids fitting group, and 28 patients in the face-to-face group. A sum of 17 patients from 28 in the teleaudiology group were males (60.7%), while the other 11 patients from 28 were females (39.3%). For the face-to-face group, 18 patients from 28 were males (64.3%), while the other ten patients from 28 were females (35.7%). The mean age and SD for teleaudiology group are 74.2 (9.2), while the mean age and SD for face-to-face group are 75.2 (10). The mean PTA for both ears in the teleaudiology group is 46.57, while the mean PTA for both ears in the face-to-face group is 47.05.

3.2. Quality Assessment

We did a quality assessment for the included studies using Cochrane Risk of Bias assessment tool as mentioned the handbook of Cochrane [13]. The quality assessment results are listed in **Figure 2** and **Figure 3**. We excluded the case reports and case series studies from the quality assessment, since they are classified are Level 4 and below in the evidence-based pyramid [21].

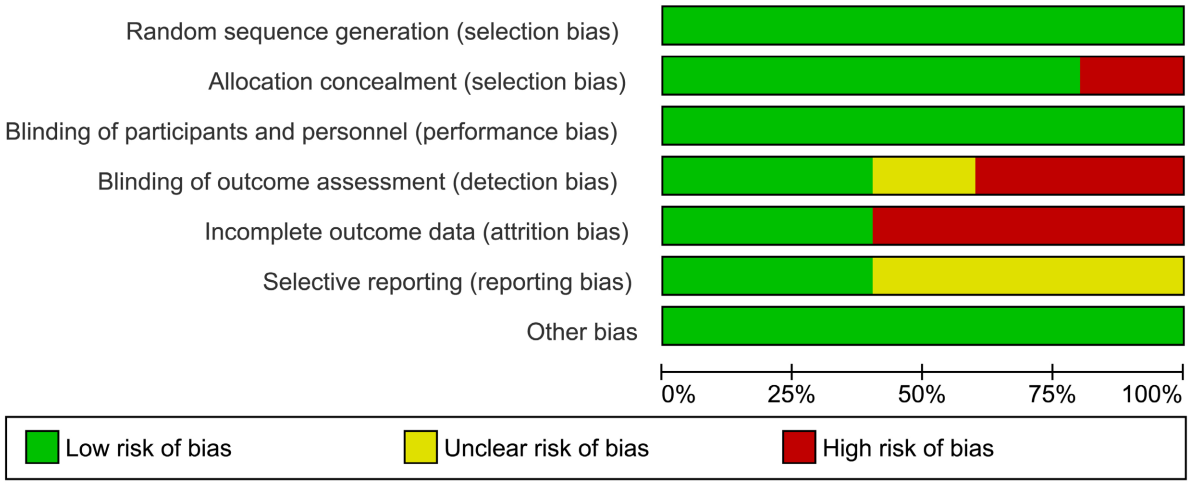

Figure 2. Risk of bias graph: Review authors' judgements about each risk of bias item presented as percentages across all included studies.

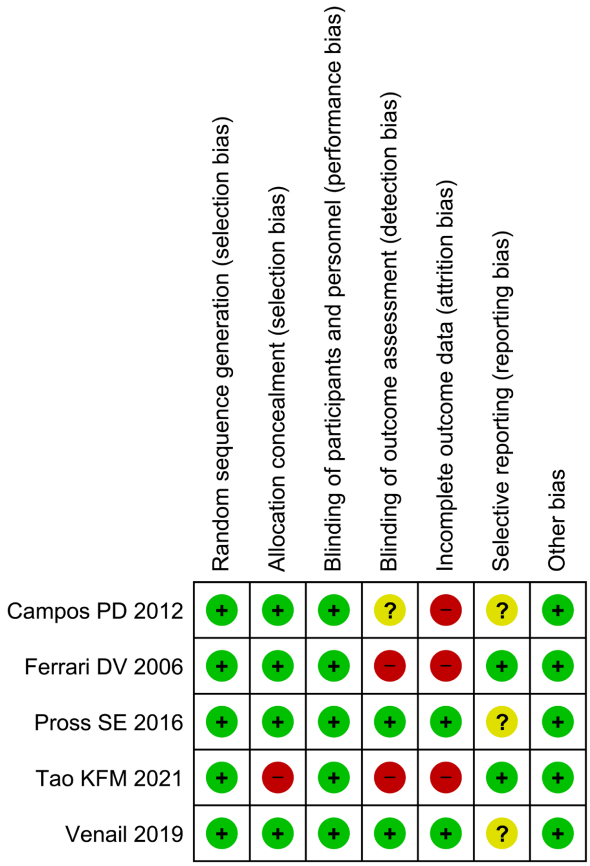

Figure 3. Risk of bias summary: Review authors' judgements about each risk of bias item for each included study.

3.3. Population, Intervention, Comparator and Outcome (PICO) Characteristics

The PICO strategy is listed in **Table 2**. Four studies out of the seven (Ferrari, 2006; Campos & Ferrari, 2012; Penteado *et al.*, 2012; Penteado *et al.*, 2014) [9] [15] [16] [17] were geographically conducted in Brazil. The rest of the studies, one was conducted in the United States of America, France and Australia.

The population that our study aimed at is people with hearing aids that require remote fitting through teleaudiology. The intervention is remote programming for the hearing aids, with exception for one study by (Penteado *et al.*, 2014) [17] the intervention was assessing the patients' satisfaction for telefitting from previous experience. The comparator is face-to-face (in-person) programming for the hearing aids, with exception for two studies by (Penteado *et al.*, 2012, Penteado *et al.*, 2014) [16] [17] since they are single arm trials without a comparator group. The outcomes and results are the brief conclusion for the experience in each trial.

3.4. Audiological Characteristics

Audiological characteristics are listed in **Table 3**. Six out of seven studies reported the aetiology of audiological examination. In four studies the audiological

Table 2. PICO strategy.

Study	Year	Country	Population	Intervention	Comparator	Outcome/Results
(Ferrari, 2006) [9]	2006	Brazil	Patients with mild-moderate sensorineural hearing loss requiring hearing aids.	Remote programming for the hearing aids.	Face-to-face programming for hearing aids.	Teleaudiology programming resulted with decreased needed time for programming, but the quality of programming wasn't the best because the slow internet bandwidth.
(Campos & Ferrari, 2012) [15]	2012	Brazil	Patients with bilateral symmetric sensorineural mild-severe hearing loss requiring hearing aids.	Remote programming for the hearing aids.	Face-to-face programming for hearing aids.	Hearing aids programming using teleaudiology was efficient and can be performed in cases of face-to-face programming difficulties.
(Penteado, Ramos *et al.*, 2012) [16]	2012	Brazil	Patients with mild-moderate sensorineural hearing loss requiring hearing aids.	Remote programming for the hearing aids.	N/A	Remote programming was possible and with further development of technology it will be time and cost effective for both of the patient and government.
(Penteado, Bento *et al.*, 2014) [17]	2014	Brazil	Patients with hearing loss who had teleaudiology hearing aids programming.	Assessing the patients' satisfaction for telefitting.	N/A	The results of telefitting were optimistic, it is denoted that the remote programming can be improve healthcare service delivery.
(Pross, Bourne *et al.*, 2016) [18]	2016	USA	Veterans who received hearing aids from January 2014 to September 2014.	Teleaudiology services	Face-to-face audiology services.	Teleaudiology and face-to-face audiology services are comparable, the benefits of teleaudiology to veterans are superior in remote areas.
(Venail, Picot *et al.*, 2019) [19]	2019	France	Patients with hearing loss requiring hearing aids.	Remote programming for the hearing aids.	Face-to-face programming for hearing aids.	Overall results didn't provide significant difference between both groups comparing teleaudiology with face-to-face programming.
(Tao *et al.*, 2021) [20]	2021	Australia	Patients with mild symmetrical sensorineural hearing loss requiring hearing aids.	Remote programming for the hearing aids and follow-up consultations.	Face-to-face programming for hearing aids and follow-up consultations.	Teleaudiology programming and follow-up consultations can provide efficient results that doesn't differ from face-to-face programming and consultations.

examination was done before the trial beginning. The other two studies conducted the audiological examination using a standard face-to-face audiometer during the trial period.

From the seven included studies, all studies did both teleaudiology and face-to-face fitting for hearing aids according to the intervention and comparator

Table 3. Audiological characteristics.

Study	Audiological Examination	Hearing aids fitting	Follow-up	Outcome measures method	Patients' satisfaction	Reason if not satisfied
(Ferrari, 2006) [9]	N/A	Teleaudiology and Face-to-face	Teleaudiology	Teleconsultation	Non-satisfied	Connection lag making the interactions between the audiologist and patients difficult
(Campos & Ferrari, 2012) [15]	Before the study begins	Teleaudiology and Face-to-face	Teleaudiology	Face-to-face	Satisfied	N/A
(Penteado, Ramos *et al.*, 2012) [16]	Before the study begins	Teleaudiology	N/A	Teleconsultation	Satisfied	N/A
(Penteado, Bento *et al.*, 2014) [17]	Face-to-Face	Face-to-face	Teleaudiology	Teleconsultation	Satisfied	N/A
(Pross, Bourne *et al.*, 2016) [18]	Before the study begins	Teleaudiology and Face-to-face	Teleaudiology	N/A	N/A	N/A
(Venail, Picot *et al.*, 2019) [19]	Face-to-Face	Teleaudiology and Face-to-face	Face-to-face	Face-to-face	Satisfied	N/A
(Tao *et al.*, 2021) [20]	Before the study begins	Teleaudiology and Face-to-face	Teleaudiology and Face-to-face	Face-to-face	Satisfied	N/A

groups in the trial. Except for two studies [16] [17], since they are single arm trials. The first study from Penteado which was published in 2012 used only teleaudiology for hearing aid fitting, but without a second setup for following up the participants. The second study from Penteado, which was published in 2014, used the in-person approach to program hearing aids, but in the second visit, they used the teleaudiology remote programming and did a follow-up with teleconsultation video conferencing.

3.5. Teleaudiology Fitting Characteristics

The characteristics of programming of hearing aids are listed in **Table 4**. Five out of seven studies mentioned the type of hearing loss, hearing loss type was sensorineural hearing loss ranging between mild and moderate degrees.

Six out of seven studies mentioned the mode for teleaudiology fitting for the hearing aids, with the exception of one study [18]. All the six studies modes of teleaudiology were synchronous. The synchronous mode refers to live telecommunication using video conference software for the delivery of the services between the provider and the patient. While the asynchronous information is saved, collected and stored in a database, then it gets utilized at a later time to

Table 4. Teleaudiology remote programming for the hearing aids characteristics.

Study	Hearing Loss Type	Mode of teleaudiology	Technologies Used	Facilitator Assistantship	Hearing Aid	Prior HA fitting experience
(Ferrari, 2006) [9]	Mild-moderate sensorineural hearing loss	Synchronous	Meetings software with LAN 10 Mbps internet bandwidth	Yes (Audiologist)	N/A	No
(Campos & Ferrari, 2012) [15]	Bilateral symmetric sensorineural mild-severe hearing loss	Synchronous	Personal computer with NOAH software and HI-Pro device, and communication through a webcam with built-in microphone	Yes (Experienced Technician)	CIC and mini-BTE hearing aids	No
(Penteado, Ramos *et al.*, 2012) [16]	Mild-moderate sensorineural hearing loss	Synchronous	Notebook, Webcam, Router, HI-Pro interface, Headset, Speakers, and tele meeting software	Yes (Audiologist)	In-the-canal and behind the ear hearing aids	No
(Penteado, Bento *et al.*, 2014) [17]	Bilateral sensorineural hearing loss	Synchronous	Fitting application on PC with HI-PRO device	Yes (Audiologist)	Mini Retro C hearing aids	No
(Pross, Bourne *et al.*, 2016) [18]	N/A	N/A	Teleconference platform	Yes (Audiology Technician)	N/A	No
(Venail, Picot *et al.*, 2019) [19]	N/A	Synchronous	Personal computer, Affinity device, NOAH 4 software, HI-Pro2 interface, AudioPro Connect platform, webcam and microphone, and soundproof Bluetooth device	Yes (Healthcare Technician)	N/A	Yes
(Tao *et al.*, 2021) [20]	Mild symmetrical sensorineural hearing loss	Synchronous	Laptop with 4G mobile network	Yes (Volunteers skilled in the hearing field)	In-the-canal hearing aids	Yes

the patient who needs the hearing aid fitting. However, all included studies used the synchronous mode only. All the seven included studies mentioned the technologies that were used to facilitate the process of remote hearing aids fitting.

Assistantship from a facilitator was done in all the included studies. Three studies from the seven the facilitator was an audiologist, three other studies from the seven the facilitator was an experienced trained technician for teleaudiology, and in only one study by Tao *et al.*, (2021) [20] the facilitators were volunteers skilled in the hearing field who are graduate students.

Four studies from the included seven mentioned the type of hearing aids that were used for participants. Two studies used the in-the-canal type. The other two studies each used different types than the other. Campos used the complete-in-canal and mini-BTE hearing aids, while Penteado used the Mini Retro C hearing aids, those details are listed in **Table 4**.

Regarding the previous experience for the patients in hearing aid fitting, only in two studies [19] [20], the participants had previous experience in hearing aid fitting through in-person approach, but not using teleaudiology. The other five studies reported that the participants didn't have previous experience in hearing aid fitting neither using face-to-face nor teleaudiology fitting.

For the follow-up process for the participants, all the studies did a follow-up visit, except [17]. All studies used teleaudiology and teleconsultation conferencing for their follow-up except [19] they used face-to-face meeting to follow-up their patients after a remote fitting was made for the hearing aids patients.

3.6. Patients' Satisfaction

Patients' satisfaction status is listed in **Table 3** in addition to the audiological characteristics.

All the included studies reported the status of patients' satisfaction from the services of teleaudiology hearing aids fitting, except one study by (Pross *et al.*, 2016) [18].

All studies participants were satisfied from the services, except [9]. The reason for non-satisfaction of the patients was reported as connection lag making the interactions between the audiologist and patients difficult.

4. Discussion

4.1. Discussing the Literature

The field of telemedicine is developing day after day during the current century, it is concerned about using the technologies that we have in our daily life to facilitate healthcare services for patients remotely without their physical presence, or to minimize the in-person visits for clinics to the need only [1]. One of the present demonstrations in the telemedicine field is using it in audiology, which is known as Teleaudiology [7]. Using teleaudiology for patients with hearing problems such as deafness with its different types as conductive deafness and sensorineural hearing loss can be significantly useful in several different manners [22]. One of the applications that the literature has discussed is using teleaudiology for remote programming of hearing aids for deaf patients, especially sensorineural hearing loss. Our review focused on this topic as a research point. Our research strategy included seven trials as listed in **Table 1**.

The first and the oldest study by (Ferrari, 2006) [9] from Brazil, has been published in 2006. The aim of this study was to test the efficacy of fitting hearing aids remotely. The participants' settings were bilateral mild or severe sensorineural hearing loss. The conferencing medium was a basic video meetings soft-

ware with a slow internet connection, compared to the time of making this review. The teleconsultation session duration was an average of two minutes for each individual patient, while in the face-to-face group the average of consultation was 126 seconds (two minutes and six seconds). The difference between both groups in consultation time was decreased with an approximate of 3% [9]. The overall audition for teleaudiology and face-to-face group was almost similar, which means that the overall results denote the efficacy of teleaudiology as a successful alternative for the standard in-person hearing aid fittings and follow-up consultations. However, some of the participants had a complaint of sporadic acoustic feedback in the background of the video call meeting, which affected the interaction between the service provider and the participants. The trial of Ferrari (2006) gave the light for audiology scientists around the world to encourage to be involved in the field of teleaudiology [9]. The major advantages of Ferrari and collaborators' study were concerned about elucidating a new concept into the field of telemedicine, however since this trial was on early time; it resulted in few ad-hoc disadvantages. First of all, the study didn't either follow or develop a clear protocol about using teleaudiology for remote programming of hearing aids, which created a gap for further prospective trials. Secondly, the small sample size for each group impacted with a risk of bias for the results.

The second study by Campos & Ferrari (2012) [15] from Brazil was published in 2012. The aim of this study was to test the efficacy of programming hearing aids through teleaudiology. The participants' settings were almost similar to Ferrari (2006) [9], but with a larger sample size. The sample size in Campos *et al.* study was 50 compared to 30 in the one by Ferrari (2006). The results of this study did not much differ from Ferrari *et al.* except in a few things, the first thing is the sample size is relatively larger, and in the contrary, the time of teleconsultation period for the teleaudiology group was longer than in-person group (2% longer). However, some of the participants had a complaint of sporadic acoustic feedback in the background of the video call meeting, which affected the interaction between the service provider and the participants, which is the same error as the previous study [9]. The major advantage of this study was that the authors increased the sample size by 66.6%, which approved more accurate results. The major disappointments of this were about two things. The first thing, the authors repeated the same issues that appeared in the 2006 trial, the network connection was slow without updates which lead to difficulty in the interaction between the provider and participants. The second thing, and similar also to the first study, the authors did not follow a proper protocol to measure the efficacy in their trial. This is still creating a gap for prospective trials in the future.

Two trials by Penteado [16] [17] from Brazil, were published consequently in 2012 and 2014. Both the studies were single arm trials, assessing remote programming for hearing aids, and the follow-up post fitting using teleconsultation. Results of both trials were positive without significant issues. Penteado *et al.* concluded that fitting hearing aids by teleaudiology facilities were possible and

effective. Denoting that with the prospective development of the technologies around the world it will be an essential pillar for audiology clinics; and will be a significant addition to healthcare systems around the world. The major advantage in Penteado trials [16] [17] was the better network stability and hardware control, but several disadvantages were found. At first, both studies had very low sample size, the 2012 trial [16] had only three patients while 2014 [17] had eight patients which impact the statistical significance of the results. Second, both trials were single arm trials without a comparator face-to-face group, which does not give honest reliability for the results. In the third issue, the authors had the same issue as the two previous trials. There was no exact protocol for participants found to test the efficacy of using remote programming to fit their hearing aids.

Brazil has been an early leading country for teleaudiology trials in the published literature from 2006 to 2014, all the previous four trials were from Brazil. A review article was made by Ferrari & Lopez (2017) [23] to conclude the Brazilian experience in teleaudiology. Since the early 1990s, the Brazilian public unified health system has been improving the quality of audiology services, ranging from primary care prevention to tertiary care services including medical and interventional treatment [23].

The authors claimed that the challenge in Brazil to offer high-quality services were controlled by several factors, including the large geographical area of the country, increased low socioeconomic contrasts, the poor infrastructure of technologies such as slow and unstable network connection, and the exclusivity of high-quality service to the modern metropolitan areas only, with a significant neglecting to the rural areas. The authors estimated a prevalence of approximate 6% of Brazilians have hearing impairment disorders (14 million from overall population of 211 million) which is causing a burden on the Brazilian healthcare system.

Telehealth has been a challenge in Brazil due to the several constraining factors in the country. They described the milestones that should be worked in to develop the telemedicine services in Brazil, including the equity between the rural and urban metropolitan cities in the services, such as network stability and quality, and the availability of personal computing devices in each home as a part of the governmental fund to the population. The authors encouraged using the telehealth services in Brazil, especially teleaudiology services since an increased prevalence of audiological disorders is endemic in Brazil, but they blamed the Brazilian government and healthcare system for not taking the required action to develop it. They suggested starting from the primary healthcare centres since they cover a higher entity of population in each state [23].

The only study from the United States of America was published by Pross and collaborators in 2016 [18]. This study was conducted on veterans from the United States army who developed sensorineural hearing loss after their service in the army forces. They resulted that teleaudiology remote fitting services for

the hearing aids were efficient as same as the in-person fitting, but with less effort and time for the participants. One of the major advantages in this trial was the low risk of bias in randomization, allocation and concealment of the participants to the two different groups. The study participants sample size was large and present with statistically significant results. The teleaudiology group had 169 patients, while the in-person programming group had 338 patients. Nevertheless, the authors didn't provide the readers with a clear protocol and recommendations for the scientist about what they should take care of and avoid in their trials, which we consider as a major error in the study design [18].

In 2019, a study has been published from France by Venail *et al.* (2019) [19]. The authors included only adults participants with previous experience in the hearing aids fitting through the face-to-face standard fitting. Two groups were allocated, the intervention group the teleaudiology remote programming and the comparator group was the standard in-person. A blinded selection for the intervention and comparator groups was applied. Both groups were evaluated and had a follow-up after five weeks from the programming session. In the experienced participants for hearing aids fitting, both remote programming and in-person fitting gave similar results in terms of the live interaction between service provider and the patient. There was no significant difference in the time between the two groups that have been spent on patients' care and reporting the hearing benefit. The major advantage of this study is, the authors used the most recent technology to apply it for teleaudiology fitting, so they provide the most realistic situation in the term of being telehealth in audiology field. While there are two major disappointments, the first is that the overall sample size of the study is relatively low for the study design and settings. The author allocated an overall of 52 participants, 26 in the intervention group and the same in comparator group. The second major issue is relatively similar to the previous study, which is about following or providing a specific protocol about this new approach in audiology clinics.

The most recent study by Tao *et al.* (2021) [20] which has been published in 2021 from Australia. The results of this study weren't providing new evidence rather than the previous six studies. The study by Tao *et al.* (2021) [20] provided major critical issues, at first the sample size was low compared to what it should be in 2021, we consider enrolling at least 350 - 400 patients to fulfil the evidence of new results in the shade of the current development. The second major issue is that the authors didn't discuss the pandemic of COVID-19 in relation to the use of teleaudiology. Despite the global crisis of SARS-COV-2, telehealth should be more defined and organized than ever before.

4.2. COVID-19 and Teleaudiology

Since the published literature didn't discuss the remote hearing aids programming through the teleaudiology amid COVID-19 pandemic. We illustrated a hypothesis diagram for a suggested protocol during COVID-19 in **Figure 4**.

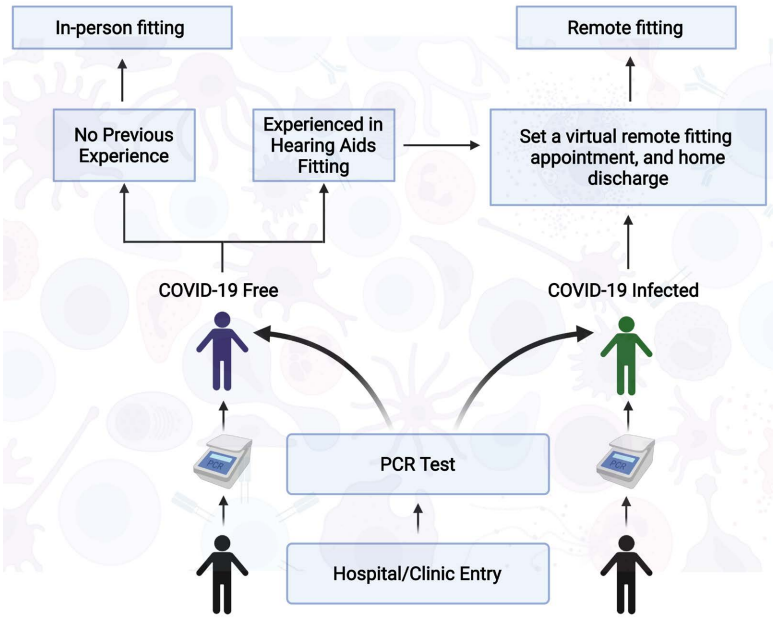

Figure 4. A suggested strategy for remote fitting amid COVID-19 pandemic. Created with BioRender.com.

5. Conclusions

During the past few years, using the applications of telemedicine in the field of audiology, also known as teleaudiology has been significantly expanded, and developed to meet the needs and to have an active role within the essential healthcare systems.

To our knowledge, we conducted the first systematic review for the efficacy of fitting the hearings aids remotely through teleaudiology. Our study included seven trials investigating the approach of using teleaudiology in remote fitting for hearing aids. This approach is new in our century and has emerged during the past few years since 2006 to the current moment. The results of our work based on the currently available literature, denote that remote programming for the hearing aids using modern technology is effective and provide us with comparable results with the standard face-to-face clinic programming, even for patients with no previous experience in hearing aids fitting in either of in-person physical presence programming or remotely over the internet using teleconferencing which is known as teleaudiology. Most results were positive and support the continuity to develop better facilities to improve teleaudiology to be an essential part of hearing aids programming with its different types. Minimal results provided a negative impact on the participating patients. This resulted because at that time there were no upgraded infrastructures and facilities of the audiology clinic or the personal computer of the patient in his home/workplace or both sides that doesn't have enough specifications to smoothly perform this modern approach. The main issues in the trials of literature were about the network connection stability, then followed by hardware devices issues such as computers compatibilities. To conclude, the results support the feasibility of re-

mote programming for hearing aids through teleaudiology as an effective solution and have been proven to save effort and time for both the providers and patients. Regardless of the current evidence didn't link between the usages of telemedicine for remote programming for hearing aids during the era of COVID-19 pandemic. The support of using the remote programming services is much more important nowadays than ever, because of the current global pandemic of COVID-19 which is considered as one of the most distressing global health issues and affected the immediate availability of physical presence in hospitals and clinics for non-COVID-19 related medical consultations.

6. Limitations and Future Prospections

During our working on this systematic review, we found some of the limitations that might have had an impact on the results; therefore we should indicate them for the readers as an essential part of the scientific integrity and medical ethics of medical research.

The major limitation in our study is the limited number of included studies, and this is because of the novelty of using teleaudiology for programming hearing aids remotely. The second limitation is that some of the included studies didn't report the whole outcomes as desired, so this affected the presentation of the full picture for the currently available evidence. We suggest audiologists have the zeal to conduct further trials in wider settings to assess the efficacy of using this novel approach for hearing aid patients. The more the trials, the higher the evidence will be available to the clinicians to make better decisions regarding their cases; this is a major rule in evidence-based medicine. The third limitation is absence of unified or standardized protocol on the standardization and focusing on proper condition and management of this novel way of remotely programming hearing aids over the internet. Unified protocols should present sufficient guidance about indications of using when to use the remote fitting when it is contraindicated, when is it recommended to use the face-to-face fitting instead of the teleaudiology, and what are the ideal alternatives if there are ad-hoc issues appeared while the process. Also, the protocols should include guidance about the different types and brands of hearing aids and how to correctly fit them to the patients. The absence of protocols in a current manner is one of the limitations that might impact bias on results. Developing unified protocols to manage the usage of teleaudiology services for hearing aids programming remotely with its different types is a necessary goal to be made, the focus on this point will make it easier for beneficiaries around the world.

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Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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