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Influence of Coca-Cola on orthodontic materials

A systematic review

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Carbonated beverages
Orthodontic adhesives
Elastomers
Orthodontic brackets

SUMMARY

This analysis was conducted to assess the impact of Coca-Cola on orthodontic materials compared to that of other fluids. Electronical searches were carried out in PubMed, Livivo, Cochrane Central Register of Controlled Trials, and ClinicalTrials.gov, supplemented by manual searches in the reference lists of the articles selected for full text evaluation. The risk of bias was assessed on the basis of a "risk of bias summary." A total of 216 bibliographic summaries of articles were obtained, eleven of which were relevant. Nine of these papers showed a low risk, while two publications from one in vivo study exhibited a high risk of bias. The continuing influence of Coca-Cola caused significant discoloration of elastomeric materials and resulted in significantly lower shear bond strength of the brackets and higher corrosion.

With regard to orthodontic appliances, additional in situ and in vivo studies are desirable. Special attention should be paid to an appropriate number of samples or patients, as most investigations lacked a sufficient number of test subjects. In addition, investigations with long observation periods and documented beverage consumption should be preferred.

The intake of cola-containing beverages during orthodontic therapy and the exposure duration of these beverages to orthodontic material should be reduced to a minimum, as this can impair the adhesive strength and lead to corrosion of orthodontic brackets. The interval between orthodontic appointments should be short to avoid discoloration of orthodontic elastomeric ligatures.

Introduction

The consumption of carbonated soft drinks (soda, carbonates) is widespread among children, adolescents, and adults worldwide (Yang et al. 2017; Brownbill et al. 2018; Beal et al. 2019). The term "carbonates" has been defined as follows: "ready to drink including draught and home dispense; regular, mid, low and no calorie; sparkling juices; cola; lemon including lemonade; lemon-lime; mixers including tonic and bitter drinks; orange; shandy; others including other carbonated fruit flavors, sparkling flavored water, health drinks and herbal drinks." (Statista 2019)

Among these beverages, drinks containing cola are the most popular. For example, data from the United Kingdom show that the market share of cola-flavored drinks accounted for 58% of all carbonated soft drinks in 2017. In contrast, the second most popular choice, lemonade, was only 8% (Statista 2019).

There are reports that cola-type beverages have adverse health effects (Calvo & Tucker 2013; Hu et al. 2019), including dental health, i.e. erosion of enamel, dentin, and restoration materials (Wongkhantee et al. 2006; Panda et al. 2017; Borges et al. 2019). Given the relatively high prevalence of adolescents and adults receiving orthodontic therapy (Lin et al. 2016; Braun & Spassov 2018; Eslamipour et al. 2018; Geoghegan et al. 2019; Vedovello et al. 2019), the question arises whether the materials used in orthodontics may also be affected by these acidic soft drinks. Among the various cola products, Coca Cola was cited most frequently in PubMed. On November 20, 2020, the search term "Coca Cola" yielded 628 hits (conversely, a search for "Pepsi Cola" yielded only 24 hits). According to the British market research company YouGov, Coca-Cola (together with Pepsi and Dr Pepper) is one of the first three best-known beverages (YouGov 2020). Due to the fact that the vast majority of the literature on this topic focuses on Coca-Cola (in contrast to other cola products) and that products from other companies may have different compositions and thus effects on materials, we deliberately restricted this study to Coca-Cola.

Our aim was to conduct a systematic review of the in vitro and in vivo studies conducted with Coca-Cola in order to determine the effects of this beverage on orthodontic materials compared to other "liquid foods." In addition, based on our results, we intended to make recommendations with regard to the consumption of this popular drink among people with orthodontic devices.

Methods

Whenever applicable, this systematic review was reported in accordance with the PRISMA Statement 2009 (Moher et al. 2009; PRISMA 2009), supplemented by additional criteria from the Clinical Appraisal Checklist for Diagnostic Test Accuracy Studies of the Joanna Briggs Institute (JBI 2019).

Search Strategy

Between January 2019 and February 2020, several electronic searches were conducted in the PubMed, Livivo, Cochrane Central Register of Controlled Trials, and ClinicalTrials.gov databases. The latest update of the electronic searches was carried out on February 29, 2020.

The following search string was used in PubMed:
- "(((Orthodontic*) OR Bracket*) OR elast*) AND Coca Cola"

The search in Livivo was based on the following search:
- "Orthodontic Brackets" OR "Orthodontics" OR "elast" AND "Coca-Cola"

Cochrane Central Register of Controlled Trials was searched for:
- "Coca Cola AND orthodontics" in "All Text"

In order to minimize publication retrieval bias, an additional search was conducted in the ClinicalTrials.gov clinical trials registry. "All studies" was selected and the search term "Coca Cola" was entered in the category "Other terms."

Eligibility criteria for relevant articles

Among the retrieved articles, three inclusion criteria were applied:
(1) study articles based on controlled studies (in vivo and in vitro investigations)
(2) inclusion of at least ten test objects or human subjects in the study
(3) the exposure of Coca-Cola to an orthodontic material

Exclusion criteria were animal testing and products other than Coca-Cola. There were no language restrictions.

Selection of relevant articles

The results of the literature search were evaluated independently by the two authors (PK, JCT): after having removed duplicates, the authors read the titles and abstracts of the identified articles to remove those publications that did not meet the inclusion criteria. In case of uncertainties regarding the appropriateness of an article, the full text was considered (broad scope: high sensitivity).

After carefully reading the full-text versions of the identified articles, papers that did not meet the inclusion criteria were excluded. A data extraction protocol (Supplement 1) was used for this purpose.

Based on a test run of the data extraction protocol using five study articles, some adjustments were made to the protocol sheet to ensure a reliable allocation of the articles. Relevant information on Coca-Cola and possible comparison groups was extracted from the corresponding papers.

The authors of the identified publications were contacted by e-mail if important information was missing from the article. Articles based on *non-randomized* studies were considered to be associated with a "high or uncertain risk" of sequencing, blinding, and concealment of allocation. When articles did not use randomization because it was not required, these publications were classified as "low risk." All data extraction protocols were reviewed by JCT.

To identify other potential relevant papers, the reference lists of the included full-text articles were perused.

All relevant articles with the same outcome were grouped together. The article with the highest scientific study design (in vivo > in situ > in vitro) was selected, while publications of lower quality were not considered.

For further analysis, we adhered to the following rules:
- If more than one article of the highest scientific study design was identified, the publication with the largest number of included objects/subjects was considered, regardless of the study duration.
- Conversely, both articles were included if two publications evaluated the same question – one study with more objects/subjects and the other with fewer objects/subjects but with additional issues. For instance, Hammad & Enan (2013) and Sajadi et al. (2014) investigated bracket bond strength. Normally only the publication of Sajadi et al. (2014) would have

been included. However, since Hammad & Enan (2013) also observed the influence of Icon® on the adhesive strength of the bracket, both papers were considered.

The inclusion and exclusion decisions of all identified relevant articles were discussed between the two authors. A third person (PE) was consulted if the two authors could not agree.

Assessment of study quality

The *Cochrane Handbook for Systematic Reviews of Interventions* (Cochrane Collaboration 2019) and Review Manager (RevMan), version 5.3, were used to assess the risk of bias and to provide a summary of the risk of bias.

The "risk of bias summary" consists of the following six bias categories:
- sequence generation,
- allocation concealment,
- blinding,
- incomplete outcome data,
- free of selective reporting,
- free of other bias.

These categories illustrate the risk for each study article. The colors suggested in the *Cochrane Handbook for Systematic Reviews of Interventions* (Higgins & Greens 2011) (Fig. 2) were used to indicate the presence of a low risk (green), uncertain risk (yellow) or high risk (red) of bias.

The following rules applied:
- If an included paper did not contain any information on funding, it was classified as "uncertain risk."
- If funding was provided by a government agency or health organization, a "low risk" was assigned.
- Studies funded by companies were assigned a "high risk" in the "Free of other bias" category.

At the level of the individual articles, the following rules applied:
- The existence of a "low risk" was assigned if five or six green items were present.
- The label "uncertain risk" was assigned if two or three yellow items were reported.
- "High risk" in connection with the reporting on (a) at least one red item or (b) more than three yellow items.

Data extraction

The following information was taken from the identified articles (Supplement 1):
- author(s),
- year of publication,
- study duration,
- aim of the study,
- number of test objects or human subjects,
- relevant intervention groups,
- experimental set-up,
- relevant results,
- financial interests.

Results

Study selection

The criteria for identification, screening, and eligibility are summarized in Figure 1. By searching the four electronic databases, a total of 216 articles were found.

Eleven articles were selected, out of which ten (Al-Khatib et al. 2005; Faltermeier et al. 2007, 2008; Ardeshna & Vaidyanathan 2009; Shahabi et al. 2011; Hammad & Enan 2013; Leao Filho et al. 2013; Kumar et al. 2014; Sajadi et al. 2014; Dias da Silva et al. 2016) were identified by electronic search, while the remaining one paper (Teixeira et al. 2008) was found in a reference list. Twenty other articles that were provisionally considered relevant after reading titles and abstracts were excluded after reading the full texts for the following reasons:
- studies with too few test subjects (Steffen 1996; Dincer et al. 2002; Fernandes et al. 2012; Parenti et al. 2012; Cavalcante et al. 2013; Zafeiriadis et al. 2014; Mikulewicz et al. 2015; Talic & Almudhi 2016)
- studies that did not investigate the effects of Coca-Cola (O'Reilly & Featherstone 1987; Bishara et al. 2005; Kim & Lee 2009; Omid Khoda et al. 2012)
- studies using bovine teeth (Rugg-Gunn et al. 1998; Navarro et al. 2011; Attin et al. 2012)
- non-randomized trials (Yip et al. 2009)
- studies that evaluated the same as other investigations, but had a shorter duration (Lew 1990; Oncag et al. 2005; Ulusoy et al. 2009; Pasha et al. 2015)

Study characteristics

All relevant articles are based on randomized controlled trials (RCTs). The sample sizes in the corresponding investigations were between n = 10 (Al-Khatib et al. 2005; Faltermeier et al. 2007, 2008) and n = 120 (Kumar et al. 2014). The investigations compared the effects of Coca-Cola with those of other aqueous solutions (comparison groups) on orthodontic materials. The following liquids were used in the comparison groups:
- artificial saliva (Teixeira et al. 2008; Shahabi et al. 2011; Leao Filho et al. 2013; Sajadi et al. 2014),
- beer (Leao Filho et al. 2013),
- Coca-Cola light (Teixeira et al. 2008),
- coffee (Leao Filho et al. 2013; Dias da Silva et al. 2016),
- citric acid (Teixeira et al. 2008),
- distilled water (Faltermeier et al. 2007; 2008; Kumar et al. 2014; Dias da Silva et al. 2016),
- Istak (non-alcoholic beer) (Sajadi et al. 2014),
- ketchup (Faltermeier et al. 2008),
- lemon juice (Shahabi et al. 2011),
- Listerine mouthwash (Kumar et al. 2014),
- orange juice (Leao Filho et al. 2013),
- phosphoric acid (Teixeira et al. 2008),
- Ringer's solution (Al-Khatib et al. 2005),
- Sprite (Hammad & Enan 2013),
- tea (Faltermeier et al. 2007; 2008; Kumar et al. 2014; Dias da Silva et al. 2016),
- UV light (Faltermeier et al. 2007; 2008),
- vinegar (Shahabi et al. 2011),
- wine (Leao Filho et al. 2013; Dias da Silva et al. 2016).

The orthodontic materials tested are summarized in Table I. These materials were analyzed for the following chemical and physical properties:
- color stability, related to elastics (Ardeshna & Vaidyanathan 2009; Dias da Silva et al. 2016), orthodontic adhesives (Faltermeier et al. 2008), or plastic brackets (Faltermeier et al. 2007),
- shear bond strength related to brackets (Hammad & Enan 2013; Sajadi et al. 2014),

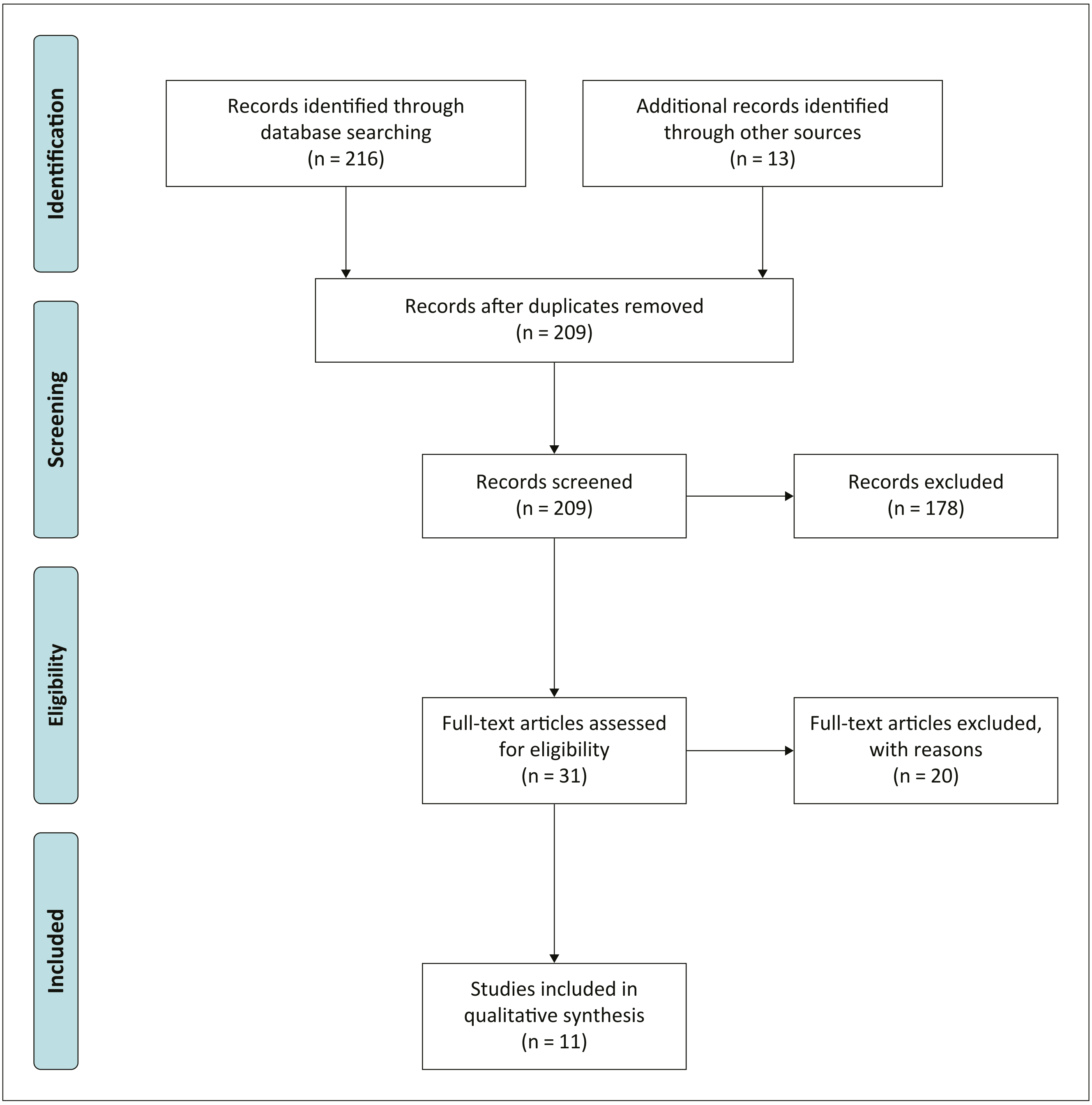

Fig. 1 PRISMA flow chart showing the selection process of the identified study articles.

- static and kinetic "friction" (LENZ 2009) related to bracket arch-wires (AL-KHATIB ET AL. 2005),
- force decay related to elastics (TEIXEIRA ET AL. 2008; LEAO FILHO ET AL. 2013; KUMAR ET AL. 2014),
- corrosion (weight loss) related to brackets (SHAHABI ET AL. 2011).

Study quality assessment

As shown in Figure 2, nine of the eleven study articles were characterized by a low risk of bias (AL-KHATIB ET AL. 2005; FALTERMEIER ET AL. 2007, 2008; TEIXEIRA ET AL. 2008; ARDESHNA & VAIDYANATHAN 2009; SHAHABI ET AL. 2011; LEAO FILHO ET AL. 2013; KUMAR ET AL. 2014; DIAS DA SILVA ET AL. 2016), while two showed a high risk (HAMMAD & ENAN 2013; SAJADI ET AL. 2014). In the category "free of other bias," seven studies (AL-KHATIB ET AL. 2005; FALTERMEIER ET AL. 2007, 2008; TEIXEIRA ET AL. 2008; ARDESHNA & VAIDYANATHAN 2009; SHAHABI ET AL. 2011; LEAO FILHO ET AL. 2013) were classified as "uncertain risk of bias" because no information on funding was given.

One investigation (HAMMAD & ENAN 2013) funded by the Egyptian Ministry of Higher Education and Scientific Research was classified as "low risk" in the category "free of other bias." Although the participants in this investigation (HAMMAD & ENAN 2013) were randomly divided into two groups, no mention was made of how the participants were divided. In addition, the participants knew the test group to which they were assigned.

In two studies (HAMMAD & ENAN 2013; SAJADI ET AL. 2014) there was a methodological need for randomization because real human teeth were used, whereas in the other nine investigations

	Sequence generation	Allocation concealment	Blinding	Incomplete outcome data	Free of selective reporting	Free of other bias
2005 Al-Khatib et al.	+	+	+	+	+	?
2007 Faltermeier et al.	+	+	+	+	+	?
2008 Faltermeier et al.	+	+	+	+	+	?
2008 Teixeria et al.	+	+	+	+	+	?
2009 Ardeshna et al.	+	+	+	+	+	?
2011 Shahabi et al.	+	+	+	+	+	?
2013 Hammad S M, Enan E T	?	?	–	+	+	+
2013 Leao Filho et al.	+	+	+	+	+	?
2014 Kumar et al.	+	+	+	+	+	+
2014 Sajadi et al.	?	?	?	+	+	?
2016 Dias da Silva et al.	+	+	+	+	+	+

Fig. 2 Risk of bias summary

Tab. I Examined orthodontic materials in the identified 11 study articles

Material	Product	Brand
Metal	Standard edgewise brackets	Dentaurum
	Bracket arch-wire combination	3M Unitek
Polymer	TrandbondTM XT adhesive	3M Unitek
	Enlight adhesive	Ormco
	Rely X Unicem adhesive	3M Unitek
	Meron Plus AC GIC	Voco
	Plastic brackets	self-made
	Resin infiltration Icon®	DMG
Elastics	Elastomeric ligatures	American Orthodontics
		Ortho Technology
	Elastomeric chains	3M Unitek
	Intermaxillary elastics	TP Orthodontics Inc.
	Elastomeric modules	3M Unitek
		American Orthodontics
		Ormco
		TP Orthodontics Inc.
		GAC International Inc.

(Al-Khatib et al. 2005; Faltermeier et al. 2007, 2008; Teixeira et al. 2008; Ardeshna & Vaidyanathan 2009; Shahabi et al. 2011; Leao Filho et al. 2013; Kumar et al. 2014; Dias da Silva et al. 2016) this was not the case.

Study findings

The effects of Coca-Cola on dental materials are summarized in Table II. Here are the main findings:

- Coca-Cola caused a significant color change in the elastomeric ligatures (Dias da Silva et al. 2016) and the elastomeric modules (with the exception of those provided by American Orthodontics) (Ardeshna & Vaidyanathan 2009) and significantly reduced shear bond strength of orthodontic brackets (Hammad & Enan 2013; Sajadi et al. 2014).
- The discoloration shown by Coca-Cola was less than that caused by tea, coffee, or wine (Dias da Silva et al. 2016).
- Coca-Cola caused more weight loss (corrosion) of brackets than vinegar or lemon juice (Shahabi et al. 2011).
- Coca-Cola damaged both adhesives (with the exception of resin-reinforced chemically hardened GIC; Meron Plus AC) and elastomeric chains less than tea (Faltermeier et al. 2008).
- The loss of strength of intermaxillary elastics was not significantly influenced by Coca-Cola or beverages such as beer, orange juice, red wine, and coffee (Leao Filho et al. 2013).
- Coca-Cola had no influence on adhesive remnant index (ARI) scores (Sajadi et al. 2014).
- Coca-Cola showed less static and kinetic "friction" (Lenz 2009) of bracket arch-wire combinations than air (Al-Khatib et al. 2005).
- The color of plastic brackets did not change significantly (Faltermeier et al. 2007).
- The resin infiltration of Icon® before bonding the brackets despite of Coca-Cola significantly increased shear bond strength compared to Coca-Cola without Icon® infiltration after debonding the brackets (Hammad & Enan 2013).

Discussion

To our knowledge, this is the first systematic review of the influence of cola-type beverages on orthodontic materials. Based on the 11 of 216 articles on RCTs that met the inclusion criteria (Al-Khatib et al. 2005; Faltermeier et al. 2007, 2008; Teixeira et al. 2008; Ardeshna & Vaidyanathan 2009; Shahabi et al. 2011; Hammad & Enan 2013; Leao Filho et al. 2013; Kumar et al. 2014; Sajadi et al. 2014; Dias da Silva et al. 2016), we found that Coca-Cola had a negative impact on orthodontic devices, particularly the shear bond strength of brackets (Hammad & Enan 2013; Sajadi et al. 2014). On the other hand, no negative influence could be found with regard to discoloration in comparison to other aqueous liquids (Faltermeier et al. 2008; Ardeshna & Vaidyanathan 2009; Dias da Silva et al. 2016). Interestingly, resin infiltration of Icon® increased shear bond strength after the brackets were debonded (Hammad & Enan 2013).

Unfortunately, the vast majority of the identified study articles were based on in vitro examinations. Such investigations may actually have their merits. For example, by isolating defined variables, elements of clinical interest can be examined without interfering influences (Sadan 2007). Findings from in

Tab. II Effects of Coca-Cola on dental material

Author	Year	Objects	Groups	Aim	Method	Results
Dias da Silva et al.	2016	n = 24 elastomer ligatures	n = 20 (4 different colors × 24 specimens × 5 solutions)	To evaluate the in vitro discoloration of different colored orthodontic ligatures by Coca-Cola, black tea, wine, distilled water, and coffee	The elastomer ligatures were stored in a test solution at 37 °C for 72 hours. The discoloration was measured with CIELab. A significant visible discoloration was defined for ΔE values > 3.3.	All ligatures of all shades tended to show significant discoloration; no difference between them was observed. Compared to all beverages tested, Coca-Cola showed the lowest discoloration.
Sajadi et al.	2014	Group 1 & 2: n = 30 teeth and brackets Group 3: n = 20 teeth and brackets	n = 3 Group 1 & 2: (shear bond strength × 30 teeth and brackets × 2 solutions) Group 3: (shear bond strength × 20 teeth and brackets × artificial saliva)	To evaluate the effects of Coca-Cola, Istak, and artificial saliva in vitro on the adhesive strength of the brackets and the ARI after removal (debonding) of the brackets	Premolars were etched. Transbond XT primer was applied to brackets and teeth. Brackets were placed on the teeth and stored in artificial saliva at 37 °C for 24 hours. Premolars were divided into three groups and immersed in the test solution for 5 minutes twice a day for 30 days.	Coca-Cola had significantly lower bracket bond strength than Istak and artificial saliva. There was no significant ARI difference among Coca-Cola, Istak, and artificial saliva. None of the solutions tested affected the ARI.
Kumar et al.	2014	n = 120 elastomerchains	n = 4 (120 elastomer chains × 4 solutions)	To evaluate and compare the effects of Coca-Cola, tea, Listerine mouthwash, and distilled water in vitro on elastomer chains stretched to a constant length of 25 mm	Twice daily, elastomer chains were stretched to a constant length of 25 mm and stored in the test solution at 37 °C for 60 seconds. Force decay was measured six times: after 1 hour, 24 hours, 7 days, 14 days, 21 days and 28 days.	The more time passed, the more loss of strength (force decay) was observed through the influence of Coca-Cola, Listerine mouthwash, and tea. A significantly higher force decay was observed with Coca-Cola compared to distilled water. No significant results were observed for Coca-Cola between the 7th and the 14th, and the 14th and 21st day, respectively. Tea was more prone to force decay than Coca-Cola.
Leao Filho et al.	2013	n = 30 intermaxillary elastics	n = 6 (30 intermaxillary elastics × 6 solutions)	To evaluate the effect of artificial saliva, Coca-Cola, beer, orange juice, red wine, and coffee in vitro on force degradation of orthodontic intermaxillary elastics	Average force ¼ inch intermaxillary elastics were stretched up to a distance of 26 mm. Loss of strength (force decay) was measured using a tensile strength machine. The elastics were divided into six groups and immersed in the test beverages for five cycles. The first two cycles lasted 15 minutes, the third to fifth cycle took 30 minutes. Between the cycles, the elastics were held in artificial saliva for 3 minutes before the tensile strength was tested. After five cycles, the final tensile strength test was evaluated.	The tested beverages did not show a deteriorating effect on orthodontic intermaxillary elastics. A significant force reduction was observed only after the first immersion cycle of the beverages.

HAMMAD & ENAN	2013	n = 15 orthodontic patients	n = 2 × 2 Group 1: (15 orthodontic patients × 2 solutions × brackets) Group 2: (15 orthodontic patients × 2 solutions × icon × brackets)	To evaluate the impact (a) of Coca-Cola and Sprite in vivo on the bracket adhesion strength with and without resin infiltration (Icon) and (b) of these beverages after debonding by SEM.	12- to 17-year-old orthodontic patients were randomly divided into a Coca-Cola and a Sprite group. One side of the teeth was treated with Icon. Then the teeth were bonded with Transbond XT. Brackets were attached to the 60 teeth to be extracted. Patients were asked to rinse three times a day 5 for minutes with the respective drink over a period of 3 months. The teeth were then extracted and the shear bond strength measured.	A significantly higher shear bond strength was observed in Coca-Cola with Icon than without Icon. Regardless of the presence of Icon, a lower shear bond strength was observed with Coca-Cola than with Sprite.
SHAHABI ET AL.	2011	n = 20 brackets	n = 4 (20 brackets × 4 solutions)	To evaluate the effect of Coca-Cola, lemon juice, vinegar, and artificial saliva in vitro on bracket corrosion.	Brackets were stored in the test solutions at 37 °C for 6 weeks.	After 6 weeks the greatest weight loss was observed in Coca-Cola. The result was statistically significant compared to vinegar and lemon juice. The weight loss of brackets increased over time.
ARDESHNA & VAIDYANATHAN	2009	n = 16 orthodontic elastomer modules	n = 15 × 4 (15 module types × 4 dietary media × 16 specimens)	To evaluate the color change, the influence of the manufacturing process, and the type of dietary drinks (coffee, Coca-Cola, tea, and a mild Indian curry powder) in vitro on elastomer modules	Dietary beverages were diluted in 250 ml water. The elastomer modules (8 × 8 mm squares) were kept in the liquids at 37 °C for 72 hours. CIELab was used to determine color change before and after the staining process. Total discoloration ($\Delta E > 3.3$) was defined as significant color change.	Coca-Cola significantly reduced the discoloration of the gray and green modules. The lowest ΔE values were observed with Coca-Cola compared to the other beverages. Coca-Cola's ΔE was significant for all manufacturers with the exception of American Orthodontics' elastomer modules. Clearer and lighter elastomer modules showed more color change than darker ones. The modules produced with the extrusion/die stamping process were more prone to discoloration than the injection-molded elastomers.
TEIXEIRA ET AL.	2008	n = 20 elastomer chains	n = 2 × 4 (2 types of elastomer chains × 20 elastomer chains × 4 solutions)	To evaluate the effect of artificial saliva, Coca-Cola light, citric acid, and phosphoric acid in vitro on two types of orthodontic elastomer chains	For each group, a test device was fabricated. Chainette elastomer chains were stretched to 1.7 mm, and Sunburst chains to 1.4 mm. They were kept in artificial saliva at 37 °C. Specimens were stored in the respective test beverages twice a day, for 15 minutes at room temperature for 21 days. Force decay was measured with a dial-type dynameter Corex initially, after 24 hours, 7 days, 14 days, and 21 days.	The biggest change in force decay was observed during the first 24 hours. Chainette chains exhibited significant lower force decay than Sunburst chains. The tested beverages did not have a statistically significant impact on force decay of the orthodontic elastomer chains tested.

Year: year of publication. Objects: number of objects/subjects per group or subgroup. Aim = aim of the study. CIELab: system used to measure color change. ARI: Adhesive Remnant Index. ΔE: variable representing numerically a color change (discoloration).

Tab. II Effects of Coca-Cola on dental material *continued*

Author	Year	Objects	Groups	Aim	Method	Results
Faltermeier et al.	2008	n = 10 adhesive specimens	n = 4 × 5 (4 different orthodontic adhesives × 10 adhesive specimens × 5 solutions)	To evaluate the impact of Coca-Cola, Ketchup, tea, distilled water, and UV light in vitro on discoloration of different orthodontic adhesives	The adhesives were stored in the respective test solution. They were exposed to a filtered xenon lamp for 72 hours. Every 20 minutes the adhesives were rinsed at 37 °C for 3 minutes and then dried for 17 minutes. After 72 hours, the colors were measured using CIELab and compared with the distilled water group. A significant and visible discoloration was defined for ΔE values > 3.3.	Minor discoloration, with the exception of Meron Plus AC, was observed in all tested adhesives after storage in Coca-Cola. Meron Plus AC showed the greatest discoloration after storage in Coca-Cola and tea. Rely X Unicem showed less discoloration than the other adhesives. Coca-Cola showed the lowest ΔE values compared to tea and Ketchup for all adhesives tested, except Meron Plus AC. In Meron Plus AC, ketchup showed lower ΔE values than Coca-Cola.
Faltermeier et al.	2007	n = 10 brackets	n = 3 × 4 (3 different filler contents × 10 brackets × 4 solutions)	To evaluate the effects of Coca-Cola, tea, UV light, and distilled water in vitro on the discoloration of plastic brackets with varying filler content	The brackets were prepared and exposed to the test solutions for 72 hours. Each immersion cycle lasted 20 minutes with a 3-minute rinse, followed by a 17-minute dry phase. The color change was evaluated with CIELab. A significant and visible discoloration was defined for ΔE values > 3.3.	UDMA and 70% filler content showed a significantly higher discoloration in Coca-Cola than UDMA and 0% filler content. The lowest discoloration in Coca-Cola was found in UDMA and 35% filler content. UV light caused a stronger discoloration than Coca-Cola and was significant for UDMA with 35% and 70% filler content. All brackets investigated showed ΔE values below 3.3. Therefore, all discoloration results were acceptable.
Al-Khatib et al.	2005	n = 10 bracket arch-wire combination specimens	n = 2 × 6 (2 brackets arch-wire combination sizes × 10 specimens × 6 solutions)	To evaluate the effects of Coca-Cola, air, and various Ringer's solutions in vitro on the coefficient of friction on two different bracket arch-wire combinations (0.017" × 0.025" and 0.018" × 0.025")	By means of a fretting machine the friction behavior of bracket arch-wire combinations was observed. The bracket on the arch-wire was loaded with 2 N. An amplitude of 200 µm at a frequency of 1 Hz was used. Each of the ten sets performed consisted of 20 cycles at 23 °C. All six solutions were tested with polymer wire holders.	Both sizes of the bracket arch-wire combinations showed a higher coefficient of friction for Coca-Cola when compared with Ringer's solution and Ringer's buffer solution. Both sizes of the bracket arch-wire combinations showed a higher coefficient of friction for ambient air compared to Coca-Cola.

Year: year of publication. Objects: number of objects/subjects per group or subgroup. Aim = aim of the study. CIELab: system used to measure color change. ARI: Adhesive Remnant Index. ΔE: variable representing numerically a color change (discoloration).

vitro studies may supplement the results of in vivo investigations (Baeshen & Birkhed 2010; Menicagli et al. 2019). The same may be the case for in situ and in vivo studies (Alexandria et al. 2019). On the other hand, different results may occur if the same variables examined in vitro are examined in the oral environment (e.g., Al Maaitah et al. 2013; Koletsi et al. 2019).

The shear bond strength of the brackets was significantly reduced in the presence of Coca-Cola (Hammad & Enan 2013; Sajadi et al. 2014). This result was also reported by several other authors (Oncag et al. 2005; Ulusoy et al. 2009; Pasha et al. 2015). Icon® was able to significantly increase shear bond strength. Hammad & Enan (2013) believe that this was most likely due to the resin infiltrate's deeper penetration into the lesion's body compared with the primer of the orthodontic cements.

Coca-Cola caused a significantly higher weight loss of brackets (Shahabi et al. 2011). According to Shahabi et al. (2011), corrosion can be explained by the ingredient carbon dioxide contained in Coca-Cola. Carbon dioxide is said to support the corrosion of many points on a surface at the same time, which leads to highly intensive corrosion. Therefore, the authors recommend avoiding the consumption of Coca-Cola during orthodontic therapy.

Coca-Cola did not affect the ARI (Sajadi et al. 2014). However, Pasha et al. (2015) reported that Coca-Cola triggered a significantly higher average value of the ARI than did Sajadi et al. (2014). The different results of the ARI can be explained by a longer immersion time of the tested objects. Pasha et al. (2015) recommend that the intake of soft drinks during orthodontic therapy should be reduced to a minimum as this affects the adhesive strength of the orthodontic brackets.

Coca-Cola had no significant influence on the force degradation of intermaxillary elastics (Leao Filho et al. 2013). Although the results do not indicate a harmful effect on intermaxillary elastics, Leao Filho et al. (2013) recommend that the results be interpreted with caution as in vitro studies are not able to fully simulate the situation in the oral cavity.

The manufacturing process plays a significant role in the discoloration of elastomeric components. The elastomer modules produced by injection molding were not statistically significant, while the modules produced by extrusion/die stamping achieved significant ΔE values ($\Delta E > 3.3$). According to Ardeshna & Vaidyanathan (2009), clinicians should be cautious when selecting elastomer modules because there are so many different brands of elastomer modules on the market.

Faltermeier et al. (2008) set the ΔE values for significant results to $\Delta E > 3.7$. Compared to other articles included in this systematic review, this threshold was higher ($3.7 > 3.3$), and its results were still significant (Ardeshna & Vaidyanathan 2009; Dias da Silva et al. 2016). Faltermeier et al. (2008) note that companies need to improve their orthodontic adhesive products in terms of color stability.

Al-Khatib et al. (2005) investigated the "friction" of stainless-steel arch wire-bracket combinations in air and different solutions. Coca-Cola showed higher "friction" than Ringer's solutions and lower "friction" compared to air. These results could be explained by the lubrication effect which in air is lower than in Coca-Cola, and it appears to be higher in Coca-Cola than in the various Ringer's solutions.

We have limited our systematic review to studies related to human teeth. While some authors recommend bovine teeth as a substitute for human teeth (e.g., Soares et al. 2016; de Carvalho et al. 2018), other authors have pointed out that bovine teeth have different morphological, chemical and physical properties (Yassen et al. 2011). For example, bovine teeth have fewer dentine tubules than human teeth (Lopes et al. 2009). Due to their limited comparability, we have not taken into account the results of studies with bovine teeth.

Only one relevant in vivo research article was available for our review (Hammad & Enan 2013). However, of the relevant articles found, it was of the lowest quality in the methodology used (Fig. 2). This contrasts with the significantly larger number of investigations, including in vivo studies, on the effect of cola-flavored drinks on enamel erosion (e.g., Tenuta et al. 2015; Yu et al. 2018; Pirca et al. 2019).

Some publications were considered as "low risk" if no randomization was required. This classification applies to all studies in which a manufactured orthodontic product was tested. The precise manufacture of orthodontic appliances makes these products unique in terms of quality and makes randomization unnecessary.

In the category "study selection," the authors have developed their own method for preselecting the relevant full-text articles. This method enabled us to reject study results with low evidence, thus improving the quality of our results.

Conclusion

As for orthodontic appliances, more in situ and in vivo studies are needed to determine the impact of Coca-Cola on orthodontic materials compared to other "liquid foods" in order to provide solid recommendations on the consumption of this popular drink among people with orthodontic appliances. Special attention should be paid to an appropriate number of samples or patients, as most investigations lacked a sufficient number of test subjects. Studies with long observation periods and documented beverage consumption should be preferred. Finally, it would be desirable to investigate the entire product range of cola-type beverages. Given the limited availability of high-quality external evidence of the effects of Coca-Cola on orthodontic materials, the following two clinical proposals are made:

1. The intake of cola-containing beverages during orthodontic therapy and the exposure time of these beverages to orthodontic material should be reduced to a minimum, as this can impair the adhesive strength and lead to corrosion of the orthodontic brackets.
2. The time between orthodontic appointments should be short in order to avoid visually noticeable discoloration of orthodontic elastomeric ligatures.

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Author contribution

PK conducted the literature search, prepared the data extraction sheets, analyzed the data, and provided the first draft of the manuscript. JCT had the idea for inaugurating the project, checked the extraction sheets, participated in the study selection process, and critically revised the manuscript. Both authors finalized the paper and approved the manuscript.

Zusammenfassung

Einleitung

Ziel der systematischen Übersicht war es, die Auswirkungen von Coca-Cola auf kieferorthopädische Materialien im Vergleich zu anderen Flüssigkeiten zu untersuchen.

Materialien und Methoden

Elektronische Recherchen wurden in PubMed, Livivo, Cochrane Central Register of Controlled Trials und ClinicalTrials.gov durchgeführt. Sie wurden ergänzt durch manuelle Suchen in den Literaturverzeichnissen der identifizierten relevanten Artikel. Das Risiko einer Verzerrung wurde auf der Grundlage eines «Risk of Bias Summary» bewertet.

Ergebnisse

Die Suche ergab Hinweise auf 216 bibliografische Artikel, von denen 11 relevant waren. Neun Arbeiten zeigten ein geringes «risk of bias»-Profil, während zwei Veröffentlichungen aus einer In-vivo-Studie ein hohes Risiko aufwiesen. Anhaltender Einfluss von Coca-Cola verursachte eine signifikante Verfärbung der elastischen Materialien und führte zu einer signifikant geringeren Scherhaftfestigkeit der Brackets und verstärkten Korrosion.

Diskussion

Der Genuss von colahaltigen Getränken während einer orthodontischen Therapie und die Expositionszeit dieser Getränke auf das dabei verwendete Material sollten auf ein Minimum reduziert werden, da durch den Einfluss dieser Flüssigkeiten die Haftfestigkeit beeinträchtigt und Korrosion an Brackets verursacht werden kann. Die Zeitspanne zwischen kieferorthopädischen Terminen sollte kurz sein, um Verfärbungen der Ligaturen zu vermeiden.

Résumé

Introduction

L'objectif de l'étude systématique était d'étudier les effets du Coca-Cola sur les matériaux orthodontiques en comparaison avec d'autres fluides.

Matériels et méthodes

Des recherches électroniques ont été effectuées dans PubMed, Livivo, Cochrane Central Register of Controlled Trials et ClinicalTrials.gov. Elles ont été complétées par des recherches manuelles dans les bibliographies des articles pertinents identifiés. Le risque de partialité a été évalué sur la base d'un « résumé du risque de partialité ».

Résultats

La recherche a révélé des références à 216 articles bibliographiques, dont onze étaient pertinents. Neuf articles ont montré un faible profil de « risque de biais », tandis que deux publications d'une étude in vivo ont montré un risque élevé. L'exposition continue au Coca-Cola a provoqué une décoloration importante des matériaux élastiques et a entraîné une résistance au cisaillement nettement inférieure des supports et une corrosion augmentée.

Discussion

La consommation de boissons contenant du cola pendant le traitement orthodontique et la durée d'exposition de ces boissons au matériau utilisé doivent être réduites au minimum, car l'influence de ces liquides peut affecter la force de liaison et provoquer la corrosion des brackets. L'intervalle entre les rendez-vous orthodontiques doit être court pour éviter la décoloration des ligatures.

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Supplement 1

Data extraction sheet

- Notes: ______________________________

- Study title: ______________________________

- Authors: ______________________________

- Year of publication: ______________________________

- Reasons for exclusion (yes = exclusion):
  - Animal trial yes ☐ no ☐
  - Animal teeth were used (e.g., bovine teeth) yes ☐ no ☐
  - No controlled trial yes ☐ no ☐
  - Number of objects/subjects per group <10 yes ☐ no ☐

- Aim of the study: ______________________________

- Methods: ______________________________

Evaluation of study risk

Study design
- Total study duration: ______________________________

- Randomization needed? yes ☐ no ☐
  If no: check “yes” for *Sequence generation* and “no” for *Allocation concealment* and *Blinding*!

Sequence generation
- Was the allocation sequence adequately generated? yes ☐ no ☐ unknown ☐

- Which method was used for the random distribution? ______________________________
  or: unknown ☐

Allocation concealment
- Was the allocation adequately concealed? yes ☐ no ☐ unknown ☐

Blinding
- Was knowledge of the allocated interventions adequately prevented during the study? yes ☐ no ☐ unknown ☐

Incomplete outcome data
- Were incomplete outcome data adequately addressed? yes ☐ no ☐ unknown ☐

  Yes? Explanation: ______________________________

Free of selective reporting
- Are reports of the study free of suggestion of selective outcome reporting? yes ☐ no ☐ unknown ☐

  No? Explanation: ______

Free of other bias
- Was the study apparently free of other problems that could put it at a risk of bias? yes ☐ no ☐ unknown ☐

Study Contents

Participants
- Exclusion of participants: ______
- Total number of participants: ______
- Experimental setting: ______
- Diagnostic criteria: ______
- Age: ______
- Sex: ______
- Country: ______

Intervention
- Experimental setting: ______
- Total number of groups: ______
- Intervention details: ______

Results

______

______

______

Miscellaneous
- Funding source: ______
- Key conclusion of the study authors: ______
- References to other relevant studies: ______