A RÉSUMÉ OF THE FINDINGS OF RESEARCH ON THE EVOLU-
TION OF DENTAL ALLOYS AND AMALGAM TECHNIQUE¹

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I. INTRODUCTION

Previous to the years of 1875-1876, when the first organized movement was made in its favor, amalgam had been an empirical product, but, beginning in 1875-1876, alloys and the amalgams resulting from them began to acquire a more scientific aspect. In 1875-1876, dentists of the calibre of Henry S. Chase, S. B. Palmer, and J. Foster Flagg, who were prominent in the profession, organized "the new departure movement" and adopted a set of resolutions, two of which are quoted below:

"*Article I.*—In proportion as teeth need saving, gold is the worst material to use.

"*Article II.*—Amalgam, per se, is an excellent filling material."

Brave words these at a time when amalgam was the "outlaw" of all filling materials. Even those who used it in their practices hardly dared to confess it to their professional brethren.

True enough, the alloys of that period were not any too dependable and the behavior of amalgams in the mouth was capricious, but the evolution in alloys was, nevertheless, steadily progressing. Flagg, in particular, made many investigations of great value, and undoubtedly furnished a firm foundation for the next champion of this material, who was no other than that remarkable man, G. V. Black. In 1895-1896, Black took up the work where his predecessors left it. His investigations finally resulted in the deduction of a method of alloy manufacture, as well as the development

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of an amalgam technique, which provided firmer foundations on which to build the scientific data of today.

The writer of "Triology" (10) visualizes the situation very nicely when he says: "Much of the material presented by Dr. Black was not new, but it remained for his wonderful scientific mind to gather isolated facts, trace out their origin, group them together in rational form, show how they were correlated, what their effects were, how to counteract or control their injurious factors, and how to best utilize those which were helpful." His endeavors helped to place alloy manufacture and manipulation on a more scientific basis. His most important discoveries were "balancing and ageing" of an alloy. It is to him that we are indebted for the present classification of alloys, as given below.

Class 1. High-percentage silver alloys, high silver-content alloys, quick setting alloys, and Black's method alloys. These terms are synonymous and signify contents of 65 to 70 per cent of silver, 25 to 28 per cent of tin, 3 to 5 per cent of copper, and 0.5 to 2 per cent of zinc. (It is true that one or two alloys of this class contain no zinc but I shall presently show you that the quarternary alloy or alloy of four component metals is the more dependable one, and that zinc is an important metal for several reasons; also, that Dr. Black was in error in his statement that "even less than 0.5 per cent of zinc was not permissible.")

Class 2. Low-percentage silver alloys, high tin-content alloys, plastic alloys, and slow setting alloys. These terms are also synonymous and signify contents of 43 to 48 per cent of silver, 45 to 60 per cent of tin, 3 to 5 per cent of copper, and 0.5 to 2 per cent of zinc. (It was from this class of alloys, which were the legacy of Flagg to the profession, that Black evolved the alloys of the high-percentage silver type. Previous to his discovery of balancing, which we shall presently discuss, the alloys in use were rich in content of tin and were low in percentage of silver. The alloys of the low-percentage silver type are not suited for filling teeth according to recent investigations. They were not sanctioned by Black and their use is principally for the making of models for the gold inlay by the indirect method, and such other purposes as call for model alloys.)

II. MODERN POINTS OF VIEW

The foregoing remarks are, in a measure, a preamble to the discussion of more recent investigations, the primary purpose of this paper. In attempting to cover this subject in a single paper, I find myself in the dilemma which Zurbrigg well expressed when he wrote (7): "The subject

of dental alloys and their amalgams is so vast and complicated, and has so many angles, that a full discussion of what they are, what are the physical properties of each metal and the reason for its use, how made and compounded, their behavior under varied conditions of both laboratory and clinical manipulation, covers a field which would require a course, rather than the program of a single evening."

It might be of interest to discuss the physical properties of each metal, but I feel assured you are already well instructed in this particular. I shall refer to that phase of the subject only as it concerns the scope of this talk.

I have said that zinc is an important metal in a dental alloy and have, thereby, contradicted Black's statement in regard to it. This problem has not yet been solved to the satisfaction of all concerned, but I unhesitatingly favor the use of zinc, a position that is supported by the majority of investigators, professional and commercial. Opponents of the use of zinc depend entirely on Black's statement concerning it and, singularly enough, offer no *recent* data to substantiate their claims; at least no such data have been published. I do not quote Ward exactly, but he says, in the American Text Book of Operative Dentistry (6), that most manufacturers have found that, to prevent contraction, zinc is a necessary metal in a dental alloy. It is admitted by alloy manufacturers, in advocating its use, that zinc is a dangerous metal if used improperly, by which they mean if used in large proportions. I know of only one alloy, containing as much as 2 per cent of zinc, that I should class as one of the dependable alloys.

If zinc is eliminated from a dental alloy, such alloy is unfit for use if over a year old. Therefore, alloy products that do not contain zinc should be dated for the protection of the dentist. The non-zinc alloy, if over a year old, takes on many of the undesirable characteristics of the low-percentage silver alloys. A very good analogy might be drawn in regard to the dangerous qualities of zinc by comparing it to some of the vegetable alkaloids, which are virulent poisons in large doses but are the most potent tonics when used in proper amounts. It is now a pretty well known fact, according to the admission of Black himself, that the zinc used by him was obtained from commercial sources. This fact alone might easily explain his statements relative to the use of that metal, as well as his use of the Wedelstadt tube in connection with his experiments, an instrument now known to be fundamentally inadequate for such tests.

I have alluded to the discovery by Black of balancing alloys. What do we mean by a "balanced" alloy? It is one that is obtained by combining the metals composing it in such proportions as to eliminate contraction and

to control expansion in the amalgam resulting from it. A very *slight* expansion is permissible, perhaps desirable, but this is exceedingly small, amounting to 1/20,000 to 3/20,000 of an inch in an experimental specimen of certain size, and is then confined to a period which may be designated as *initial*. We shall discover, as we proceed, that modern research has evolved a method of control over this expansion. This is accomplished by varying the mercury-alloy ratio, by the type of the cut of the alloy, the duration of trituration, and the packing pressure, each of which will be discussed later.

A recent writer on this subject has said: "Balancing an alloy, then, is the controlling of the tendency of one metal to contract by that of another to expand, until a point of neutrality is found where the resulting amalgam remains practically dimensionally stable. This necessitates the possibility of a change of formula, even if slight, with a new batch of metals. The balancing process applies particularly to the silver-tin content of the alloy" (10). Balancing was accomplished by Black, therefore, by increasing the amount of silver until it neutralized the contracting tendencies of tin. To quote Ward, in substance (6): one of Dr. Black's prominent assumptions was that, in all events, there must be no contraction and his great ambition seems to have been to produce an amalgam in which there would be no movement after its insertion in the cavity. This quotation illuminates, to the careful student of the subject of alloys and amalgam (dental), many of Black's statements relative to the mercury-alloy ratio, manipulation, etc., and indicates why so many of his opinions are subject to revision on account of the use of modern instruments which are more delicate and accurate, which measure movement that former instruments would not record, and which, of course, were not available to Black.

The properties of the metals in a dental alloy, and their influences in "balancing" such an alloy, may be summarized as follows:

Silver: expansion, strength, improvement of color

Tin: contraction, plasticity, improvement of color

Copper: strength, stability

Zinc: toughness, amalgamation facilitated, improvement of color, stability

I alluded to annealing. According to some writers, Black discovered the phenomenon of "ageing." I am inclined to the opinion that Flagg deserves credit for this. In any event, this discovery was made in the accidental observation that exposure of an alloy to heat (in storage) retarded the setting of the alloy. Modern investigation, however, furnishes methods of control over this phenomenon to be discussed later. This is a matter of some disagreement, but apparently reliable data have been fur-

nished to support the above statement, and until it is disproved it seems reasonable to accept it.

It was found that the alloys of high silver content set so rapidly that the amalgam resulting from them could not be properly inserted in a cavity. This is true of that class of alloys as they are manufactured today, and they require artificial annealing to retard the setting process to the degree necessary for their proper manipulation. This rapid setting is attributed to the large amount of silver they contain, and also to the hardening caused by the process of cutting the alloy into filings (or shavings). Again I quote Ward, in substance (6): It is a well known fact that the working of metals forces their molecules into unnatural positions, and that by annealing they are largely restored to their normal state. Dr. J. Foster Flagg seems to have been the first to call attention to the fact that alloys which are freshly cut behave differently from those which have stood for some time. Dr. Black traced the phenomenon through a great number of experiments and finally arrived at the conclusion that the cut alloy is hardened by the violence of cutting, the condition thus produced being analogous to the condition of the same metals induced by hammering. After a great many experiments, it was proved that the change was brought about by annealing or "ageing," that is, by a molecular change in the cut alloy. By annealing, which is the reverse of hardening, the metal flows and this tension is relieved. . . . It has been shown that annealing has four effects on the final result. First, upon a change in volume; second, upon strength; third, upon the rate of setting; fourth, upon the percentage of mercury to make a plastic mass."

At least one of the modern investigators does not admit all these effects. Artificial annealing, to which manufacturers resort, is accomplished in several ways: under water, in steam, with dry heat in jacketed ovens—all for longer or shorter periods depending on the degree of temperature employed.

The more modern research has shown that there is a correct point and method of annealing for each individual alloy, and that an alloy can be over or under annealed. The statement has been made, and data substantiate it, that a correct method and amount of annealing will produce an alloy from which the resulting amalgam will be unvarying—an alloy that will work the same under identical conditions and produce a mix of uniform strength regardless of the age of the alloy, if it is kept reasonably free from exposure to air and not stored where it is exposed to undue heat. I have long felt assured that many manufacturers anneal their alloys to a degree that is necessary to satisfy the desire of the profession for a slower setting

product. I believe that, by so doing, they decrease the value of their product.

An important consideration, aside from the formula for the alloy, is the type of the cut and the size of the alloy particles. The alloy should be very finely cut (filings), never coarsely into shavings. The latter must be reduced to filings during the process of amalgamation, which involves a loss of time. More important reasons for the finer state of division are the possibilities of greater surface oxidation during the process of manufacture, and also in the package and in handling. Reducing the size of the alloy particles results in facilitating amalgamation, in a more perfect solution of the alloy, in a smoother and more velvety mix, and in hastening volume changes during amalgamation and hardening, a most desirable feature for it contributes to earlier stability of the filling.

The foregoing covers the field I wish to discuss at this time so far as the details of manufacture are concerned. Our next consideration will be the effects of manipulation.

I have said that "so far as manufacturing was concerned, there have been fewer changes from Black's methods than in manipulation." However, I wish again to emphasize the statement that the few changes in that particular from Black's methods play an important part in the evolution of alloys and the amalgam technique, even if they appear trivial. Much progress has been made since the appearance of Black's articles in the *Dental Cosmos* (1895-1896) in respect to manipulation, and this evolution has been greatly assisted by the fact that instruments are now available that are much more sensitive and accurate than those he used.

III. RESULTS OF RECENT RESEARCHES

The most important investigations of recent date have been conducted by Arthur W. Gray, at the L. D. Caulk Company's Laboratories, Milford, Delaware, and by the United States Bureau of Standards, Washington, D. C. These investigations have been conducted along scientific lines with the aid of modern instruments and have yielded much interesting data. They agree in the main so far as their conclusions have been published. Many of us, who are interested in the research aspect of alloys and their amalgams, have been disappointed in the articles on this subject in the recent edition of the American Text Book of Operative Dentistry. We had hoped that Editor Ward was conducting investigations of this subject that would lead him to offer more definite statements than his article on amalgam contains. The article gives a wealth of information on this subject from every angle except that of the modern researches.

Ward has evidently reviewed the investigations referred to and gives a few of Gray's charts, but has evaded the real issue regarding them.

In considering the results of the recent investigations I shall discuss the influence of variations in the mercury-alloy ratio, the influence of the size of the alloy particles, the influence of trituration time, and the influence of packing pressures. The influence of annealing has already been discussed.

In a recent issue of the *Journal of the National Dental Association*, Guy S. Millberry (4), discussing the recent investigations referred to above, wrote, in substance, as follows: The things which are most helpful to us as practising dentists, expressed in terms of common understanding, are that practically all previous tests on crushing strength have been inaccurate because of the small dimensions of the cubes tested, the type of the apparatus used, and the absence of temperature control and regulation. In his experiments, Gray used a 9000 kgm. testing machine, which he modified by the addition of an electric motor drive which applied the load with regularity, and by the addition of electric heaters for bringing the specimen under test to the desired temperature, which was determined by a suitably placed thermo-element.

The test specimens in Gray's experiments, to which Millberry alluded, were 10 mm. in height and 10 mm. in diameter, and were prepared by molding the freshly mixed amalgam in a thick-walled steel tube, the interior of which was highly polished. A measured force, applied by the testing machine and maintained for a measured time, was used in packing the amalgam between an accurately fitting piston and the removal bottom of the mold. This packing squeezed out the excess of mercury and condensed the plastic mass into a firm smooth cylinder with parallel ends. The procedure secured both uniformity of cross-section and uniformity of packing conditions. In hand-packed specimens there would be great variations in crushing strength but specimen cylinders formed by the above methods would insure comparative results. In some of these tests, the pressure under which the amalgam was condensed varied from 25 to 3200 kg. and the packing pressure also was maintained from 1 to 16 minutes. Gray's experiments resulted in his discovery of a very important law connecting the crushing strength of an amalgam with the pressure employed in packing it. This has been termed the "logarithmic law" (9). As I understand one phase of its interpretation, given the pressure under which a cylinder is packed and its temperature at the time of its being tested, a logarithm can be plotted on a chart and the crushing point of the specimen will follow this logarithm consistently. This, of course, verifies the law. From this law, it also follows that every doubling of the packing pressure is accompanied by the same increase of strength.

In the experiments conducted by the United States Bureau of Standards (5), "the amalgamation and condensation procedure (unless otherwise specified) was according to manufacturers' instructions. . . . The artificial or matrix cavities were holes in steel blocks drilled and polished. The amalgam was condensed in these, using three or four different-sized pluggers. Those specimens which failed to show perfect adaptation to the form were rejected." These specimens were hand packed, 1 cm. in length and 6 mm. in diameter. As I understand the report, an interferometer instead of an Olsen machine was used in making the tests for crushing strength.

With these explanatory remarks, let us consider the five points mentioned above. When each of these factors was varied in Gray's experiments, the other factors remained constant. Each of the factors, in its turn, was varied individually until the ultimate finding, which yielded the best results, was a conglomerate of each individual factor in relation to the group of factors.

a. It was found by the investigators that the *mercury-alloy ratio* had an important influence on the resulting amalgam. Different proportions of mercury and alloy were carefully tested and, to quote Gray, it was found that approximately five parts of alloy by weight to eight parts of mercury by weight yielded the best results for strength and thorough amalgamation with the particular alloy tested. This is sometimes expressed as a mercury-alloy ratio of 1.6. Even ten parts of mercury can be used without loss of strength (1). In conjunction with a more prolonged trituration time than has been commonly practised, the liberal use of mercury was found to exert an important effect on volume changes, that is, they took place mainly during the period of amalgamation; and when the amalgam was placed in the cavity it was practically a stable product (relatively speaking). This liberal mercury-alloy ratio also serves to facilitate amalgamation and makes for a more thorough mix—a result we should strive to attain by any legitimate means in the operative procedure.

b. I stated before that the *size and shape of the alloy particles* are also involved in attainment of the results enumerated in the foregoing discussion of the mercury-alloy ratio. "As the alloy particles become progressively smaller, the reaction curve shows the same results as those that follow increasing the mercury-alloy ratio and the trituration time, as well as he same control of initial volume changes" (1). This hastens final stability.

c. "Increase of *trituration time*, in the presence of the liberal mercury-alloy ratio above noted, is accompanied by a progressive increase of strength until the maximum is reached when trituration is maintained for about

six minutes. The experimental specimens that were used to obtain the above data were made from a 6 gm. mix" (1). A smaller mix would require a shorter trituration time. It was found, however, that so slight a gain of strength results from triturating longer than five minutes that the limits for this procedure are placed at from three to five minutes according to the size of the mix. After six minutes of trituration there is a partial setting of the amalgam, showing that, in the operative procedure, a vigorous and thorough amalgamation with a suitable mortar and pestle is highly desirable and should be maintained for from three to five minutes. Emphasis should be laid on use of a mortar and pestle—I do not believe that the palm of the hand is adapted for this purpose. The manner of trituration is important also—it should be conducted vigorously, for it may be stated as a law that any procedure that insures closer union of the mercury and alloy results in a stronger and more thoroughly dissolved product, accelerates the action, and shortens the time required for the filling to reach its final stable condition.

It is for this reason that I am a thorough advocate of a suitable mechanical mixer. I say "suitable," for many of the mechanical mixers are worthless. Speaking of the types with which I am familiar, I place their value in the following order: Rex, Caulk, Sibley. If you will permit me to continue to be personal, for I have made a study of this feature from the standpoint of operative procedure, I believe that the problem of proper mixing presents quite a field of investigation for the scientific laboratory and one which might wisely be developed as the next step in the improvement of the amalgam technique. I have insistently made this contention with some small results and, until it is proved that I am incorrect, I shall continue to be an enthusiastic advocate of mechanical mixing. I am convinced that thorough amalgamation is accomplished much more quickly with the use of the mechanical mixer. I have the temerity to state, without any scientific data to support me, however, that a three-minute mix in a suitable mechanical mixer will accomplish the same result as a six-minute mix in a hand mortar, which you remember gives the maximum strength without the danger of incipient setting of the amalgam. Therefore, by deduction, not from scientific investigation, I believe that the six-minute limit is one of time rather than a limit placed by completeness of the solution of the alloy in the mercury. At the risk of appearing ridiculous, I shall hold to this belief until scientific data discredit the assumption.

Before leaving the subject of trituration, I wish to call your attention to the effects of insufficient trituration. Insufficient trituration-time results in the production of a granular mass of less strength, with a color

that is not so pleasing and which I designate as a battle-ship gray. A more important result is the fact that the alloy particles are not thoroughly impregnated with the mercury and much excess of mercury is retained *among* the alloy particles, a condition that is conducive to volume changes over a long period after the filling has been placed in the cavity. In contradistinction, under properly prolonged trituration, more mercury is retained or contained in the *mass*, but not between the alloy particles, for the alloy is in more perfect *solution*, and the excess of mercury in the latter instance is capable of being expressed under heavy packing pressure, without danger of expressing an undue amount of tin and thus upsetting the balance of the alloy.

d. That the manner of packing (*packing pressure*) is of great importance, in the operative procedure, has been shown admirably by Harper (2, 3) whose technique in this particular I unhesitatingly recommend. The greater the pressure applied in packing or condensing a filling, the smaller the mercury content in the finished filling and the greater the strength of the filling. The strength of the filling and the mercury content are always in inverse ratio to each other. I hinted at this in my reference to the "logarithmic law" (1).

Gray observed that, under a given or constant packing pressure, "constant mercury content is reached before constant strength, when the mercury-alloy ratio is progressively increased" (1). Gray has also shown conclusively that dimensional changes in an amalgam can be altered at will, that is, variable results can be secured by varying the mercury-alloy ratio, or the trituration time, or by modifying packing pressures (1). This controverts Black's statements that shrinkage and expansion are not under the control of the operator but wholly under that of the manufacturer and are determined entirely by the composition of the alloy.

In contradicting, as I have in this discussion, many of Black's statements, I do not wish to be misunderstood as discrediting the man who was one of the most broadly educated dentists the world has ever known. Black gave us many ideas which, true to his own prophecy, have yielded to the ever progressing law of evolution. Had he possessed the instruments now available, who can say his investigations would not have yielded different results?

IV. PRACTICAL APPLICATIONS

The practical application of the foregoing, from the standpoint of the operative procedure, may be briefly expressed as follows:

a. We must use one of the high silver-content alloys and one that is manufactured by a reliable firm.

- b. The alloy must be finely cut.
- c. The alloy must be properly annealed.
- d. We must use a "liberal quantity of mercury"—not less than eight parts of mercury to five of alloy by weight. More will do no harm but is a waste and develops a "sloppy mix."
- e. We must triturate the mass vigorously from three to five minutes in a hand mortar (personally, I say, with a mechanical mixer of approved pattern).
- f. We must condense or pack the amalgam with as much force as possible, using smooth faced pluggers, carefully stopping the same, and removing the excess of mercury and fluid amalgam from the cavity as we pack layer after layer.
- g. We must pack the cavity with a generous overplus.
- h. We must use a matrix when a wall or walls are missing.
- i. We must properly restore the mass and form of the tooth in all its details.
- j. We must properly finish and polish the filling.

There is yet a wide field for investigation of amalgam. Ward believes that chemical compounds exist in them but with feeble affinities. The surface of the truth in this field has been barely scratched but a great opportunity awaits the mind that is properly trained to investigate it thoroughly.

I cannot forbear to remark that it is unfortunate that so great a majority of dentists regard amalgam as a plastic that can be properly handled without any particular skill, and make no endeavor to improve their technique. That Black held an entirely different view is evidenced from the following comment in his work on Operative Dentistry (6): "Fillings made of modern amalgams are a close second to gold in their durability and protection to the teeth. The difference is that *amalgam is the more difficult to make perfectly. It is more difficult to learn the manipulation and even then is more difficult to secure perfect results, filling after filling.*"

As Millberry aptly says (4): "Operative procedure on our part should be developed to such a degree that the combined results of skilful effort and dependable material will benefit humanity."

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