

Study of the antibacterial effects of Kombucha on the bacterial isolates from diabetic foot ulcer

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Abstract

Introduction: Diabetes is one of the most important metabolic diseases worldwide. Wound infections due to antibiotic resistant bacteria can cause lower limbs ulceration and amputation in diabetic patients. The present study was performed with the aim of the evaluation of antibacterial effects of cellulose disc from kombucha- on bacteria isolated from diabetic foot ulcers.

Materials and Methods: In this descriptive-analytical study, bacterial were isolated from diabetic wounds and identified based on biochemical and molecular characterization. Then the antibacterial effect of Kombucha cellulose layer was evaluated on the isolates using disc diffusion (qualitative) and agar dilution (quantitative) methods, and the data was statistically analyzed.

Results: The most frequency of pathogenic bacteria that isolated in the present study from diabetic wounds were included 56% *Escherichia coli* (*E.coli*), 22% *Enterobacter cloacae* (*E. cloacae*), 6% *Citrobacter diversus* (*C. diversus*), 4% for each of *Enterobacter aerogenes* (*E. aerogenes*), *Citrobacter freundii* (*C. freundii*) and *Klebsiella pneumonia* (*K. pneumonia*), and 2% for each of methicillin-resistant *Staphylococcus aureus* (MRSA), and *Staphylococcus aureus* (*S. aureus*). The Results of antimicrobial effect of kombucha cellulose disc showed that the disc weighing 0.5 mg was effective on all bacteria during agar disk diffusion method and the largest diameter of the growth inhibition zone was related to MRSA (27.5 mm). The minimum inhibitory concentrations (MICs) of Kombucha cellulose layer were 12.5 mg/ml on MRSA, 25 mg/ml on *S. aureus*, 75 mg/ml on *E. aerogenes*, *C. diversus* and *K. pneumonia*, 71.15 mg/ml on *E.coli*, 85 mg/ml on *E.cloacae*, and 100 mg/ml on *C. freundii*.

Conclusion: The findings of this study showed that the cellulose layer of Kombucha has excellent antibacterial effects against infectious bacteria in diabetic wounds and can be used in various medical and therapeutic targets.

Keywords: Diabetic foot ulcer, Kombucha scoby, Antibiogram, Disk diffusion method

Introduction

Diabetes is one of the metabolic disorder characterized by high blood sugar levels. Complications of this disease include cardiovascular, neurological, and kidney dysfunctions (1-2). Diabetes has adverse

health consequences in human society and is a major cause of death and disability (3-4). It occurs when pancreatic langerhans islands are unable to produce insulin or the body can not use the produced insulin effectively (1). A very common complication of diabetes is inadequate wound healing or a diabetic foot

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ulcer infection, which often requires long-term hospitalizations and treatment and often leads to amputation (4-5). Ischemia, neuropathy, and infection are the three most important pathologically factors which together or alone lead to complications of diabetic ulcers (6-7).

For proper treatment of diabetic foot ulcer infections, first need to know the microbiology of the infection (8-9). Infection of diabetic wounds is caused by the accumulation of pathogenic microorganisms (bacteria, fungi, viruses, and parasites) (10). Most common pathogens interfering acute, untreated, and superficial wound infections include aerobic Gram-positive bacteria, especially *S. aureus*, and beta-haemolytic streptococci (A, B). In patients who are at risk for amputation because of chronic ulcers, infections are caused by a combination of the mentioned Gram-positive bacteria along with facultative anaerobic Gram-negative bacteria such as *E. coli*, *Proteus* and *Klebsiella* spp., and anaerobic bacteria such as *Pepto streptococcus* spp. (11). MRSA is one of the most common bacteria that have been isolated from diabetic wounds (12). Also, the results of a study which conducted in India on patients with infectious ulcers showed that 14 out of 55 isolates of *E. coli* produced beta-lactamase (13). In another study which conducted in Spain with the aim of detection of infectious agents in diabetic foot ulcers, 102 isolated bacteria were identified, in which 68 isolates were Gram-negative bacilli (14).

Foot wound infections are the most common cause of hospitalization in diabetic patients. Many causative bacteria are resistant to a variety of antibiotics; therefore, the use of non-antibiotic treatments would be effective on preventing these antibiotic resistant infections. It is necessary to incorporate traditional medicine with modern therapeutic procedures to obtain the greatest effects in the

shortest time. Kombucha is an Asian-based traditional drink containing fermented black tea extract (15-17). It has traditionally been used to treat many diseases (15). A floating cellulose layer and a sour liquid environment beneath are the two major components of kombucha tea (16). Kombucha is not an individual fungus but contains a community of several yeasts and bacteria (18). The kombucha suspension is a symbiotic culture of *Acetobacter xylinum* (*A. xylinum*) and yeasts which produce a Zoogloea mass. Bacteria have a unique ability to synthesize a floating cellulose network that resembles a superficial mold on a basal medium. The main material of this layer is almost pure cellulose. The composition of bacterial cellulose formed by *Acetobacter* in kombucha solution is different from the composition of cellulose made by algae or plants which consists of β -D-glucan. The cellulose which secreted by *Acetobacter* contains 4-1 glucopyranose bonds. The diameter of the fibrils produced is about 17 angstroms. Some strains of *A. xylinum* also secrete xanthan, which is called Acetan (19). *A. xylinum* produces cellulose synthetase enzyme that makes low weight cellulose microfibrils with a low bulk mass, which join together at the top surface to form a cellulose layer or disk. Kombucha microorganisms attach to the underside of this cellulose disc and create colonies. Therefore, one of the tasks of this cellulose layer is to keep the microorganisms in the vicinity of the gaseous phase of the environment and thus provide the oxygen they need. This layer enhances the ability of kombucha microorganisms to compete with other organisms for food supply. The matte color of the cellulose layer prevents the passage of ultraviolet rays, thereby protecting the underlying microorganisms from possible damage and mutations caused by the rays (20-22). Kombucha drink contains a wide range of amino acids, organic acids, enzymes,

vitamins (groups B and C) and is mineral rich. This drink is a natural source of glucuronic acid that strengthens the body by promoting oxidative metabolism and is not easily found in nature (15, 17, 20). Other benefits of kombucha are production of antibiotics and anti-cancers, as well as stimulating esophageal gastroesophageal reflux that promotes the immune system, and detoxifies and purifies blood (3). However, widespread claims about the benefits of this extract have been based on objective observations and less based on scientific evidence (23). Most researches have been conducted on kombucha supernatant and syrup-like extract and less information has been published on the antimicrobial properties of the kombucha cellulose layer. The purpose of the present study was to investigate the antibacterial activity of discs prepared from kombucha cellulose layer against infectious bacteria isolated from diabetic wounds.

Materials and Methods

Identification the Isolated Bacteria from Diabetic Wounds

In this descriptive - analytical study, 50 bacterial isolates from diabetic wounds were collected from different hospitals in Isfahan, Iran, during 3 months. The isolates were cultured on blood agar (BA) and eosin methylene blue (EMB) media (HiMedia Company, India) and incubated at 35 °C for 18- 24 hours. The pure isolates were identified according to Gram staining and biochemical testing (Biometrix API KIT) (25). The final confirming identification was done by amplification of 16S rDNA gene by PCR using universal primers: DG74 (5' AGGAGGTGATCCAACCGCA3') and RWO1 (5' AACTGGAGGAAGGTGGGGAT3') and a Ribo-Prep PCR kit. The annealing temperature in the original PCR protocol was

55°C that was modified to 50, 55, and 60°C in this study. The amplification reaction mixtures contained 5 µl of 10 mM Tris-HCL buffer (pH 8.3), 1.5 mM MgCl₂, 0.001% gelatin, 1U of Taq DNA polymerase (Perkin-Elmer, Norwalk, Conn), 200 µM (each) deoxynucleotide triphosphates (dATP, dCTP, dGTP and dTTP), 50 pmol of each primer, and 2 µl of the DNA that extracted from each isolate by boiling method. The PCR was carried out in a thermocycler (Amplisense Biotechnology, Russia) in 30 thermal cycles consist of denaturation (94°C, 1 min), primer annealing (55 °C, 1 min), and extension (72 °C, 1 min); followed by a final extension (72°C, 7 min). The expected 362-bp PCR products were detected by agarose gel electrophoresis. The bands were visualized by staining with DNA green viewer, and photographs were taken on UV light. The resulting sequences were analyzed using Chromas software version 2.1.1 and aligned with the reported sequences in the NCBI database (www.ncbi.nlm.nih.gov/Blast) by BLAST server (24).

Determination of Antibiotic Resistance pattern in the Isolated Bacteria from Diabetic Wounds

Antibiotic resistance pattern of the bacterial strains was evaluated against the antibiotics such as cefixime (CFM, 50 µg), gentamicin (GM, 10 µg), ciprofloxacin (CP, 50 µg), and penicillin (P, 5 µg) by disk diffusion (Kerby-Bauer) method according to CLSI standard. For this purpose using sterile loops, 1 to 2 colonies of 18-24 hrs bacterial cultures were removed and added to sterile nutrient broth media to obtain 1.5×10^8 bacterial cells per ml (equal to the turbidity of the McFarland standard 0.5 with optical density of 0.08-0.1 at the wave length of 620 nm). Then the bacteria were transferred to Müller Hinton agar (MHA, Scharlau, Spain) media by sterile loops and the antibiotic containing

standard disks were aseptically put on the media with 20 mm distances from each other. Finally, the diameter of growth inhibition zones around the disks was measured after incubation for 24 hrs at 37 °C. Bacterial ATCC strains were used as positive controls. The diameters of the growth inhibition zones were compared with standard table (PadtanTeb Company, Iran). The results were recorded in terms of sensitive, resistant or semi-sensitive for each strain (25).

Detection of Antibacterial Activity of Kombucha Cellulose Disk on the Isolated Bacteria

First the bacterial suspensions with the turbidity equal to McFarland standard 0.5 were cultivated on MHA media. After drying the media surface, the cut pieces of kombucha cellulose (approximately 6 mm diameter) were aseptically transferred to the surface of medium and incubated for 24 hrs at 37 °C. Then the diameters of growth inhibition zones around the disks were measured (25).

Detection of the Minimum Inhibitory Concentrations (MIC) by Kombucha Cellulose on the Isolated Bacteria

Agar dilution method was used. First, each 19 ml melted MHA media were distributed in sterile universal test tubes. Then 1 ml of each different concentrations of kombucha cellulose (12.5, 25, 50 and 100 mg/ml) was added to each of them; completely mixed for 10 seconds and spread in sterile plates. The negative control plate only contained 20 ml of MHA culture medium. The bacterial suspensions containing bacterial cells (1.5×10^4) were then inoculated in spots onto the media and incubated for 24 hrs at 37 °C. The concentrations of kombucha cellulose that inhibited bacterial growth by more than 99% were considered as MIC (26).

Results

Biochemical and Molecular Characterization of Isolated Bacteria from Diabetic Ulcer

The amplified regions in 16S rDNA gene of the isolates formed 362 bp bands that are shown in Figure 1. The number and percentage of bacteria involved in diabetic wound infections were determined (Table 1). Six Gram-negative bacteria including *E. coli*, *E. cloacae*, *E. aerogenes*, *C. diversus*, *C. freundii*, and *Klebsiella* sp. as well as one Gram-positive bacterium, MRSA, were identified. *E. coli* had the most prevalence (%56) among the diabetic wound infecting bacteria.

Table 1. The diabetic wounds infection agents and their frequency.

Isolate	Frequency	Percentage
<i>E. coli</i>	28	56
<i>E. cloacae</i>	11	22
<i>E. aerogenes</i>	2	4
<i>C. diversus</i>	3	6
<i>C. freundii</i>	2	4
<i>K pneumonia</i>	2	4
MRSA	1	2
Total	50	100

Results of Antibiotic Susceptibility Against the Isolated Bacteria

The results of sensitivity and antibiotic resistance bacteria isolated from diabetic wounds using Kirby Bauer method are presented in Table (2). Most Gram-negative bacteria were sensitive to gentamicin and Cefixime, respectively

The Susceptibility of the Isolated Bacteria to Kombucha Cellulose Disk by Disk Diffusion Method

The results from measurement of growth inhibition zones are shown in table 3. The Kombucha cellulose discs inhibited the growth of all bacterial isolates. The greatest growth inhibition zone was belonged to MRSA with the growth inhibition zone

diameter of 27mm. *E. aerogenes*, *Kelbsiella pneumoniae*, *C. freundii*, *E. coli* and *E. Cloacae* afterward showed the highest

diameter of the growth inhibition zones, respectively.

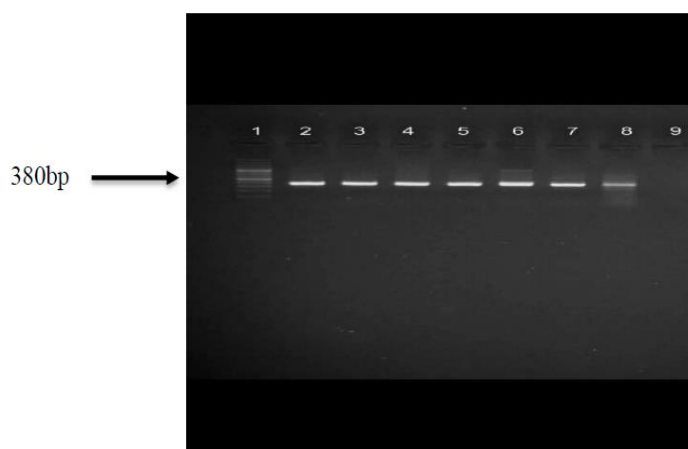


Figure 1. The Resulting PCR Product in a 1% Agarose Gel with Ethidium Bromide Staining. Lan 1: 100-bpDNA ladder, lan 2: *Enterobacter cloacae*, lan 3: *Kelbsiella pneumoniae*, 4: *Eshershia coli*, 5: *Enterobacter cloacae*, 6: *Kelbsiella pneumoniae*, 7: *Citrobacter frondi*, 8: *Citrobacter diversus*, 9: *Enterobacter aeroginosa*.

Table 2. The pattern of resistance or sensitivity of bacteria against different antibiotics.

Antibiotic	P (5 µg/disk)			CP (50 µg/disk)			GM (10 µg/disk)			CFM (50 µg/disk)		
Bacteria	R*	I*	S*	R	I	S	R	I	S	R	I	S
<i>E.coli</i>	-	-	-	12	0	16	0	2	26	8	3	17
<i>E.coli</i> ATCC25922	-	-	-	0	0	1	0	0	1	0	0	1
<i>E.Cloacae</i>	-	-	-	0	0	11	0	0	11	0	0	11
<i>E. aerogenes</i>	-	-	-	1	0	1	0	0	2	1	0	1
<i>E.aerogenes</i> ATCC13048	-	-	-	0	0	1	0	0	1	0	0	1
<i>C. diversus</i>	-	-	-	0	0	3	0	0	3	2	1	0
<i>C. freundii</i>	-	-	-	0	0	2	0	0	2	0	2	0
<i>C. freundii</i> ATCC8090	-	-	-	0	0	1	0	0	1	0	0	1
<i>Klebsiella pneumonia</i>	-	-	-	0	0	2	0	0	2	0	1	1
<i>K. pnemoniae</i> ATCC13883	-	-	-	0	0	1	0	0	1	0	0	1
MRSA	0	0	1	1	0	0	0	0	1	-	-	-
<i>S.aureus</i> ATCC25923	0	0	1	0	0	1	0	0	1	-	-	-

*The number of resistant isolates is presented in the first row and the number of sensitive isolates is shown in the second row in front of each bacterium. Cefixime(CFM), gentamicin (GM), ciprofloxacin (CP), penicillin (P). MRSA: methicillin resistant *Staphylococcus aureus*.

The Susceptibility of the Isolated Bacteria to Kombucha Cellulose Discs by Agar Dilution Method

The results from measurement of minimum inhibitory concentrations (MICs) are shown in Table 4.

Discussion

Today, one of the most important reasons for not treated infections is microbial resistance to antibiotics due to the overuse of antimicrobial drugs.

Table 3. The pattern of susceptibility of bacteria against kombucha cellulose disk by disk diffusion method.

Agent	Growth inhibition zone diameter (mm)
<i>Escherichia coli</i>	19.81±5.84
<i>Escherichia coli</i> ATCC	18.00
<i>Enterobacter cloacae</i>	18.58±4.17
<i>Enterobacter aerogenes</i>	24.75±1.12
<i>Enterobacter aerogenes</i> ATCC	16.16±9/00
<i>Citrobacter diversus</i>	20.75±1.76
<i>Citrobacter freundii</i>	20.70
<i>Citrobacter</i> ATCC	27.70
<i>Kelbsiella pneumonia</i>	21.00±12.2
<i>Kelbsiella</i> ATCC	20.00
MRSA	50.27±4.24
<i>Staphylococcus aureus</i> ATCC	23.60

Table 4. The pattern of minimum inhibitory concentration of kombucha cellulose discs on the bacterial isolates by agar dilution method.

Agent	Minimum inhibitory concentration (mg/ml)
<i>Escherichia coli</i>	71.15±25.19
<i>Escherichia coli</i> ATCC	50
<i>Enterobacter cloacae</i>	85.24±.15
<i>Enterobacter aerogenes</i>	75.35±35
<i>Enterobacter aerogenes</i> ATCC	100
<i>Citrobacter diversus</i>	75.35±35/00
<i>Citrobacter freundii</i>	100
<i>Citrobacter</i> ATCC	50
<i>Kelbsiella pneumonia</i>	75.35±35
<i>Kelbsiella</i> ATCC	50
MRSA	12.5
<i>Staphylococcus aureus</i>	25
<i>Staphylococcus aureus</i> ATCC	100

In other words, the use of antibiotics in high doses leads to the persistence of infection. Also, antibiotic-resistant genes transmit the resistance between generations or even from one species to another. Therefore, due to the resistance of many microbes to chemical drugs, and the severe side effects of chemical drugs attention has been paid to plant sources and the use of traditional herbs (27).

As mentioned above, kombucha has been considered in traditional medicine due to its content, including a wide range of amino acids, organic acids (acetic, lactic, glucuronic, and usnic acids), enzymes, vitamins (B and C), minerals, and antibiotics (16-17,19).

Over the past few decades, many properties of kombucha has been studied. Different efforts have been done for detection of the benefits of kombucha such as its

antibacterial, antifungal, antiviral, anti-parasitic, and anti-cancer effects as well as reflux improvement in esophageal gastric emptying, immune system stimulation, increasing the metabolism level, detoxification, and blood purification (17,19). The presence of acetic acid, lactic acid, gluconic acid and glucuronic acid, along with other compounds such as eosinic acid and nisin and small amounts of ethanol, gives high antimicrobial ability to Kombucha (17,19). One of the natural antibiotics in Kombucha is usnic acid. The main source of usnic acid are lichens and this compound has been effective against Gram-positive bacteria such as *S. aureus*, *E. faecalis*, and probably some viruses. Nisin is a bacteriocin produced in kombucha. This compound is mainly presents in dairy fermented products and produced by lactic

acid bacteria such as *Lactococcus lactis* subsp. *Lactis* (28-29). This antibiotic exerts its activity by binding to the bacterial membrane, entering the membrane layer, forming temporary pores, and interacting with lipids (29). In addition to these compounds, the antimicrobial property of kombucha can be attributed to the presence of tannins that originate from black tea (15). Esam (2014) isolated antibiotic-resistant bacteria from diabetic wounds and studied the effect of kombucha on them. Kombucha showed considerable antimicrobial activity against the isolated bacteria (25). The antibacterial effects of kombucha tea was examined on 7, 14, 21, and 28 days of incubation on the isolated bacteria. The observations showed that on the seventh day of incubation no growth inhibition zone was observed but on the 14th day the highest antimicrobial activity was seen and this effect decreased on the 21th and 28th days (30). Dafrissens et al reported that the antimicrobial activity of kombucha against Gram-positive and Gram-negative bacteria is generally associated with acetic acid produced during fermentation (18). In the present study, for the first time, it was shown that direct use of kombucha cellulose disk had antimicrobial activity against the bacteria which isolated from diabetic woundssuch as *E. coli*, *E. cloacae*, *E. aerogenes*, *C. freundii*, *C. diversus*, *Klebsiella*, and *S. aureus*. Although the mechanism of activity is still unclear, it may be in parts attributed to the beneficial characteristics of the cellulose layer produced by *A. xylinum*, one of the important bacteria exist in kombucha. The

microorganisms (yeast and bacteria) in kombucha attach to the underside of the cellulose disc and microbial masses (colonies) are formed in this area (15). It can be concluded that the kombucha microbial consortium can act as a potent biofilm carrier in transmitting antibiotics and bacteriocins (by binding to cellulose disk) that play a role in the elimination of pathogens, and in addition, the solid cellulose membrane of the fungus with highly nanoporous materials, is able to pass antibiotics or other drugs into the wound and at the same time create an effective physical barrier against any external infections (20).

Conclusion

Based on the results of this study, it can be concluded that kombucha cellulose layer can show excellent antibacterial activity against bacteria that cause infections in ulcers, including diabetic ulcers, and can be used in various medical fields for wound healing.

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Conflict interests

The authors declare that they have no competing interests.

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