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USE OF ARTIFICIAL INTELLIGENCE ANFIS METOD FOR DETERMINATION OF BRACKET DEBONDING FORCES BETWEEN TWO DIFFERENT ADHESIVES

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Abstract. Fixed technique for applying brackets would be impossible without using adhesives for their fixation to the tooth enamel. However, the use of adhesives entails a number of problems which are a consequence of their imperfection, besides the fact that they have been actually applied for a number of decades already. The paper will analyse the debonding force values for bracket-tooth interface. For comparative analysis of the strength of bracket-tooth interface, with the application of different types of adhesives, 80 extracted teeth of the frontal region were used (central, lateral incisor teeth and canines of the upper and lower tooth arch). For the debonding process of applied orthodontics brackets, single-axial Stretch system for examination of tissues was applied to determine the value of the force necessary to separate the bracket from tooth surface, i.e. it was used to test debonding force. The direction of the used force for debonding was under angle of 90 degrees to the vertical axis of the tooth. By comparison of mean values of the strength of interface among the tested groups, it was determined that the highest average value of bond strength was with the group of teeth with which Con Tec Duo was used, a little lower mean value was recorded with the use of Con Tec LC adhesive. Artificial intelligence method was used for determination of debonding force and adhesives relationship. In the current paper were used numerical and attribution variables for modelling namely the Adaptive Network-based Fuzzy Inference System (ANFIS) method of artificial intelligence.

Keywords: adhesives, orthodontic bracket, debonding, stretch system, artificial intelligence.

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AIMS AND BACKGROUND

Orthodontics, as science and practice, has developed through its history depending on the development of biology, medicine and technique. Advancement of technique in general and the knowledge derived from it made possible the use of that information to design orthodontic devices with certain elements comprising orthodontic device itself: bracket, screws, wires, rubber cups for traction, rubber bands, etc., with quite precisely defined characteristics required by the therapy, all of which makes work significantly easier and provides a safer therapy outcome[1,2].

One of the problems encountered relatively frequently by an orthodontist in his everyday work while using the fixed technique is occurrence of failure of brackets fixed to the tooth by adhesive. This requires re-application of the bracket, implying a waste of time both for the patient and the therapist, and entails other consequences too. One of the consequences is that if the bracket fails for the second time, it is not advisable to adhere it for the third time.

Numerous studies of the material used for bonding brackets have been undertaken because of the reasons mentioned above. These materials differ both by their chemical composition, the curing method, sensitivity to moist environment during bonding of brackets, etc. as well as by the existence of extensive correlative dependence between these elements. This additionally complicates the deriving of absolutely safe conclusions as to "which is the best adhesive agent for bonding brackets in every specific case", depending on the age of the patient, etc. Shear bond strength and interfacial analysis of high-viscosity glass ionomer cement bonded to dentin with protocols including silver diamine fluoride[3], orthodontic bracket bonding to glazed full-contour zirconia[4].

Taking into account the importance of the mentioned problems and the views of these processes and phenomena that are frequently contradictory, the aim of this study is as follows: to exactly determine the difference between the various types of adhesives (bonding agents), in terms of their adhesiveness, the course and comfort during work, and to define the guidelines and operating instructions for specific types of bonding agents, self-etch adhesives for the bonding of orthodontic brackets[5].

Nowadays, based on extensive research, there is a belief that the strength of bracket-tooth interface within the range 3–7 MPa is satisfactory for the clinical work of an orthodontist[3–5], while other authors state a somewhat bigger range of values 2.8–10 MPa (Refs 6 and 7), whereas, according to Newman et al.[8], an acceptable minimum of the bond strength with regards to etched enamel ranges between 6–8 MPa. On the one hand, orthodontists require as safe (strong) adhesive bond as possible, thus decreasing the possibility of undesired separation of bracket (bracket failure) during the therapy; on the other hand, a stronger enamel-adhesive bond increases the risk of damaging tooth enamel during debonding[9–11]. It is more fortunate a circumstance if during debonding bracket is separated from the adhesive, with adhesive remaining on the tooth, rather than a situation where adhesive is bonded more strongly to the bracket, thus, separating adhesive together with the bracket may entail damage of enamel if the enamel-adhesive bond is strong. In the former case it is better to carefully remove the remaining part of the adhesive on the tooth with hard polishing rubber cups, rather than with turbine and diamond drill. This enamel damage that occurs relatively frequently should be repaired according to certain generally accepted principles that apply to such cases and situations. Synthesis and characterisation of novel nanocomposites with nanofillers particles and their applications as dental materials are reported[12].

The influence of current density in the electropolishing process at stereometric surface properties of the Co-Cr dental alloys was studied[13] and the influence of Nd:Yag laser shock peening process parameters on tribomechanical behaviour of dental cast alloys was investigated[14] and corrosion resistance, roughness and structure of $Co_{64}Cr_{28}Mo_5$ (Fe, Si, Al, Be)$_3$ and $Co_{63}Cr_{29}Mo_{6.5}$(C, Si, Fe, Mn)$_{1.5}$ biomedical alloys was done[15].

Effect of time on shear bond strength of four orthodontic adhesive systems was investigated[16].

EXPERIMENTAL

80 extracted teeth of the frontal region (central, lateral incisors and molars of upper and lower dental arch) were used for comparative analysis of bracket-tooth bond strength for application of Con Tec LC and Con Tec Duo adhesives. The criteria for teeth selection for the study were the following: no caries on labial surface, no cracks of enamel that can be caused by the pressure of forceps during tooth extraction, no hypoplastic macroscopically visible areas, and no decalcification caused by any reason.

Integrated Design Approaches for 3D Printed Tissue Scaffolds was used[17].

The common procedure of tooth preparation for bonding brackets (regardless of adhesive type) was in accordance with the procedure that most commonly used for *in vitro* studies[18–20]. The procedure consisted of storing the freshly extracted human teeth in a solution of 0.1% (weight/volume) thymol. Teeth were cleansed and polished. The procedure of bonding brackets to teeth was done only after finishing the preparation (Fig. 1).

Fig. 1. Bracket bonded on a molar (prepared for experimental analysis)

During bonding brackets, a protocol determined by the requirements was applied, i.e. manufacturer's instructions for each of the mentioned adhesives used in the study, i.e. the adhesives tested for the purpose of comparative analysis of bracket-tooth bond strength[21]. Quantitative analysis of the relationship between blood vessel wall constituents and viscoelastic properties has been determined as well as the dynamic biomechanical and structural *in vitro* studies in aorta and carotid arteries have been carried out[22].

The study was done *in vitro* as this was done by many other investigators before[19–23] who tested certain characteristics of adhesive types in order to understand their specific properties, advantages and shortcomings compared to each other. An *in vitro* study of adhesives is more favourable compared to *in vivo* study, because it eliminates the factor of speed of work depending on researcher's dexterity, thus reducing the possibility of contamination of the working area with saliva (which in turn reduces the adhesive strength of the bonding agent), having in mind that most adhesives are sensitive to moist as "one of the most common causes for bracket failure". Besides, laboratory study may indicate potential clinical success in certain conditions[24].

In order to avoid the influence of type of the bracket on bracket-tooth bond strength, the same type of metal bracket Discovery Slot 0.56 × 0.76 mm/22 × 30 inch, Cuspid brackets with hooks was used with tested adhesives.

Con Tec LC adhesives were used with the first group, in which curing was done by chemical activation, while in the second group Con Tec Duo adhesives were used which are chemically and light-cured.

The process of debonding of placed orthodontic brackets aimed at determining the size of force necessary to separate the bracket from tooth surface was measured in the Centre for Bioengineering of Kragujevac University. For the purpose of this study, the Centre for Bioengineering modified its device, a single-axial Stretch system for tissue testing[25,26], so that a new sensor for force of 300 N was mounted and used to test the force of separation of bracket from the tooth. The device on which testing was done is presented in Fig. 2, and the position of the tooth before starting debonding is presented in Fig. 3. The direction of application of debonding force was at the angle of 90 degrees at the vertical axis of tooth.

Energy indicators are not merely energy statistics; rather, they extend beyond basic statistics to provide a deeper understanding of causal relationships in the energy–environment–economics nexus, and to highlight linkages that may not be evident from simple statistics[27–29].

In all this, special attention should be paid to sustainable development, i.e. protect the human environment. Production must take place in accordance with highly developed environmental standards, an example of a toxic oil[29].

When are used different bonds must be taken care about methodological problems of economy and profitability[30].

Fig. 2. Device on which study was performed (Stretch system)

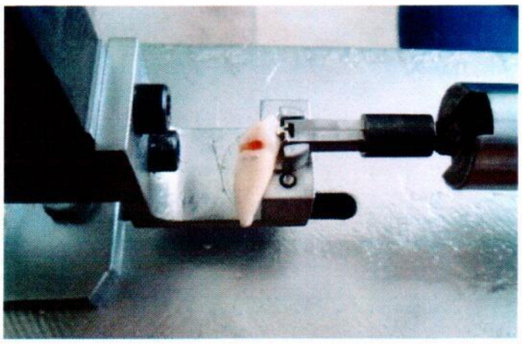

Fig. 3. Position of tooth in the device Stretch system, before starting debonding

Tensile force was accomplished at constant speed of 1 mm/min. The device automatically recorded the force with 0.3 N accuracy. The graph presents the forces in the function of time with 0.15 s intervals.

RESULTS

The values of debonding force on the *upper and lower dental arches* are presented in Table 1 for each tooth separately. The table presents the obtained values for all teeth within the groups (sample 40) tested with Con Tec LC and Con Tec Duo adhesives, whereas Table 2 presents the results of statistical analysis of debonding force for adhesive Con Tec LC and Table 3 the results for adhesive Con Tec Duo.

Table 1. Debonding forces for upper and lower dental arches for Con Tec LC and Con Tec Duo adhesives

ConTec LC	Debonding force (N)	Tooth arch	Type of tooth	ConTec Duo	Debonding force (N)	Tooth arch	Type of tooth
1	2	3	4	5	6	7	8
18.	42.43	L	1,2	8.	48.78	L	1,2
8.	42.52	L	1,2	18.	48.95	L	1,2
28.	42.61	L	1,2	38.	51.86	L	1,2
38.	42.91	L	1,2	13.	55.45	L	1,2
3.	49.03	L	1,2	3.	56.23	L	1,2
23.	49.13	L	1,2	28.	56.32	L	1,2
33.	49.81	L	1,2	23.	56.83	L	1,2
13.	50.08	L	1,2	17.	58.73	L	1,2
17.	54.89	L	1,2	33.	59.64	L	1,2
7.	55.25	L	1,2	15.	60.78	L	1,2
27.	55.28	L	1,2	7.	61.12	L	1,2
37.	55.81	L	1,2	27.	61.12	L	1,2
15.	57.96	L	1,2	37.	61.83	L	1,2
5.	58.21	L	1,2	5.	63.27	L	3
25.	58.46	L	3	25.	63.75	L	3
35.	58.81	L	3	35.	68.52	L	3
22.	63.73	L	3	22.	68.98	L	3
2.	63.84	L	3	2.	70.08	L	3
12.	64.18	L	3	12.	70.14	L	3
32.	64.81	L	3	32.	71.47	L	1,2
30.	82.98	U	2	20.	90.89	U	2
10.	83.08	U	2	30.	92.34	U	2
40.	83.11	U	2	10.	94.09	U	2
20.	83.15	U	2	40.	94.48	U	2
6.	90.49	U	2	26.	98.79	U	2
26.	90.51	U	2	6.	99.74	U	2
36.	90.59	U	2	36.	99.87	U	2
16.	91.05	U	2	16.	102.87	U	3
9.	104.11	U	3	9.	111.78	U	3
19.	105.06	U	3	29.	116.67	U	2

to be continued

Continuation of Table 1

1	2	3	4	5	6	7	8
29.	105.13	U	3	39.	116.67	U	3
39.	105.81	U	3	19.	120.43	U	3
14.	113,98	U	3	24.	124.25	U	3
4.	114.77	U	3	14.	124.34	U	3
24.	114.96	U	1	34.	127.43	U	1
34.	115.07	U	1	21.	128.67	U	1
11.	117.13	U	1	31.	128.69	U	1
21.	118.21	U	1	4.	128.97	U	1
1.	118.32	U	1	1.	130.12	U	1
31.	118.57	U	1	11.	137.76	U	1

U – upper dental arches; L – lower dental arches.

Table 2. Results of statistical analysis of debonding force for adhesive Con Tec LC

Descriptive parameter (debonding force (N) – adhesive Con Tec LC)	Dental arch		Total
	upper	lower	
N	20.00	20.00	40.00
MIN	82.98	42.43	42.43
MAX	118.6	64.81	118.57
I	35.59	22.38	76.14
Mo	–	–	–
Me	105.1	55.27	73.90
X_{sr}	102.3	53.99	78.15
SD	13.88	7.59	26.84
CV	13.57	14.06	34.35

N is the number; I – range; Mo – mode; Me – mean; X_{sr} – average value; SD – standard deviation; CV – coefficient of variation.

Table 3. Results of statistical analysis of bond strength obtained with Con Tec Duo adhesive

Descriptive parameter (debonding force (N) – adhesive Con Tec Duo)	Dental arch		Total
	upper	lower	
N	20.00	20.00	40.00
MIN	90.89	48.78	48.78
MAX	137.76	71.47	137.76
I	46.87	22.69	88.98
Mo	116.67	61.12	61.12
Me	116.67	60.95	81.18
X_{sr}	113.44	60.69	87.07
SD	15.33	6.83	29.17
CV	13.51	11.25	33.50

N is the number; I – range; Mo – mode; Me – mean; X_{sr} – average value; SD – standard deviation; CV – coefficient of variation.

Table 4 presents comparative results of statistical analysis for debonding force with Con Tec LC and Con Tec Duo adhesives.

The obtained total results for debonding force of teeth of the upper and lower dental arch show that the biggest average value X_{sr} = 87.07 N was obtained with the group of teeth in which Con Tec Duo adhesive was used for bonding brackets, whereas a somewhat lower average value X_{sr} = 78.15 N was obtained with the group of teeth in which Con Tec LC was used.

The results of testing of significance of differences by *t*-test show that there is no statistically significant difference between the mean values of debonding forces for brackets fixed with Con Tec LC and Con Tec Duo adhesives ($p = 0.158601$).

Table 4. Comparative results of statistical analysis for parameter *F* (debonding force) with tested adhesives – total results (summary for all tested teeth of the upper and lower tooth arch

Analysed statistical elements for parameter *F* (debonding force)	Con Tec LC	Con Tec Duo
N	40.00	40.00
MIN	42.43	48.78
MAX	118.57	137.76
I	76.14	88.98
Mo		61.12
Me	73.90	81.18
X_{sr}	78.15	87.07
SD	26.84	29.17
CV	34.35	33.50

N is the number; I – range; Mo – mode; Me – mean; X_{sr} – average value; SD – standard deviation; CV – coefficient of variation.

ANFIS MODELLING

ANFIS build through MATLAB, and 40 trials comprised the training data set. The different number of membership functions (MF) were used in the training process. To obtain optimal ANFIS architecture, the different architecture of network and training algorithms were used. In this case, the architecture of the network depends on the number of membership functions. Two MF's of the jaw, three MF's of the tooth, and two MF's of glue were used for generating the ANFIS model (Fig. 4).

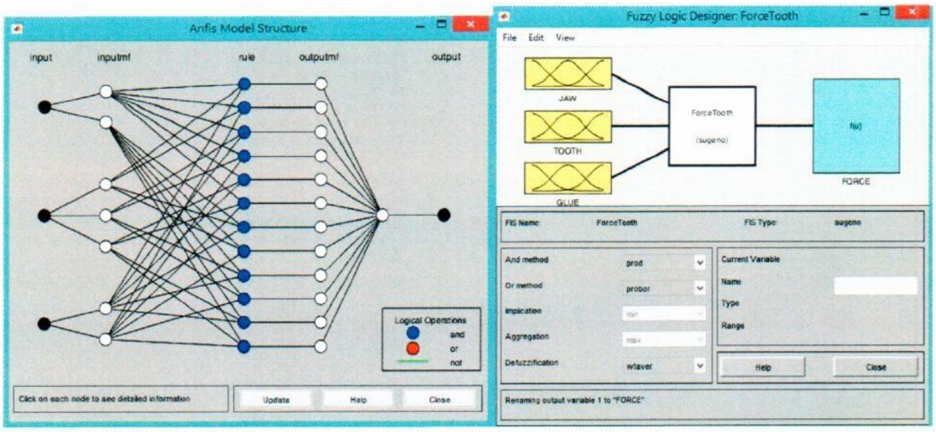

Fig. 4. ANFIS architecture

The generalised combination of two Gaussian membership functions (gauss2mf) gives the lowest training error (Fig. 5). Therefore, this function was chosen for the training process of ANFIS in this study. The best ANFIS architecture was determined with hybrid method optimisation and 200 epochs. Root mean square error (RMSE) is often used for calculate error in ANFIS modelling. In this case RMSE is 3.09.

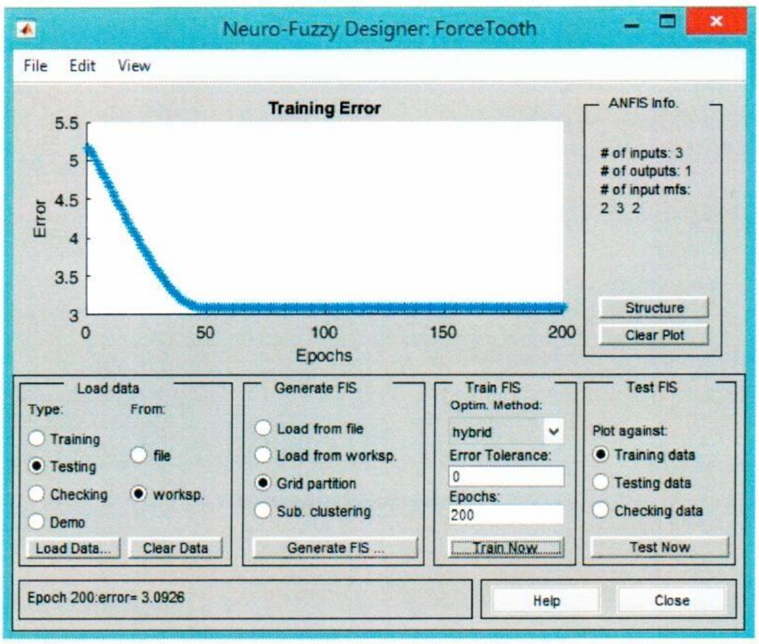

Fig. 5. Training error with gauss2mf

When the training of ANFIS was successfully finished, the system is checked by testing data. The testing data set is obtained from experimental data. The input-output test consists of 8 data sets. Test error is satisfied and amounts RMSE 5.4. Figures 6–8 show testing results of training by ANFIS neural network method.

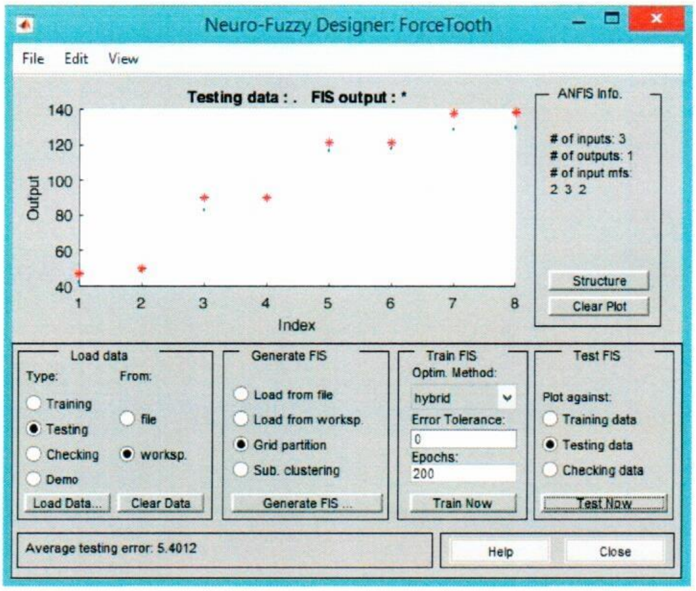

Fig. 6. Testing error

Fig. 7. Creating rules with the appropriate membership function

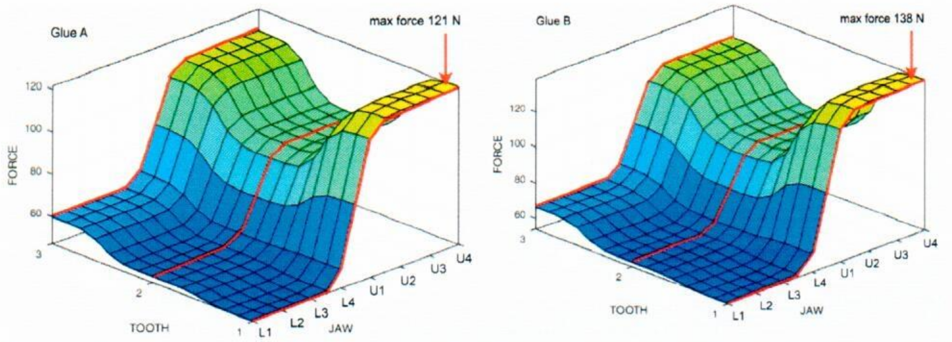

Fig. 8. Influence of number of teeth and tooth position on tooth pressure force: *a* – glue A and *b* – glue B

CONCLUSIONS

Based on comparative analysis of the results of the debonding force with tested adhesives for fixing brackets to tooth enamel, the following conclusions may be derived:

Comparison of mean values of debonding forces between tested adhesives showed that the highest average value of debonding force was with the group of teeth in which the adhesive Con Tec Duo was used, whereas somewhat lower value was obtained by use of Con Tec LC adhesive.

The results that gave a clear insight in the bracket-tooth bond strength achieved by the tested adhesives that are nowadays most commonly used in practice have the following clinical-theoretical implications.

If the degree of tooth dislocation is bigger, which requires higher activation of arch, i.e. stronger force to move the tooth, it is necessary to use the adhesive by which the strongest toot-bracket bond is achieved, in order to avoid undesirable failure of the bracket (Con Tec Duo).

If the degree of disruption of tooth position is smaller, adhesives that achieve a lower bracket-tooth bond may be used too (Con Tec LC).

The successful determination of debonding force and adhesives' relationship with the help of an artificial intelligence method was possible because the used variables in the models were combination of numerical and attribution values. For processing was used novel ANFIS modelling system.

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