Original Article

An Internet-Based Asthma Self-Management Program Increases Knowledge About Asthma

Results of a Randomized Controlled Trial

Benedikt Kohler, Christina Kellerer, Konrad Schultz, Michael Wittmann, Oxana Atmann, Klaus Linde, Alexander Hapfelmeier, Antonius Schneider

Summary

Background: Asthma education (AE) is associated with reduced hospitalization and disability. We compared the effectiveness of an electronic AE program (eAEP) with a conventional face-to-face AE program (presence-based AEP; pAEP) for asthma knowledge (AK) with regard to self-management.

Methods: A randomized controlled pilot study was conducted in a pulmonary rehabilitation clinic. AK was determined by means of the Asthma Knowledge Test (AKT). The change in AKT score within each group was calculated with a paired t-test. Group differences were estimated with adjusted linear regression models.

Results: In the intervention group ($n = 41$), the AKT score increased from 41.57 (standard deviation 5.63) at baseline to 45.82 (3.84) after completion of the eAEP ($p < 0.001$), and again to 47.20 (3.78) after completion of the pAEP ($p = 0.046$). In the control group ($n = 41$), the score increased from 41.73 (4.74) at baseline to 45.72 (3.65) after completion of the pAEP ($p < 0.001$). There was no relevant difference in knowledge gain between the eAEP and the pAEP group after completion of the corresponding educational sessions ($p = 0.881$). The AKT score was higher in the eAEP group after obligatory participation in pAEP than in the group that only completed the pAEP ($p = 0.020$).

Conclusions: An internet-based AEP could help to reduce the knowledge deficits of a large proportion of patients with asthma.

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Asthma is a common chronic disease with a prevalence of approximately 10% in industrialized countries (1, 2). The cornerstones of treatment are guideline-based medication regimes (3, 4), and asthma education programs that are intended to equip the patient for effective self-management of the disease (3–5). Optimal asthma self-management demands the ability to self-assess clinical signs and symptoms in order to recognize a worsening in asthma severity in good time. This is supported by instruments such as an asthma diary, with documentation of peak flow variability, and a personal asthma action plan to aid self-adjustment of treatment. It has been demonstrated in many cases that these measures improve quality of life and reduce hospitalizations and emergency treatments (5, 6).

These components of self-management are taught in structured asthma education programs (AEP). In Germany, AEP must have a structured concept and cannot be accredited unless their effectiveness has been demonstrated. In ambulatory care, AEP are mostly provided by pulmonologists, but some primary care physicians also offer AEP. Structured and accredited AEP in the hospital setting are implemented mostly at rehabilitation clinics. Because of their favorable impact on clinical outcomes, in Germany AEP are embedded within the Disease Management Program (DMP) for asthma (7).

Despite their nationwide dissemination, awareness of AEPs among patients is much too low. An analysis of the DMP in Bavaria revealed that only a quarter of patients with asthma had participated in AEP (7), which is particularly problematic given their above-mentioned enormous importance for health outcomes. Notably, the take-up rate is similarly low in other countries (5). This may be at least partly attributable to patients' refusal to acknowledge their illness (8). Another reason may be that their physical or psychological burden is not great enough to motivate them to participate in education programs. This applies particularly to those with seasonal asthma (8). Time constraints, long journeys to practices that offer AEP and other organizational factors may also present barriers to

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higher participation in AEP. Web-based education programs might represent a solution to this problem, because they are readily accessible and patients can schedule their own learning times.

We developed an electronic AEP (eAEP) that conforms with the accreditation criteria for an AEP with obligatory attendance (presence-based AEP, pAEP). This eAEP provides an opportunity for patients—especially those with low willingness to participate in pAEP—to acquire medical knowledge on the diagnosis, treatment, and self-management of asthma. The aim of the pilot study was to evaluate, for the first time:

- Whether patients' knowledge regarding asthma self-management increases after completion of an eAEP
- How the knowledge gain of patients who complete an eAEP and a pAEP compares to that of patients who only take part in a pAEP.

Methods

The evaluation comprised a two-armed, single-center, randomized controlled pilot study conducted between July and October 2018 at a pulmonary rehabilitation clinic in Bad Reichenhall, Bavaria, Germany. The study was approved by the medical ethics committee of the Medical Faculty of the Technical University of Munich (project number 211/18S) and registered at the German Register of Clinical Trials (DRKS; www.drks.de; number DRKS00015078).

To be eligible for participation in the study, patients had to be at least 18 years old, have sufficient knowledge of the German language and give written consent to study participation. The diagnosis of asthma was confirmed clinically by a pulmonologist on admission, by means of whole-body plethysmography and bronchodilation testing or— if necessary—bronchial provocation (9). Patients were invited to participate during the first or second day of their hospital stay. After informed consent by the patients and documentation of patient characteristics, asthma history, and current medication, patients were randomized to the intervention or control group. The study design is shown in *Figure 1*. After inclusion all patients completed the Asthma Knowledge Test (AKT). The AKT was developed to measure the knowledge and self-management skills of patients at least 16 years old with asthma of any severity (10). The AKT questionnaire has to be adapted whenever the corresponding guidelines are revised (11). Details of the psychometric properties of the AKT are provided in the *eMethods*.

Patients randomized to the intervention group were asked to complete the eAEP by the end of their first week at the clinic. To this end, they were given access codes for use on the clinic's PC or on their own laptop. At the end of week 1 patients in the intervention group completed the AKT a second time. During weeks 2 and 3, all patients participated in the obligatory pAEP that formed part of the clinic's routine program. It was unclear whether eAEP would lead to the same knowledge gain as conventional pAEP, because the didactic

Study design

AKT, asthma knowledge test; eAEP, electronic asthma education program; pAEP, presence-based asthma education program

intensity might be lower. It was therefore vital for the patients from the eAEP group to participate in the pAEP, in order to ensure optimal acquisition of knowledge on asthma self-management. After the last pAEP session all participants once more completed the AKT.

Asthma education programs eAEP and pAEP

The eAEP was constructed as a website (www.asthma-selbstmanagement.de, password: *asthmacare*; in German) and programmed using Wordpress® as content management system. It consists of:

- A homepage
- Four course chapters with a short quiz at the end of each
- A concluding quiz
- A glossary incorporating a list of frequently asked questions (FAQ).

The eAEP was developed in an iterative process on the basis of the pAEP (Bad Reichenhall model). Every chapter was critically revised step-by-step by pulmonologists with long experience and in-depth expertise of patient education (KS and MW) and a primary care physician (AS) who is a member of the author board of the National Clinical Care Guideline Asthma (*Nationale Versorgungsleitlinie Asthma*). The contents of the individual chapters are outlined in the *eMethods*.

The pAEP was a traditional asthma education program consisting of three group sessions of 90 min each and one session of 45 min. The size of the group

FIGURE 2

Flow chart of the study

COPD, chronic obstructive pulmonary disease; eAEP, electronic asthma education program; pAEP, presence-based asthma education program

varies from 5 to 20 patients. The sessions address the following topics:

- Anatomy and physiology of the airway
- Drug treatment
- Disease control
- Self-management

Patients receive printed information materials for each session. In addition to the structured lessons, the patients have numerous opportunities to improve their knowledge of asthma during ward rounds, physiotherapy sessions, and skills training (“spray school”). The aim is to optimize patients’ usage of the asthma diary and inhaler devices. This is achieved by providing at least one additional teaching unit in the form of a 45-min session of practical device in the use of inhalers.

Endpoints

The primary endpoint of the study was the total sum of correct answers in the AKT. The increase in AKT score within each group was calculated using the paired t-test. Group differences were estimated by means of logistic regression, adjusted for age, sex, years since asthma diagnosis, and baseline AKT scores. Further statistical details are provided in the *eMethods*.

Results

Of the 133 patients contacted, 87 met the eligibility criteria (Figure 2). Forty-three patients were randomized to

the intervention group and 44 to the control group. Five patients were excluded from analysis: one patient in the control group was mistakenly given access to the eAEP, and two patients in each group did not return a (baseline or follow-up) questionnaire. Therefore 82 patients were included in the per protocol analysis to determine the efficacy of the new program. Fifty of these patients (61%) were men, 32 women; the mean age was 50 years (Table 1). The groups exhibited close similarity with regard to lung function parameters, asthma control, previous asthma education and current asthma medication at baseline.

In the intervention group, the mean AKT score increased from 41.57 (standard deviation 5.63) at baseline to 45.82 (3.84) after completion of the eAEP ($p < 0.001$), and again after completion of the pAEP to 47.20 (3.78) ($p = 0.046$) (Table 2). In the control group the mean score increased from 41.73 (4.74) at baseline to 45.72 (3.65) after completion of the pAEP ($p < 0.001$). The regression analysis (Table 3) showed a non-significant group difference of -0.12 (95% confidence interval $[-1.68; 1.44]$) between the eAEP and pAEP group after completion of the corresponding educational sessions ($p = 0.881$). However, knowledge gain was higher in the eAEP group after participation in the obligatory pAEP than in the pAEP-only group; the group difference was -1.74 (95% CI $[-3.22; -0.27]$) ($p = 0.020$). The secondary analysis,

TABLE 1

Characteristics of the study population

Characteristic	Intervention group (n=41)	Control group (n=41)	All (n=82)	Group comparison (p-value)
Male sex, n (%)	26 (63)	24 (59)	50 (61)	0.82 ^{*1}
Age in years, mean (SD)	49 (12)	52 (8)	50 (10)	0.18 ^{*2}
BMI in kg/m ² , mean (SD)	29.5 (5.8)	29.9 (4.8)	29.7 (5.3)	0.79 ^{*2}
Smoking status (current/ex/never)	4/10/27	6/10/25	10/20/52	0.79 ^{*3}
Education status				0.56 ^{*3}
General secondary school (<10 years), n (%)	16 (39)	21 (51)	37 (45)	
Intermediate secondary school (10 years), n (%)	15 (37)	13 (32)	28 (34)	
High school, n (%)	9 (22)	7 (17)	16 (20)	
Other, n (%)	1 (2)	0	1 (1)	
Lung function parameters				
FEV1 (% of pred.), mean (SD)	82.6 (21.9)	80.9 (20.4)		0.73 ^{*2}
FEV1/FVC, mean (SD)	72.2 (13.5)	71.6 (12.6)		0.83 ^{*2}
FEV1/FVC (% of pred.), mean (SD)	91.3 (16.9)	90.0 (15.5)		0.93 ^{*2}
Asthma status				0.30 ^{*3}
Well-controlled asthma, n (%)	7 (17)	3 (7)	10 (12)	
Partially controlled asthma, n (%)	14 (34)	19 (46)	33 (40)	
Uncontrolled asthma, n (%)	20 (49)	19 (46)	49 (48)	
Years since original diagnosis, mean (SD)	15 (12)	21(17)	18 (5)	0.08 ^{*2}
Outpatient treatments for asthma during previous 12 months				0.95 ^{*3}
None, n (%)	34 (85)	36 (88)	70 (86)	
One, n (%)	3 (8)	3 (7)	6 (7)	
Two, n (%)	1 (3)	1 (3)	2 (3)	
Three, n (%)	2 (5)	1 (2)	3 (4)	
Previous asthma education programs				0.71 ^{*3}
None, n (%)	14 (34)	16 (41)	30 (38)	
One, n (%)	20 (49)	19 (49)	39 (49)	
Two, n (%)	2 (5)	2 (5)	4 (5)	
More than two, n (%)	5 (12)	2 (5)	7 (9)	
Asthma medication				
ICS, n (%)	39 (95)	39 (95)	78 (95)	1.00 ^{*1}
SABA, n (%)	33 (81)	30 (73)	63 (77)	1.00 ^{*1}
LABA, n (%)	36 (88)	36 (88)	72 (88)	1.00 ^{*1}
LAMA, n (%)	12 (29)	13 (32)	25 (31)	1.00 ^{*1}
Montelukast, n (%)	2(5)	1 (2)	3 (4)	1.00 ^{*1}
Theophylline, n (%)	2 (5)	1 (2)	3 (4)	1.00 ^{*1}
Omalizumab, n (%)	1 (2)	1 (2)	2 (2)	1.00 ^{*1}

^{*1} Fisher's exact test; ^{*2} t-test for independent variables; ^{*3} chi-squared test

BMI, Body mass index; FEV1, 1-s capacity; FVC, forced vital capacity; ICS, inhaled corticosteroids; LABA, long-acting beta-2 agonists; LAMA, long-acting muscarinic antagonists; SABA, short-acting beta agonists; SD, standard deviation

TABLE 2

Comparison of asthma knowledge gain (AKT score) between the groups (paired t-test)

AKT score at	Intervention group mean (SD)	Difference mean (95% CI)	p-value	Control group mean (SD)	Difference mean (95% CI)	p-value
T1 (baseline)	41.57 (5.63)			41.73 (4.74)		
T2 (after eAEP)	45.82 (3.84)	T2-T1= 4.20 [2.54; 5.86]	<0.001	—		
T3 (after pAEP)	47.20 (3.78)	T3-T2= 1.09 [0.02; 2.12]	0.046	45.72 (3.65)	T3-T1= 3.98 [2.75; 5.21]	< 0.001

95% CI, 95% confidence interval; AKT, Asthma Knowledge Test; eAEP, electronic asthma education program; pAEP, presence-based asthma education program; SD, standard deviation; T1–T3, measurement times

TABLE 3

Regression analysis with regard to asthma knowledge as measured using the AKT at T2/T3 and T3

Variable	T2/T3		T3	
	Coefficient (95%CI)	p-value	Coefficient (95%CI)	p-value
Constant	27.77		29.98	
Sex	-0.02 [-1.65; 1.61]	0.981	0.23 [-1.30; 1.76]	0.680
Age	0.31 [-0.05; 0.11]	0.442	0.04 [-0.03; 0.11]	0.287
Years since first diagnosis of asthma	-0.01 [-0.06; 0.06]	0.968	0.01 [0.04; 0.07]	0.627
AKT T1 (baseline)	0.39 [0.23; 0.56]	<0.001	0.36 [0.18; 0.54]	< 0.001
Group difference	-0.12 [-1.68; 1.44]	0.881	-1.74 [-3.22; -0.27]	0.020

95% CI, 95% confidence interval; AKT, Asthma Knowledge Test; eAEP, ; pAEP, presence-based asthma education program; T2/T3, comparison of knowledge gain between eAEP and pAEP after completion of the respective education program; T3, comparison of knowledge gain between the eAEP group after completion of the obligatory pAEP and the pAEP-only control group

in which missing answers counted as incorrect answers, showed the same statistical relationships.

The eAEP was generally assessed very positively (Table 4). Thirty-four patients gave individual feedback in free-text answers: 27 (79%) liked the design and structure of the program, while 24 (71%) praised the information content and comprehensibility. Personal comments highlighted the possibility of using the website as a source of information about asthma medication and self-management, or for in-depth learning after participation in the pAEP.

Discussion

In this study, the patients who completed each program, the eAEP and the pAEP, had a knowledge gain of around 4 points on the AKT. However, after obligatory completion of the pAEP, the patients in the eAEP group had an additional gain in knowledge of just under 2 points compared with patients who only took part in the pAEP.

Internet-based support systems (IBSS) for self-management and education, together with mobile technologies, are increasingly seen as valuable tools for patients with chronic disease (12). A systematic

review of systematic reviews on digital interventions for asthma self-management demonstrated improvements in indicators of self-management such as the usage of asthma action plans and appropriate medication use (13). In this review only two studies were identified which compared IBSS with pAEP regarding knowledge of asthma. However, these studies included only pediatric patients and their parents, not adult patients (14, 15). A significantly higher knowledge increase in the intervention group was found in both studies, in agreement with our results.

We found no studies evaluating the knowledge increase in adult asthma when using IBSS in comparison with conventional asthma education. The knowledge gain of 4 points on the AKT in our study was similar to that in the control group of a large asthma educational study at another German pulmonary rehabilitation clinic (11). Participation in both educational formats, eAEP and pAEP, led to a further increase in AKT score. This indicates successful presentation of the educational content in the eAEP. In their free-text statements, the patients emphasized the usefulness of the eAEP by positive comments regarding its clarity

TABLE 4

General evaluation of the eAEP by the intervention group (n=41)

	Strongly agree n (%)	Tend to agree n (%)	Neither agree nor disagree n (%)	Tend to disagree n (%)	Completely disagree n (%)	No answer n (%)
The web presence is visually appealing	21 (51)	16 (39)	2 (5)	1 (2)	0	1 (2)
The contents are exactly adapted to my learning progress	20 (49)	14 (34)	6 (15)	0	0	1 (2)
The font size is exactly right	22 (54)	16 (39)	1 (2)	1 (2)	0	1 (2)
The linguistic level of the website is exactly right	28 (68)	11 (27)	1 (2)	0	0	1 (2)
I would recommend the eAEP	28 (68)	11 (27)	0	0	1 (2)	1 (2)
I learned a lot about asthma from the eAEP	23 (56)	10 (24)	5 (12)	1 (2)	0	2 (5)
I would rather use the eAEP than the pAEP	4 (10)	5 (12)	20 (49)	9 (22)	1 (2)	2 (5)

eAEP, electronic asthma education program; pAEP, presence-based asthma education program

and convenience. It was stressed as a decisive advantage that information on asthma management could be sourced from the website if learned content of the pAEP had been forgotten. This points to a high potential for blended learning, but further research into this topic is required.

However, asthma care will not be improved solely by increasing patients' knowledge about asthma self-management. Rather, the whole system—including the care provided outside the hospital setting by primary care physicians and pulmonologists—must be addressed (16). According to Pinnock et al. (5), the core components of effective self-management are:

- Asthma education
- A personal asthma action plan
- Regular visits to a physician for professional review of self-management skills

The most comprehensive study covering all these aspects was carried out by van der Meer et al. (17). They showed that their complex intervention, comprising weekly internet-based asthma control monitoring plus online and group education sessions, improved asthma control itself as well as lung function. Thus, patients need to have sufficient knowledge about asthma and self-management before such internet-based measures are implemented. Ultimately, it is clear that an internet-based AEP might help to reach and fill in the knowledge gap of patients with low willingness to take part in pAEP. Based on previous findings (5, 16), a comprehensive approach to implementation of eAEP would be expedient. Patients would have to pay regular visits to the treating physician, and a personal action plan would have to be developed with each individual patient. Moreover, self-monitoring should take place, with documentation of the peak flow in an asthma diary.

Limitations

After development of the website, this study investigated the basic efficacy of eAEP in an exploratory design, because it was not clear what the differences and distributions of the knowledge gains as measured by the AKT would be. Therefore, the p-values should be interpreted cautiously in a more descriptive manner. A non-inferiority trial would be necessary to confirm non-inferior knowledge gain. Given the observed standard deviation of 4 points and a non-inferiority margin of 1 point in the AKT, would 253 patients would be required in each group to achieve a power of 80% (two-sided alpha = 5%) for such a trial.

Another limitation is that we did not document clinical endpoints. Because the efficacy of the eAEP was unknown, we wanted to evaluate it in conditions of maximal patient safety. For this reason, every patient had to complete the pAEP during their stay at the rehabilitation clinic. Due to the specific setting of a rehabilitation clinic, patients might have had an unusually high amount of time and little distraction. Moreover, selection in respect of age, duration and severity of disease and previous knowledge about asthma must be assumed. Therefore, the transferability of the results to routine care needs to be evaluated cautiously, ideally under consideration of clinical endpoints such as asthma control and hospitalization. When implementing eAEP in an ambulatory setting, it should be evaluated whether a combination with knowledge testing by a family physician within the framework of regular reviews has improved patient care.

Furthermore, in interpreting the results it should be kept in mind that the patients in the eAEP group completed the AKT once more than those in the control group. Theoretically, this might have led to an increase

Key messages

- Despite the obvious impact on quality of life, the length of hospital stays, and emergency treatments, only around one fourth of patients take part in asthma education programs.
- Internet-based asthma education programs may offer a solution to the education deficit owing to the ease of access and the participants' opportunity to schedule their own learning times.
- We found no significant difference in knowledge gain between patients participating in an internet-based asthma education program and patients participating in a conventional asthma education program with personal attendance.
- Asthma knowledge increase was higher when internet-based and conventional asthma education programs were combined.
- An internet-based approach could help to reach patients who are not willing to attend a conventional asthma education program.

in correct answers. However, question-specific memorization seems implausible, as the AKT comprises 54 widely differing questions.

Another important point is that all patients received additional skills training and advice about asthma care during ward rounds, which is very important for optimal self-management. Naturally, this is true for both the intervention group and the control group. However, it underlines the importance of supporting an internet-based AEP with regular visits to the treating physician, in order to achieve adequate skills training and for physicians to reassure themselves that the patient is applying self-management strategies correctly.

Summary

We found similar gains in knowledge for the eAEP group and the pAEP group. The combination of both programs led to a higher knowledge gain. These findings permit the conclusion that an internet-based approach may help to persuade patients who are not willing to take part in a pAEP to join in asthma education. Future studies should examine how eAEP can best be implemented in the hospital setting or in ambulatory care. The necessity of combining an eAEP with regular monitoring, skills training, and motivation of the patient to attain optimal self-management must not be forgotten.

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We are grateful to the German Airway League for permission to include a link to its website www.atemwegsliga.de, which features e-learning modules showing the correct way of using various inhaler devices.

Data sharing statement

Data sharing is not compatible with the approval of the study by the medical ethics committee and the data protection officer for the rehabilitation clinic. The patients were assured that no third parties would be granted access to their data, even in anonymized form. Inquiries relating to statistical analysis can be directed to the corresponding author.

Conflict of interest statement

AS is an external expert for the Federal Joint Committee (Gemeinsamer Bundesausschuss) with regard to the development of the disease management programs for asthma and COPD; he received regular remuneration for taking part in the sessions.

The other authors declare that no conflicts of interest exist.

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► Supplementary material

eMethods:

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CLINICAL SNAPSHOT

Incidental Detection of a Pericardial Cyst

An 89-year old man complained of recurring non-radiating retrosternal pain with no clear relation to exercise. The patient was known to have coronary heart disease and had undergone a percutaneous coronary intervention on the ramus interventricularis anterior. On echocardiography the dimensions of the right ventricle (RV) were normal and no abnormality of left ventricular pump function (LV-PF) was found. No defects were detected. Coronary angiography, repeated to clarify the findings, showed no progression of the coronary status. Radiographically, the right heart silhouette was enlarged compared with earlier images (*Figure 1, orange arrows*) Cardiac magnetic resonance imaging to determine the reason for the enlargement detected a large hyperdense pericardial cyst (diameter 77 × 45 mm) (*Figure 2, white arrows*). Pericardial cysts can cause angina pectoris. A pericardial cyst can be operatively resected, but in this case the patient did not want to undergo surgery. A 12-month follow-up appointment was arranged to check for growth of the cyst.

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Supplementary material to:

An Internet-Based Asthma Self-Management Program Increases Knowledge About Asthma

Results of a Randomized Controlled Trial

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eMETHODS

Details of the website www.asthmaselbstmanagement.de

The homepage of this German-language website provides information about the structure, aims, and contents of the program. Chapter 1 imparts basic knowledge about the physiology, anatomy, and function of the respiratory system and about asthma. Chapter 2 addresses the basics of drug treatment for asthma with emphasis on the distinction between bronchodilating agents and inhaled corticoids, with links to brief videos where the handling of various inhaler devices is demonstrated. The subject of chapter 3 is self-monitoring, with a focus on asthma diaries and utilization of peak flow meters; an asthma diary with peak flow protocol is available for download. Chapter 4 addresses the knowledge and skills required for specific emergency situations such as asthma attacks and pulmonary infections. Patients are advised to download a personal asthma action plan and fill it out together with their physician. The quiz sections generate individual feedback, based on the accuracy of the answers to stimulate cognition and learning processes. Participants could access the electronic asthma education program (eAEP) either on their own laptops or on a computer in the clinic.

Structure of the Asthma Knowledge Test (AKT)

Due to updating of the guidelines, two items of the AKT were excluded for this study. Thus, the version we used consisted of 54 questions. The answer options are ‘right’ and ‘wrong’. The questions cover four domains:

- Pathology (7 items)
- Treatment knowledge regarding medication (15 items)
- Self-management and interoception (26 items)
- Knowledge about non-medical treatment (6 items).

The possible score ranges from 0 to 54 points, with a higher score indicating better knowledge. The original version shows good internal consistency (Cronbach’s alpha 0.92) (18).

Furthermore, after completing the eAEP patients in the intervention group were asked to assess the program by answering 14 standardized and three open questions regarding user-friendliness, content, utility, and presentation.

Randomization procedure

The sequence was computer generated with permuted block sizes. Allocation was concealed by using centrally stored, sequentially numbered, opaque sealed envelopes.

Statistical analysis

Given the exploratory character of the study we did not perform a formal sample size calculation, which would have required prior knowledge of the

expected effect size. Our aim was to recruit 80 (2×40) patients to compare the effectiveness of the two study arms, whereby a two-sided 95% confidence interval for the difference of the average AKT sum scores extends 1.75 points from the observed mean difference, assuming a common standard deviation of 4 (*Table 2*) and that the confidence interval is based on the large-sample z statistic (nQuery Advisor 7.0).

The data were analyzed in IBM SPSS 25 (IBM Corp., Armonk, N.Y., USA). The distribution of quantitative data is described by mean and standard deviation. Qualitative data are presented as absolute and relative frequencies.

Originally, it was planned to count missing answers in the AKT as incorrect answers (in line with previous studies [11]). However, the distribution of missing answers turned out to be skewed: For all 82 patients, the median number (interquartile range) of missing answers was four (two to six) per AKT question at baseline and after participation in the presence-based asthma education program (pAEP). In contrast, the median number of missing answers per question after completing the eAEP was three (two to four) for the 41 patients concerned. This cast doubt on the strategy of counting all missing values as incorrect answers, as even by chance a participant responding to all questions would answer 50% of them correctly. After consultation with the principal statistician (AH) and before running the inferential analyses, we decided to replace missing answers by multiple imputation. This strategy seemed more appropriate and less susceptible to bias, to exploit the inherent correlation structure between questions within and across the items of the questionnaire for imputation.

The imputation method of fully conditional specification was used to produce ten imputed datasets. The results were aggregated in accordance with Rubin's rule (13). Imputation was performed separately for within-group and between-group comparisons, including age, sex, years since asthma diagnosis, AKT baseline scores, and the respective AKT follow-up scores (at individual item level) in the linear imputation models. Changes of the total sum score within the intervention group (AKT before and after eAEP) were analyzed with a paired t-test. The total sum score after completion of the pAEP was compared between intervention and control group by means of linear regression models that were adjusted for age, sex, years since asthma diagnosis, and AKT baseline scores.